RITA Intelligent Transportation Systems
Joint Program Office

Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference: 2011 Update

www.its.dot.gov/index.htm
Final Report — September 2011
FHWA-JPO-11-140

U.S. Department of Transportation
Research and Innovative Technology Administration

Produced by Marcia Pincus
ITS Joint Program Office
Research and Innovative Technology Administration
U.S. Department of Transportation

Notice

Cover photograph source: Source: ©Thinkstock.com/Menzies; Steele;Ng

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-11-140		

4. Title and Subtitle Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference: 2011 Update	**5. Report Date** September 2011 **6. Performing Organization Code**
7. Author(s) James Bunch, Carolina Burnier, Elizabeth Greer, Greg Hatcher, Amy Jacobi, Firoz Kabir, Cheryl Lowrance, Mike Mercer, Kathryn Wochinger	**8. Performing Organization Report No.**
9. Performing Organization Name And Address Noblis 600 Maryland Ave., SW, Suite 755 Washington, DC 20024	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-05-D-00002
12. Sponsoring Agency Name and Address ITS-Joint Program Office Research and Innovative Technology Administration 1200 New Jersey Avenue, S.E. Washington, DC 20590	**13. Type of Report and Period Covered** Final Report, January 2009 to August 2011 **14. Sponsoring Agency Code** HOIT-1

15. Supplementary Notes
Marcia Pincus, COTR

16. Abstract
Intelligent transportation systems (ITS) provide a proven set of strategies for addressing the challenges of assuring safety and reducing congestion, while accommodating the growth in transit ridership and freight movement. This report presents information on the performance of deployed IT'S under each of these goal areas, as well as information on the costs, deployment levels, and lessons learned regarding ITS deployment and operations since the last such report in 2008.

The report, and the collection of four Web-based resources upon which it is based, have been developed by the U.S. DOT's ITS Joint Program Office (JPO) to support informed decision making regarding ITS deployment.

17. Key Words	18. Distribution Statement
Intelligent Transportation Systems, ITS, Benefits, Costs, Deployment Statistics, Lessons Learned	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	266	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Table of Contents

List of Tables

List of Figures

Executive Summary

Intelligent transportation systems (ITS) provide a proven set of strategies for advancing transportation safety, mobility, and environmental sustainability by integrating communication and information technology applications into the management and operation of the transportation system across all modes. In the future, ITS technologies will transform surface transportation by offering a connected environment among vehicles, the infrastructure and passengers' wireless devices, allowing drivers to send and receive real-time information about potential hazards and road conditions.

The U.S. Department of Transportation's ITS research program focuses on the overall advancement of ITS through investments in emerging ITS technologies, as well as supporting the evaluation of deployed ITS. This report presents information on the benefits, costs, deployment levels, and lessons learned regarding ITS deployment and operations obtained since the 2008 report.

The report is based upon four related Web-based databases, known collectively as the ITS Knowledge Resources (KRs). The Knowledge Resources were developed by the U.S. DOT's ITS Joint Program Office (JPO) evaluation program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS. The Knowledge Resources contain over fifteen years of summaries of the benefits, costs, lessons learned, and deployment status of specific ITS implementations, drawn primarily from written sources such as ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers. They can be accessed online at www.itskrs.its.dot.gov.

Findings

As of August 1, 2011, there were a total of 1,418 summaries of ITS benefits, costs, and lessons learned in the ITS Knowledge Resources Databases from the United States and around the world, as shown in Table ES-1.

Table ES-1. Summaries in the Knowledge Resources Databases

Summary Type	Number of Summaries
Benefits	686
Costs	228
Lessons Learned	504
Total	**1418**

Geographic Location of Benefits, Costs and Lessons Learned

Figure ES-1 shows the distribution of the summaries across the United States. There are also 276 international summaries located outside the United States. The relative size of the circle in each state corresponds to the total number of summaries in that state, with the proportion of the circle shown as blue, red, or tan representing the proportion of benefits, costs, and lessons learned summaries. In general, the number of summaries in the Knowledge Resources closely aligns with the level of deployed ITS, with some of the larger states providing the higher number of summaries (for example, California, followed by Florida, Washington, Texas, Minnesota, New York, Michigan, Virginia, Maryland, Illinois). As shown in the bottom left of the figure, 159 summaries are classified as nationwide rather than attributed to a specific state or states. Nationwide summaries are often based upon the experiences of several states, such as from a crosscutting study, or are based on average values or other "summary" measures from survey results across the U.S. Several observations can be drawn from this geographic information:

- States with large numbers of summaries generally are those with larger metropolitan areas, where more ITS are likely to have been implemented, while predominately rural states, such as those in the Midwest and upper New England, tend to have fewer summaries in the Knowledge Resources. It stands to reason that more evaluations have been conducted in the more urban states.

- Some states can be identified as "early adopters" of ITS technologies having been involved in model deployment projects and field operational tests. Many of these states continue to evaluate their systems on a yearly basis, see the benefits from their ITS investments, and continue to expand their systems. Florida, for example, consistently does yearly evaluations.

- Other states in the same region can benefit from these early ITS investments by using the evaluation data summarized in the Knowledge Resources to choose cost effective technologies, which provide substantial impact, while avoiding common pitfalls in implementation.

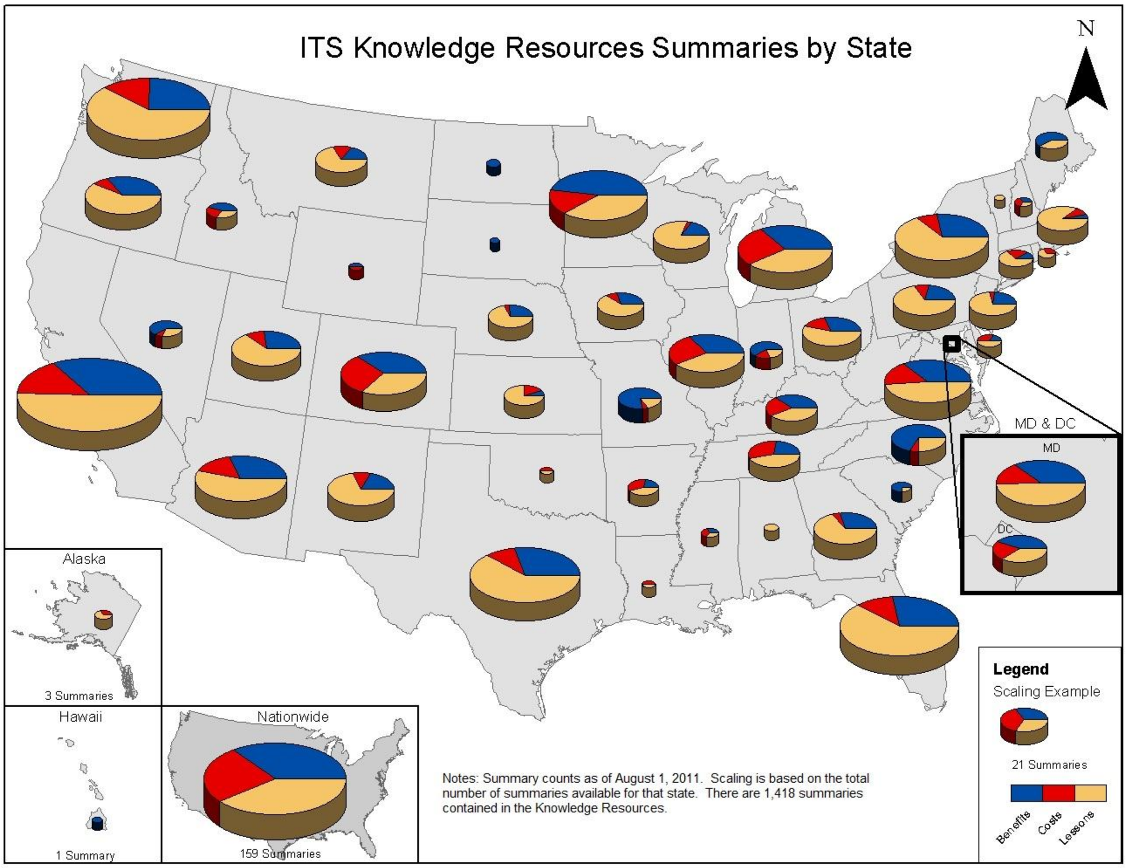


Figure ES-1. ITS Knowledge Resource Summaries by State

Growth in the Knowledge Resources by Technology Area

Each summary is categorized by the ITS application described. There are 17 ITS applications that can be categorized into five technology areas: Intelligent Vehicles, Management and Operations, Transit, Roadway Operations and Freight. Figure ES-2 shows the growth in summaries that have been added since 2008 by technology area. The highest growth has occurred in the area of Intelligent Vehicles (42 percent growth), followed by Transit (37 percent growth), Management and Operations (29 percent growth), Freight (23 percent growth), and then Roadway Operations (21 percent growth). The trends in Knowledge Resources benefits, costs, and lessons learned summary growth are generally consistent with the deployment trends shown throughout this report and at the Deployment Tracking web site, http://www.itsdeployment.its.dot.gov.

Applications that are being implemented at a faster pace over the last several years are more likely to have been studied, resulting in summaries developed for the Knowledge Resources. Figure ES-3 shows the growth in summaries by Application area. For example, transit agencies have been rapidly expanding the deployment of ITS, and the transit management area is one of the top ITS applications in terms of KR summary growth.

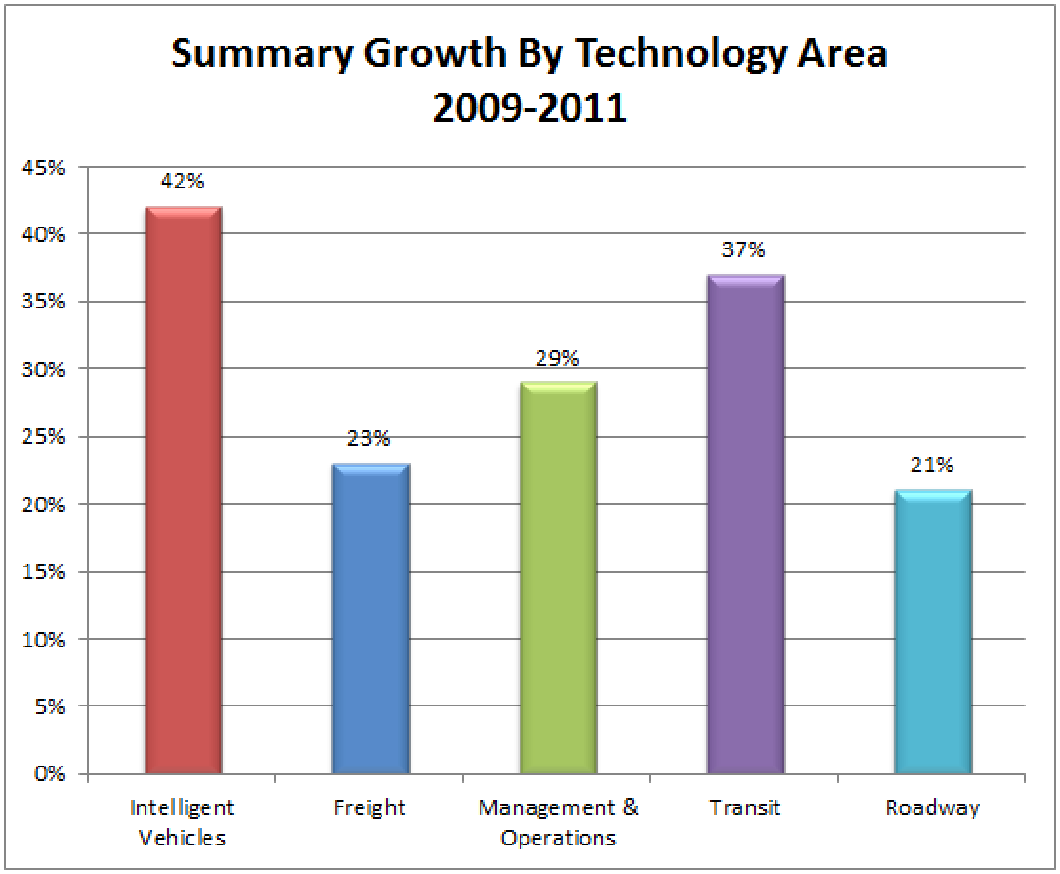


Figure ES-2. Knowledge Resources Summary Growth by Technology Area from December 31, 2008 through August 1, 2011

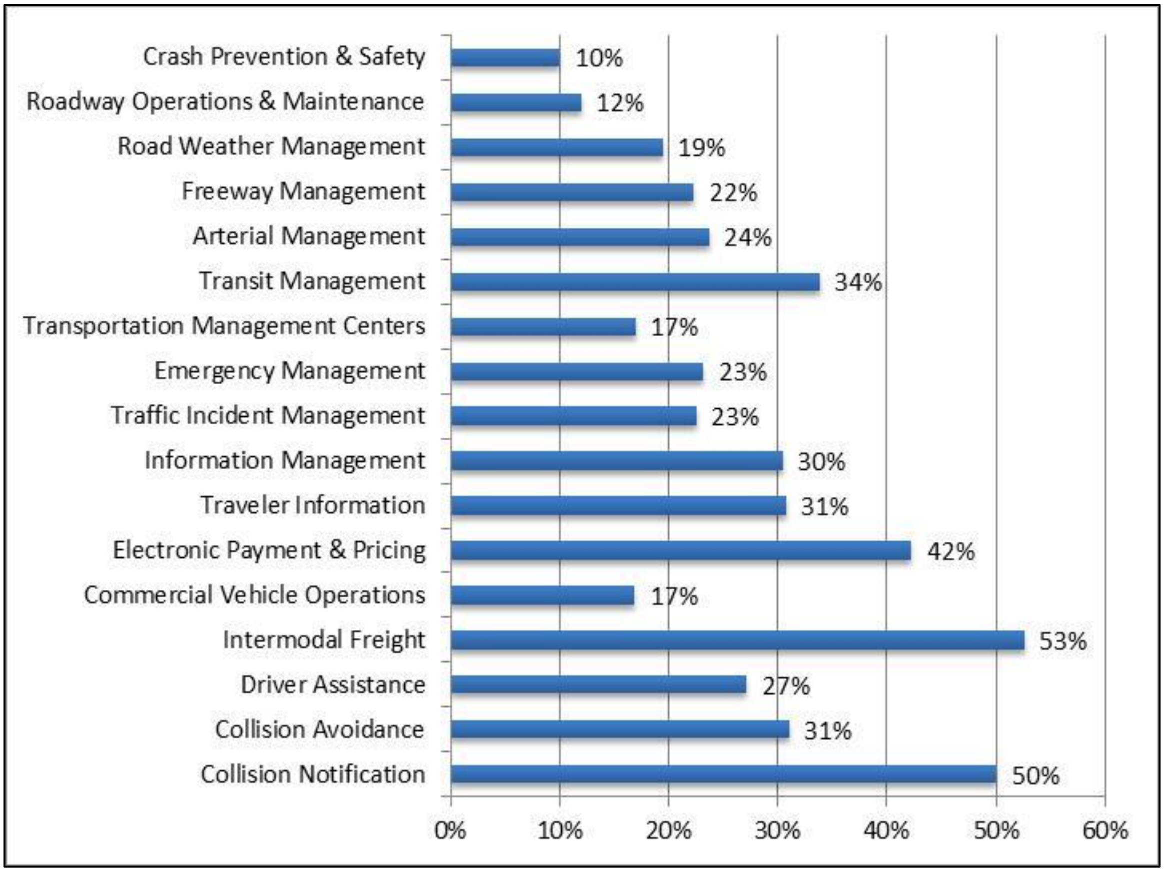


Figure ES-3. Percent Change in ITS Knowledge Resources Summaries from December 31, 2008 to August 1, 2011 by Application Area.

A number of factors have driven the growth in these areas in the last three years:

- New research findings have emerged that include benefits, cost and lessons learned regarding connected vehicle technologies that fall in the application areas of Collision Avoidance, Collision Notification and Driver Assistance (31 new summaries since 2008). The ITS initiative on Integrated Vehicle Based Safety Systems (IVBSS) provided important findings regarding the safety, mobility and productivity benefits and user acceptance of lane departure warnings, curve speed warning, and forward and rear collision systems. These results will serve as the foundation for further connected vehicles research, and allow state and local agencies to plan for new-to-market technologies in this area.

- Transit agencies are moving beyond the implementation of first generation standalone systems to deploying systems that integrate automated vehicle location (AVL) and computer-aided dispatch (CAD), automatic passenger counters (APC), electronic payment and smart card systems, and real time information. Transit agencies are also at the forefront in providing open source real time data for trip planning applications. (There were 44 summaries added since 2008.)

- The Management and Operations category includes Electronic Payment and Pricing, Traveler Information, Traffic Incident Management, Emergency Management, and Transportation Management Centers. There were 148 summaries added since 2008. In Management and Operations, evaluation of electronic payment and pricing shows it to be one of the successful ITS applications with numerous benefits including delay reductions, improved throughput, and fuel economy. Continued advancements in personal communications have accelerated the implementation of traveler information applications in the last three years. Travelers can now monitor and make informed decisions on travel choices in real-time using GPS-equipped personal communication devices and multi-modal route guidance tools available on the Internet or mobile devices.

- In the Freight technology area (21 summaries added since 2008), the Electronic Freight Management (EFM) initiative that applies Web technologies to improve the ability of supply chain partners to collaborate and exchange information on the status of cargo and assets within the supply chain has produced results in the Intermodal Freight application. Evaluation data indicate that shippers, freight forwarders, container freight stations, and customs brokers, among others, experience a wide variety of specific productivity, service quality, and data quality and availability improvements. Commercial Vehicle Operations (CVO) technologies and services are also increasingly being integrated into Federal safety and other regulations. This includes: mandated use of Electronic On Board Recorders (EOBRs), the installation of speed limiters/governors for speed management, and onboard safety systems.

- The technology area of Roadway Operations includes the application areas Arterial Management, Freeway Management, Road Weather Management, Roadway Operations and Maintenance, and Crash Prevention and Safety. A total of 112 summaries were added to Roadway Operations since 2008. According to the 2010 Deployment Study, state and local transportation agencies continue to deploy ITS technologies such as traffic sensors and advanced traffic signal systems, and communicate information to travelers via dynamic message signs (DMS), highway advisory radio (HAR), or 511 systems. These technologies are now considered mainstream. With the value of these ITS technologies proven, evaluation of their deployment has slowed. Newer technologies such as variable speed limits and road weather systems are being evaluated and implemented.

- Efforts toward integrating ITS technologies received increasing attention in the three year period, as agencies focus on maximizing their ITS investments and obtaining and providing the best possible information to the traveling public. Transportation Management Centers (TMC) have become integral to ITS operations strategies: traffic surveillance, traffic incident management, emergency management, electronic payment and congestion pricing, traveler information, and information management. The capital cost of physical components can range from $1.8 million to $11.0 million per facility, and have Operations and Maintenance costs that range from $50,000 up to $1.8 million per year.

- The rapid adoption of smartphones and personal navigation devices has transformed the U.S. transportation environment in the last three years. The impact of these devices is discussed in the Transit Management, Traveler Information, and Driver Assistance chapters. Transit agencies have been in the forefront of this transformation by providing real-time information about transit schedules and delays along routes. In surface transportation, smartphone use as a personal navigation device is rapidly expanding in market penetration.

These devices allow travelers to make travel planning decisions with real-time data about traffic conditions, affecting the goals of mobility, productivity and environmental sustainability.

- The economic downturn continues to impact the evaluation and deployment of ITS technologies. With limited capital and operating budgets, state and local agencies are focused on the cost effectiveness of their investments. Higher gas prices and lower operating budgets have encouraged agencies to focus on signal timing, transit signal priority, service patrols and other ITS technologies that conserve energy while increasing mobility.

ITS Technology Benefits by U.S. DOT Goal Area

The U.S. Department of Transportation is focused on ITS investments that have the potential for significant payoff in improving safety, mobility, productivity, and environmental sustainability. The Knowledge Resources databases provide a unique opportunity to assess which ITS technologies have the greatest impact upon these important goals. Analysis of the goal areas with the most benefits captured in the Knowledge Resources is presented below.

Safety

As shown in Figure ES-4, the eight technologies with the highest number of safety benefit summaries associated with them are: Collision Avoidance, Dynamic Message Signs, Speed and Right of Way Warnings, Speed Enforcement, Road Weather Information and Management, Traffic Signal Enforcement, Work Zone Management, and Variable Speed Limits.

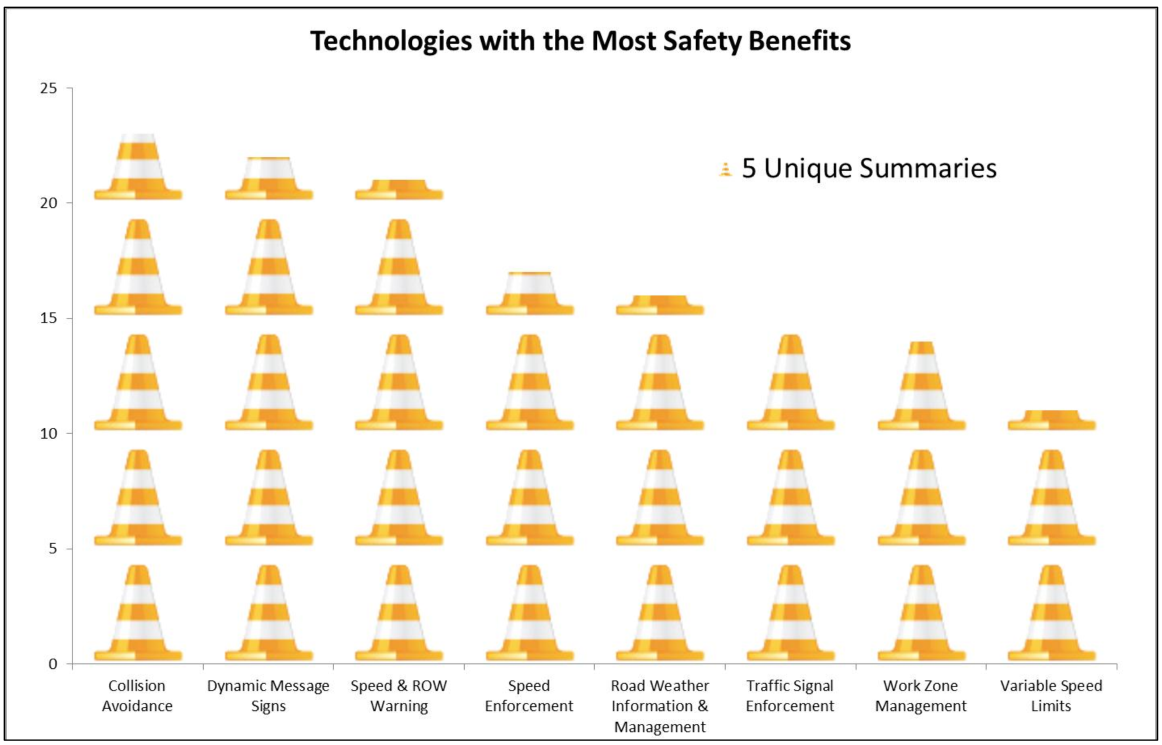


Figure ES-4. Top Five Technologies with the Highest Number of Safety Benefit Summaries

Benefit Snapshot - Safety

Source: iStockphoto.com/dchadwick

Scottsdale, Arizona – A speed enforcement camera demonstration program on Loop 101 Freeway in Scottsdale, Arizona decreased the total number of target crashes by 44 to 54 percent, the total number of injury crashes by 28 to 48 percent, and Property Damage Only crashes by 46 to 56 percent. (Benefit ID: 2011-00734)

Mobility

Mobility improvements are measured in travel time or delay savings, as well as travel time budget savings, and on-time performance. Figure ES-5 shows the top eight technologies with the highest number of mobility benefit summaries in the Knowledge Resources. They are: Dynamic Message Signs, Advanced Signal Systems, Adaptive Signal Controls, Transit Signal Priority, Pre-Trip Information, Surveillance, Work Zone Management, and Automatic Vehicle Location / Computer-Aided Dispatch.

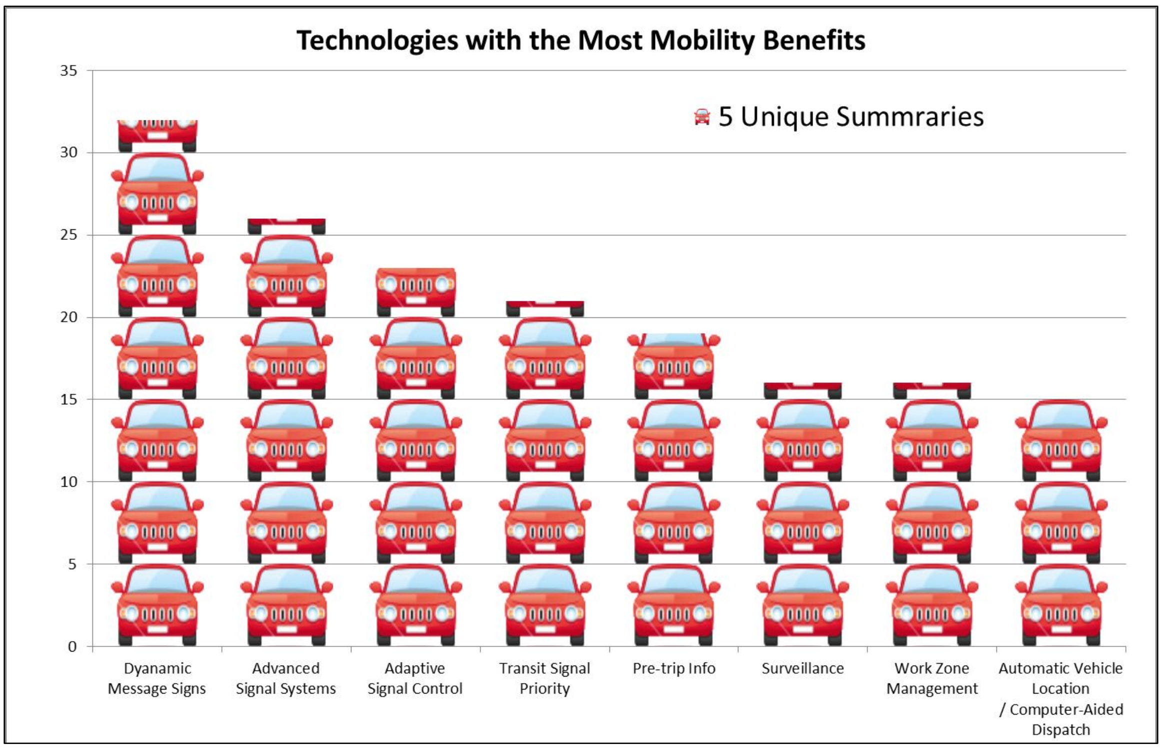


Figure ES-5. ITS Technologies with the Highest Number of Mobility Benefit Summaries

Benefit Snapshot – Mobility

Source: iStockphoto.com /Strendvssel

New York State - TMC operators and New York State Thruway Authority staff were able to reduce traffic queues by 50 percent using vehicle probe data available through the I-95 Corridor Coalition. The police, with the New York State DOT and the New York State Thruway Authority staff, were able to look at the trouble spots in the area along 1-87 and 1-287 during a holiday weekend and determine if and when to implement changes such as closure of full parking lots, ramp closures to prevent back-ups onto the freeway, and activation of dynamic message signs to alert motorists to the changes made. (Benefit ID: 2010-00653)

Productivity

Productivity improvements are typically documented in cost savings to transportation providers, travelers, or shippers. Figure ES-6 shows the top eight technologies associated with the most productivity benefits. They are: Automatic Vehicle Location / Computer-Aided Dispatch, CVO Electronic Screening, Road Weather Information & Management, Winter Maintenance Strategies, CVO Credential Administration, Service Patrols, Dynamic Message Signs, and Freight and Asset Tracking.

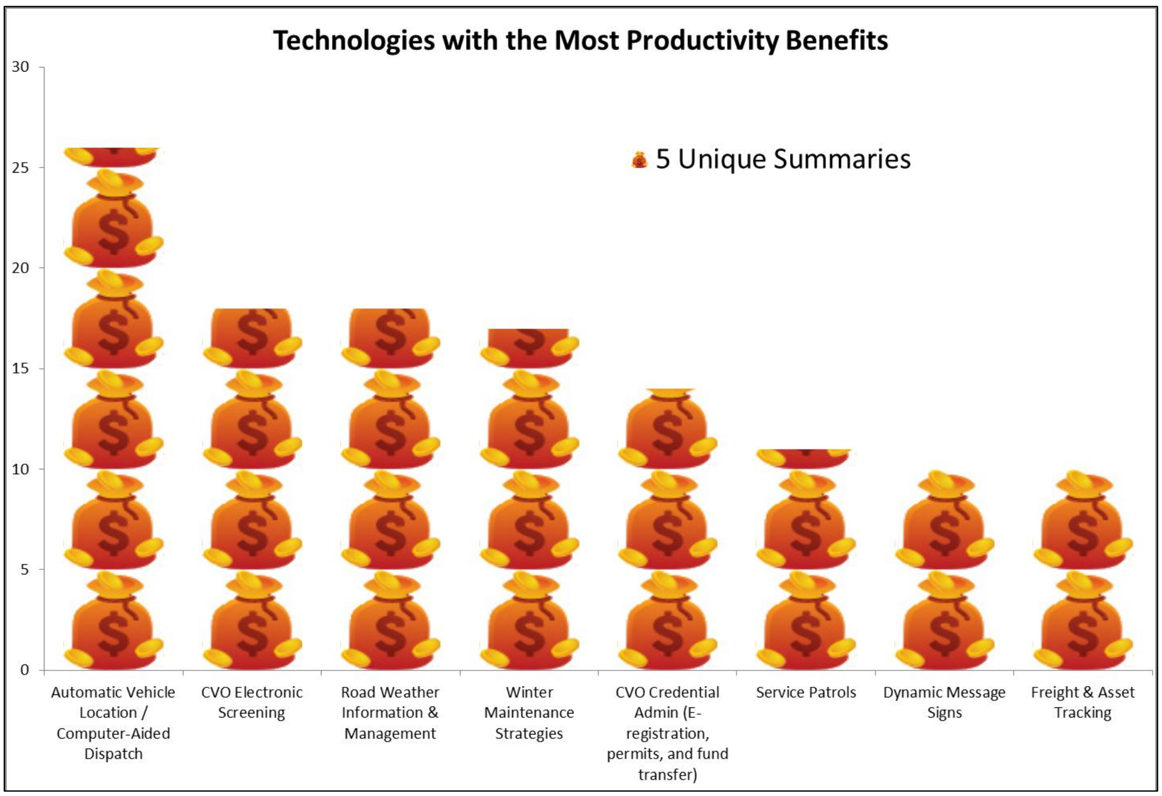


Figure ES-6. ITS Technologies with the Highest Number of Productivity Benefit Summaries

Benefit Snapshot – Productivity


Source: ©iStockphoto.com/breckeni

Indiana - During the 2008-2009 snow and ice season, the implementation of a Maintenance Decision Support System (MDSS) resulted in statewide savings of $9,978,536 (188,274 tons) in salt usage and $979,136 (41,967 hours) in overtime compensation from the previous winter season. (Benefit ID: 2010-00633)

Energy and Environment

Benefits in the area of Energy and Environment are typically documented through fuel savings and reduced pollutant emissions. Figure ES-7 shows the top eight technologies identified with the highest number of energy and environmental benefits. They are: Advanced Signal Systems, Dynamic Message Signs, Service Patrols, Roadway Surveillance, Pre-Trip Information, Speed Control, Congestion Pricing, and Electronic Toll Collection.

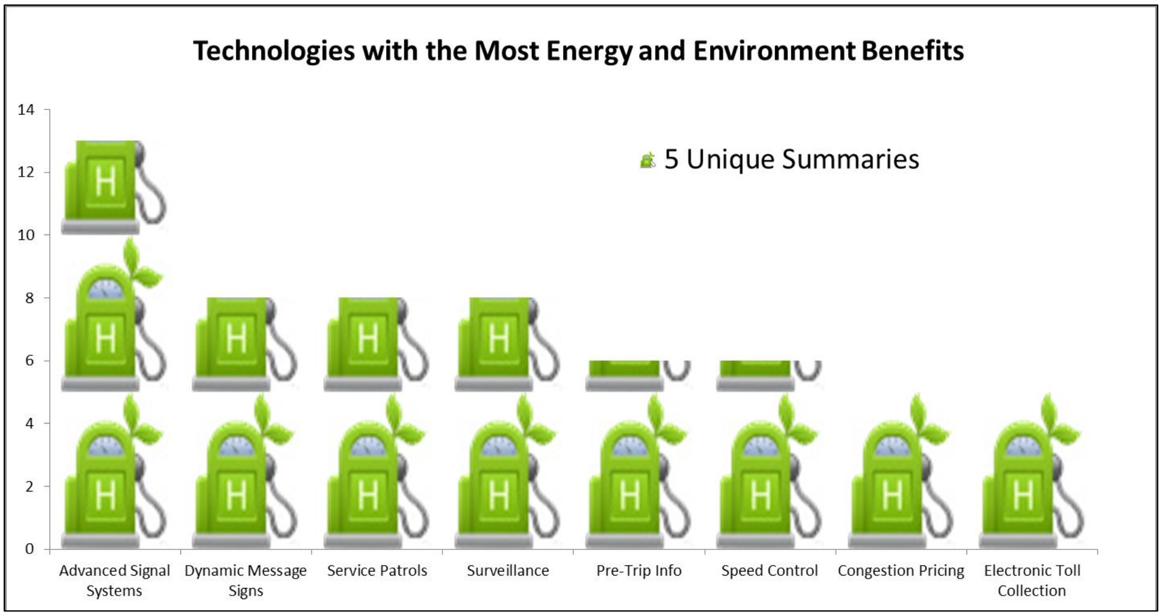


Figure ES-7. ITS Technologies with the Highest Number of Energy and Environment Benefit Summaries

Benefit Snapshot – Energy and Environment


Source: ©iStockphoto.com/Hermera

Oakland County, Michigan –Retiming 640 traffic signals during a two-phase project resulted in carbon monoxide reductions of 1.7 and 2.5 percent, nitrogen oxide reductions of 1.9 and 3.5 percent, and hydrocarbon reductions of 2.7 and 4.2 percent. (Benefit ID: 2007-00426)

Conclusion

In the fifteen years that the ITS JPO has been tracking the evaluation of ITS technologies, there has been steady growth in the number of studies documenting the benefits, costs and lessons learned of ITS. Looking back over the last three years, the most recent additions to the ITS knowledge resources indicate the following evaluation trends:

- Collision avoidance, driver assistance systems, and road weather management systems evaluations are capturing numerous safety impacts that should continue to increase as more of these systems are implemented.
- Mobility impacts are often captured for arterial management, electronic payment and pricing systems, freeway management, traffic incident management, transit management, and traveler information systems. Service patrols, advances in traffic signal timing, and incident detection have all had impacts on getting travelers moving.
- The highest productivity impacts (such as cost savings, benefit-cost ratio, or cost-effectiveness measures) are found in CVO, intermodal freight, road weather management systems, freeway management, traffic incident management, transit management and traveler information evaluations.
- Traveler information, electronic payment pricing, and transit management systems are often associated with high customer satisfaction benefits which enhances the success of these ITS applications.
- Transit management and electronic payment and pricing systems are often associated with efficiency benefits, such as increased passenger throughput.
- Although a substantial number of summaries capture energy and environmental impacts, many ITS evaluations are still not addressing this important goal area. Recent trends indicate that traveler information systems, arterial management, driver assistance, and freeway management applications are more likely to be evaluated for these measures.

In the last three years, productivity and efficiency goal areas constitute a higher percentage of the total benefits, costs, and lessons learned in the Knowledge Resource databases than in previous years. It appears that evaluators have given greater priority to these goal areas in an environment where budgets are limited and investments are subject to greater scrutiny. In this new and changing landscape, transportation decision-makers will look to the Knowledge Resources for evaluation guidance in choosing ITS investments and making improvements in their operations.

Chapter 1 Introduction

Mobility and safety challenges continue to be a problem for the U.S. transportation system. The decline in mobility has slowed slightly due to the economic downturn of the last three years; however, the problem continues to be very large. In 2009, urban Americans traveled an additional 4.8 billion hours and purchased an extra 3.9 billion gallons of fuel costing an estimated $115 billion due to congestion. Of this total, $33 billion was related to the cost of congestion on truck operations. Congestion declined in 2008 but resumed in 2009. As the economy strengthens, congestion will likely return to the higher levels of just three years ago. The cost of congestion to the average commuter was $808 in 2009.[1] Fatalities on U.S. highways continue to decline over the past few years with 32, 788 deaths reported in 2010. Even with the decline in fatalities, there are still preventable roadway tragedies every day.[2] Public transportation systems provided 10.2 billion trips in 2010, and freight volume on U.S. highways reached 21.5 billion tons in 2008, with 61.6 percent provided by trucks.[3, 4]

Intelligent transportation systems (ITS) provide a proven set of strategies for addressing the challenges of assuring safety and reducing congestion, while accommodating the growth in transit ridership and freight movement. ITS improve transportation safety and mobility, and enhance productivity through the use of advanced communications, sensors, and information processing technologies encompassing a broad range of wireless and wireline communications-based information and electronics. When integrated into the transportation system's infrastructure, and into vehicles themselves, these technologies relieve congestion, improve safety, and enhance U.S. productivity. Connected vehicle technology has the potential to enable many services presently provided by infrastructure- or vehicle-based ITS to benefit from enhanced communication between vehicles and the infrastructure.

ITS deployment can impact transportation system performance in six key goal areas: safety, mobility, efficiency, productivity, energy and environment, and customer satisfaction. A wide variety of performance measures are used across the evaluations discussed in this report to assess ITS performance under each of these goal areas. Safety is measured through changes in crash rates or other surrogate measures such as vehicle speeds, traffic conflicts, or traffic law violations. Mobility improvements have been measured in travel time or delay savings, as well as travel time budget savings, and on-time performance. Efficiency findings document the capability of better managed transportation facilities to accommodate additional demand, typically represented through increases in capacity or level of service within existing road networks or transit systems. Productivity improvements are typically documented in cost savings to transportation providers, travelers, or shippers. Benefits in the area of Energy and Environment are typically documented through fuel savings and reduced pollutant emissions. Customer Satisfaction findings measure, usually through surveys, the perception of deployed ITS by the traveling public.

This report presents information on the performance of deployed ITS under each of these goal areas, as well as information on the costs, deployment levels, and lessons learned regarding ITS deployment and operations. The report, and the collection of four Web-based resources upon which it is based, have been developed by the U.S. DOT's ITS Joint Program Office (JPO) to support informed decision making regarding ITS planning and deployment.

This collection of four Web-based resources provides ready access to information supporting informed decision making regarding deployment and operations of ITS to improve transportation system performance. Information presented in these online knowledge resources is the basis for this document. The four knowledge resources are the ITS Benefits Database, ITS Costs Database, ITS Deployment Statistics Database, and the ITS Lessons Learned Knowledge Resource. A fifth Web site, the ITS Applications Overview, provides access to information from each of the knowledge resources using an organization structure similar to that used in this report.

The collection of four Web-based resources on ITS deployment, benefits, costs, and lessons learned support informed decision making regarding ITS deployment and operations.

Additional information on each finding cited in this document can be found in the online knowledge resources, along with links to the original source documents, when available. See the "About This Report" section, below, for more information on accessing specific citations in this report online. Each of the knowledge resources is briefly described below. Additional information about each resource is available online including details about each site's organization, frequency of updates, and how to contribute information to the resources. When visiting the Web sites, follow the link to the "About This Site" and "Frequently Ask Questions (FAQ)" pages of each site for this information.

ITS Knowledge Resources Home Page

The ITS Knowledge Resources (KR) Home page integrates the Knowledge Resources databases described below, as well as providing a novel mapping application, social media connectivity (transportation related RSS feeds, twitter page, and blogs), Help information, comment and feedback mechanisms, and a tag cloud showing popular key words. The Home page interface provides an easy to use, centralized access point for all the Knowledge Resources databases and related functions and can be found at www.ITSKnowledgeResources.its.dot.gov. The new Home page also provides an effective and convenient way to offer new features, and solicit user feedback.

Source: ITS Knowledge Resources Portal

ITS Benefits Database

The major objectives of the ITS Benefits Database, available through the KR Home Page or directly online at www.itsbenefits.its.dot.gov, are to:

- Document findings from the evaluation of ITS research, deployments, and simulations pertaining to the effects of ITS on transportation systems performance.
- Provide transportation professionals with convenient access to the benefits of ITS research and deployment so that they can make informed planning and investment decisions.

Within the ITS Benefits Database, findings from ITS evaluations and other sources are presented in a concise summary format. Each benefit summary includes a title in the form of a short statement of the evaluation finding, context narrative, and identifying information such as date, location, and source, as well as the evaluation details and methodologies that describe how the identified ITS benefit was determined. The ITS Benefits Database documents represent findings of ITS evaluations, regardless of outcome, and includes several findings of neutral impact and a few examples of negative impacts under particular goal areas. The Web site includes useful search capabilities and also presents findings through several organization schemes including the ITS application areas discussed in the chapters of this report, the ITS goal areas, and by location.

ITS Costs Database

The ITS Costs Database, available online through the KR Home Page or directly online at www.itscosts.its.dot.gov, was established as a national repository of cost estimates for ITS deployments. The purpose of the ITS Costs Database is to support informed decision making of transportation leaders.

The ITS Costs Database contains estimates of ITS costs that can be used for developing project cost estimates during the planning process or preliminary design phase, and for policy studies and benefit-cost analyses. Both non-recurring (capital) and recurring or operations and maintenance (O&M) costs are provided where possible.

Three types of cost data are available: unit costs, sample unit costs and system cost summaries. The primary difference in the three types is the level of aggregation. Unit costs are the costs associated with an individual ITS element, such as a video camera for traffic surveillance or a dynamic message sign. A range of costs (e.g., $500 to $1,000) is presented for the capital cost and annual O&M cost of each element as well as an estimate of the length in years of its usable life. Unit costs are available in two formats: unadjusted and adjusted. The adjusted format represents costs that have been indexed to represent the cost in the most current year available. Sample unit costs are a compilation of actual or estimated costs of ITS elements on a per project basis and can be related back to the unadjusted unit costs. System cost summaries are the costs of an ITS project or portion of an ITS project such as the cost of expanding a statewide road weather information system or the detailed costs for a signal interconnect project. Each entry describes the background of the project, lists the ITS technologies deployed, and presents the costs and what the costs covered.

ITS Deployment Statistics Database

The ITS Deployment Tracking Project collects and disseminates information on the level of deployment and integration of ITS technology nationally. Information is gathered through a series of national surveys, covering metropolitan as well as rural deployment. Data have been collected in a series of national surveys conducted in 1997, 1999, 2000, 2002, 2004, 2005, 2006, 2007, and 2010. In the most recent survey, conducted in 2010, information was gathered from the largest U.S. metropolitan areas. Within each metropolitan area, agencies involved with freeway, arterial, and transit management; public safety (law enforcement and fire/rescue/emergency medical services); and toll collection were surveyed. More than 1,500 agencies were covered in the 2010 survey, with a response rate of nearly 85 percent. The deployment statistics database serves as a source of information on ITS deployment for the U.S. DOT, State and local transportation agencies, researchers, vendors, and the general public. Results from this survey and all previous national surveys are available online through the KR Home Page or directly at www.itsdeployment.its.dot.gov. The Web site also provides access to survey results in the form of downloadable reports and fact sheets.

ITS Lessons Learned Knowledge Resource

A lesson learned is the knowledge gained through experience or study. It is a reflection on what was done right, what one would do differently, and how one could be more effective in the future. The ITS Lessons Learned Knowledge Resource, available online through the KR Home Page or directly at www.itslessons.its.dot.gov, provides the ITS professional community with access to those lessons learned from others' experiences. This knowledge resource serves as a clearinghouse to document and share experiences of transportation practitioners in their planning, deployment, operations, maintenance, and evaluation of ITS to enable informed decision making regarding future ITS projects and programs. ITS lessons are collected primarily from case studies, best practice compendiums, planning and design reviews, and evaluation studies. The National Transportation Library, the Transportation Research Board's Transportation Research Information Services, international transportation literature databases (e.g., Transport), and conference proceedings are major sources for the documents that are reviewed. Interviews of subject matter experts are also used as sources of new lessons.

The lessons learned in this knowledge resource are based on the experiences of one or more ITS stakeholders from numerous ITS projects and programs in the country. Thus, a major focus for lessons presented in this document has been to gather typical field evidence—evidence-based lessons learned—that other stakeholders could benefit from learning.

About this Report

This report is ninth in the series based upon evaluation results collected by the ITS JPO including information on ITS deployment statistics. Deployment information is drawn from selected findings of the ITS Deployment Tracking surveys conducted by the ITS JPO in 2010. Highlighted benefits, costs and lessons learned represent recent findings that have been included in the databases since the last report: *Intelligent Transportation Systems Benefits, Costs, and Lessons: 2008 Update*.

Accessing Source Documents Online

Many of the findings presented in this report include numbered annotations further described in the "Endnotes" section near the end of the document. These endnotes provide reference information and short identification numbers that are hyperlinked directly to the Web site location or can be manually entered into the Knowledge Resources Web site search feature to quickly access more complete information on the cited finding and a link to the cited source document, if it is available online.

Report Organization

Following this introductory chapter, this report discusses 17 different areas of ITS applications. These chapters are divided into two groups discussing technologies deployed on the transportation infrastructure and those deployed within vehicles. Each chapter broadly describes the various ITS technologies that are typically deployed within a particular application area such as freeway management or commercial vehicle operations. A broad discussion of findings from the collected studies within the benefits, costs, and deployment knowledge resources follows. The chapters conclude with a series of recent findings from the knowledge resources, presented in tabular format. Included within the tables are the ranges of selected unit costs of ITS elements used to deploy the particular application. Costs are adjusted to 2009 dollars. The unadjusted costs can be found at the ITS Costs Database Web site. Narratives of field evidence for selected key lessons learned are interspersed throughout this report, presented after the tables within each chapter.

Intelligent Infrastructure

A wide variety of infrastructure-based ITS applications improve the safety and mobility of the traveling public, while enabling organizations responsible for operating transportation facilities and providing services to do so more efficiently. The following 14 chapters of this report cover ITS applications that can be deployed on the transportation infrastructure to improve the operation of highway and public transportation systems, as well as freight movement. The first five chapters discuss applications on the roadway infrastructure. The transit management chapter describes applications for public transportation systems. Six chapters discuss ITS applications that support improved management and operations of transportation systems, utilizing both the roadway and transit infrastructure. Finally, two chapters describe ITS strategies for facilitating freight movement.

Many of the applications discussed in the following chapters, while presently facilitated by technology deployed primarily within the transportation infrastructure, can be improved through connectivity with vehicle equipment and mobile devices. Enhanced communication between the roadside and vehicles would enhance the capability of many of the applications discussed. For example, warnings of approaching vehicles or stopped traffic could be more readily communicated to drivers, without relying on the presence of dynamic message signs at the appropriate location.

Intelligent Vehicles

In-vehicle applications of ITS use vehicle-mounted sensors and communications devices to assist with the safe operation of vehicles, prevent crashes, and mitigate the consequences of crashes that do occur. Collision avoidance systems monitor a vehicle's surroundings and provide warnings to the driver regarding dangerous conditions that may lead to a collision. Driver assistance systems provide information and, in some cases, assume partial control of the vehicle to assist with the safe operation of the vehicle. With the aim of speeding aid to victims after a crash occurs, collision notification systems alert responders when a crash occurs, with more advanced systems providing additional information on crash characteristics that can aid medical personnel.

Connected vehicle research represents an opportunity to improve a number of the vehicle-based ITS applications described in the following chapters. Updated information provided to vehicles through in-vehicle technologies could, for example, provide warnings of cross traffic at approaching intersections or enable navigation systems to avoid congested areas based on current traffic conditions. For more information on connected vehicle research activities, see www.its.dot.gov/connected_vehicle/connected_vehicle.htm.

Chapter 2 Arterial Management

Source: iStockphoto.com / RiverNorthPhotography

Arterial management systems manage traffic along arterial roadways, employing vehicle detectors, traffic signals, and various means of communicating information to travelers. These systems make use of information collected by traffic surveillance and detection technologies such as video imaging detector systems (VIDS) to smooth the flow of traffic along travel corridors. They also disseminate important information about travel conditions to travelers via technologies such as dynamic message signs (DMS), highway advisory radio (HAR), or mobile devices. Traffic sensors and surveillance devices may also be used to monitor critical transportation infrastructure for security purposes.

Traffic signal control systems address a number of objectives, primarily improving traffic flow and safety. Adaptive signal control systems coordinate control of traffic signals along arterial corridors, adjusting the lengths of signal phases based on prevailing traffic conditions. Advanced signal systems include those that provide the ability for proactive management of signal systems by allowing traffic conditions to be actively monitored and archive traffic data, and may include some necessary technologies for the later development of adaptive signal control. Coordinated signal operations across neighboring jurisdictions may be facilitated by these advanced systems. Pedestrian detection, specialized countdown signal heads, and bicycle-actuated signals can improve the safety of all road users at signalized

Categories

intersections. Arterial management systems can also apply unique operating schemes for traffic signals, portable or dedicated DMS, and other ITS components to smooth traffic flow during special events.

Surveillance at intersections continues to grow rapidly, more than doubling since 2000 to 48 percent of signalized intersections in the country's largest metropolitan areas in 2010.

A variety of techniques are available to manage the travel lanes available on arterial roadways and ITS applications can support many of these strategies. Examples include dynamic posting of high-occupancy vehicle restrictions and the use of reversible flow lanes allowing more lanes of travel in the peak direction of travel during peak periods. Variable speed limits (VSL) can be used to adjust speed limits in real-time based on changing traffic conditions, adverse weather, and work zone activities. Parking management systems, most commonly deployed in urban centers or at modal transfer points such as airports and outlying transit stations, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking spaces. Transportation agencies can share information collected by arterial management systems with road users through technologies within the arterial network, such as DMS or HAR. They may also share this information with travelers via broader traveler information programs such as 511, the Internet, and even smartphone applications. Arterial management systems may also include automated enforcement programs that increase compliance with speed limits, traffic signals, or other traffic control devices.

Information sharing between agencies operating arterial roadways and those operating other portions of the transportation network can also have a positive impact on the operation of the transportation system. Examples include coordinating operations with a freeway management system, or providing arterial information to a traveler information system covering multiple roadways and public transit facilities.

Recognizing that congestion has become a national problem, the U.S. DOT launched the *National Strategy to Reduce Congestion on America's Transportation Network*. One element of this strategy is to reduce congestion by promoting operational and technical improvements that have the potential to enable existing roadways to operate more efficiently.[5] Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/congestion/.

In addition to the individual ITS technologies profiled in this chapter, the Integrated Corridor Management (ICM) initiative has the potential to improve arterial management strategies. The purpose of the ICM initiative is to demonstrate that ITS technologies can be used to efficiently and proactively manage the movement of people and goods in major transportation corridors by facilitating integration of the management of all networks in a corridor. The results of the initiative will help to facilitate widespread use of ICM tools and strategies to improve mobility through integrated management of transportation assets. The ICM initiative will also demonstrate how proven and emerging ITS technologies can be used to coordinate the operations between separate corridor networks (including both transit and roadway facilities) to increase the effective use of the total transportation capacity of the corridor.[6] ICM Deployment demonstrations in Dallas and San Diego are being implemented in 2011 and 2012 with an independent national evaluation. Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/icms.

Several ITS applications that impact traffic operations on arterial roadways are discussed elsewhere in this report. Transit signal priority systems, discussed within the transit management chapter, can ease the travel of buses or light rail vehicles on arterial corridors and improve on-time performance. Signal preemption for emergency vehicles reduces the likelihood of crashes during incident response while improving response times. These systems are discussed in the emergency management chapter. The electronic payment and pricing chapter discusses pricing strategies that are used on a growing number of arterial streets.

Findings

As of July 11, 2011, there were 212 evaluation summaries of Arterial Management applications in the Knowledge Resource databases, as shown in Figure 2-1. The Arterial Management category with the largest number of summaries was Traffic Control, followed by Information Dissemination and Surveillance categories, as shown by Figure 2-2.

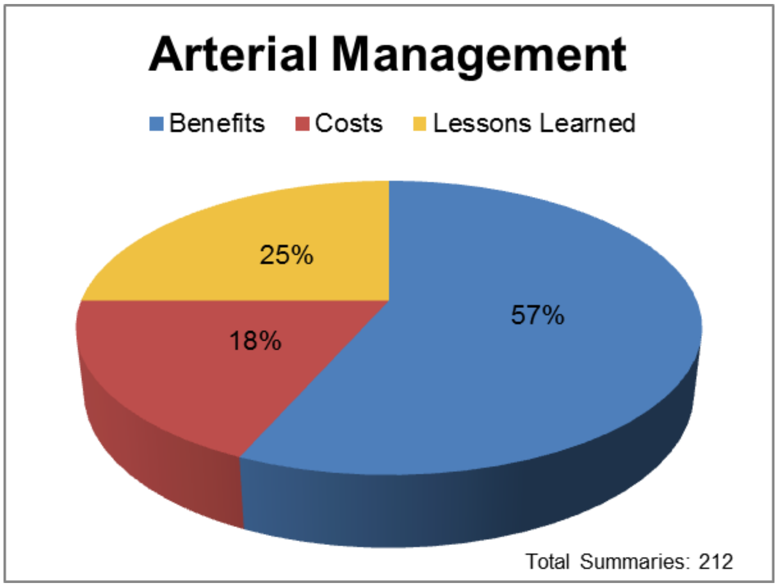


Figure 2-1. Arterial Management Summaries in the Knowledge Resources

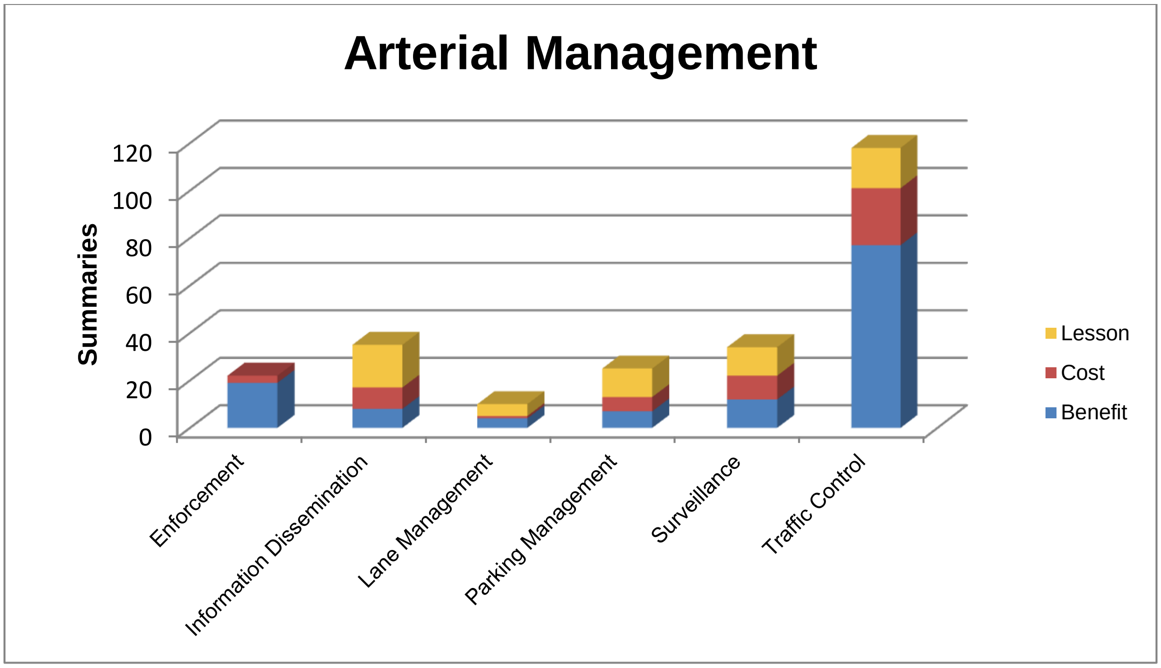


Figure 2-2. Summaries in the Knowledge Resources by Arterial Management Category

Benefits

Table 2-1 summarizes the findings contained in the ITS Benefits Database and highlighted later in this chapter. Studies demonstrate the ability of traffic control ITS applications to enhance mobility, increase efficiency of the transportation system, and reduce the impact of automobile travel on energy consumption and air quality. The ability of both adaptive signal control and coordinated advanced traffic signal systems to smooth traffic can lead to corresponding safety improvements through reduced rear-end crashes.

Studies of parking management systems demonstrate the potential of these systems to improve traffic flow in congested urban areas and improve travelers' experiences at major transportation facilities, such as airports and suburban transit and commuter rail stations.

A 2011 study by the Insurance Institute for Highway Safety found that red light enforcement programs in 14 U.S. cities resulted in a 24 percent lower rate of fatal red light running crashes during a four year period relative to what it would have been without camera enforcement.[7]

Table 2-1. Arterial Management Benefits Summary

Arterial Management Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Surveillance						◉
Traffic Control	◉	●	●	●	●	◉
Lane Management					◉	
Parking Management		●	◉			●
Information Dissemination		◉		●		
Enforcement	●					●

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇃↾ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

Optimizing signal timing is considered a low-cost approach to reducing congestion. Based on data collected over the years and recently reported in the 2007 National Traffic Signal Report Card the costs to update signal timing remains about $3000 per intersection. While this amount is reasonable, costs could be slightly more or less.[8] Well-trained technicians are needed to maintain traffic signal hardware so that the signal system is operating well and according to the timing updates. A current assumption is one traffic signal technician can maintain 30 to 40 signals. The average costs of a technician is $60,000 per year which includes salary, benefits (approximately 30 to 35 percent of salary), vehicles, parts/supplies, and other required items.[9]

In Oakland, California the total capital cost of the Bay Area Rapid Transit (BART) smart parking system are in-line with estimates, however, researchers noted that the scale of the deployment would need to be much larger (greater than 50 spaces per station) if operations were expected to recover the system costs. Capital costs to implement the system which included two roadside DMS units, an integrated web-based reservation system, and interactive voice response (IVR) support were estimated at $205,000.[10]

Deployment

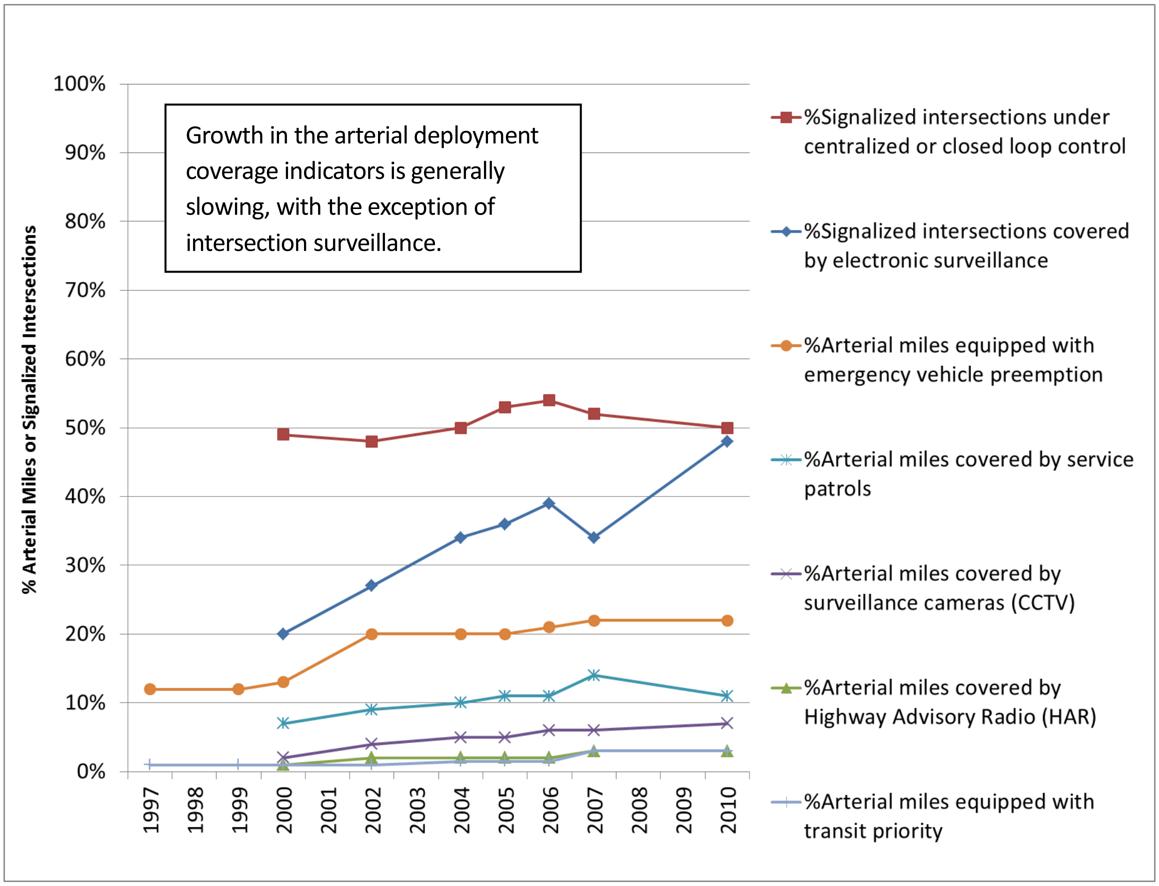


Figure 2-2. Deployment Trends for Arterial ITS, 2000 – 2010

Figure 2-2 shows deployment trends for key ITS technologies supporting arterial management from 2000 to 2010, based on a series of surveys of arterial management agencies in the country's largest metropolitan areas. Half (50 percent) of traffic signals in these metropolitan areas were under centralized control through closed loop or computer control in 2010. The trend to bring traffic signals under centralized control has leveled off in recent years. In contrast, surveillance at intersections continues to grow rapidly, more than doubling since 2000 to 48 percent of signalized intersections. Arterial street miles covered by service patrols in these metropolitan areas peaked at 15 percent in 2007, but has seen a steady decline over the past few years to about 11 percent. Deployment of closed circuit television (CCTV) cameras on arterial streets is still at a low level, but continues to experience a moderate rate of growth. HAR and transit signal priority have yet to be deployed in large numbers.[11]

Selected Highlights from the ITS Knowledge Resources on Arterial Management

Surveillance

Many strategies for arterial management are enabled by traffic surveillance and detection technologies, such as sensors or cameras monitoring traffic flow. The surveillance and detection technologies used to monitor traffic flow in support of ITS applications can also be used to monitor key transportation facilities for security purposes.

Surveillance	
Deployment	
Forty-eight (48) percent of signalized intersections in the country's largest metropolitan areas use electronic surveillance to monitor traffic. [12]	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Monroe County, New York, the Camera Deployment and Intelligent Transportation Systems (ITS) Integration project reduced incident validation times by 50 to 80 percent saving between 5 and 12 minutes per incident.[13]
Costs	
Unit Costs Data Examples	
Roadside Detection subsystem: • Inductive Loop Surveillance at Intersection: $7.5K-$13.3K • Remote Traffic Microwave Sensor at Intersection: $14K • Closed Circuit Television (CCTV) Video Camera: $8K-$16K Transportation Management Center subsystem: • Hardware, Software for Traffic Surveillance: $134K-$164K Roadside Telecommunications subsystem: Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	
Costs of ITS Deployments	
New York - The Monroe County Department of Transportation (MCDOT) opened a Regional Traffic Operations Center (ROTC) in 2002 to improve operations throughout the City of Rochester and along the county's arterial roadways. The ROTC lacked real-time visual traffic surveillance capability; a system function the MCDOT felt would enhance system operation and efficiency. To address this need, MCDOT undertook the ITS Camera Deployment and Systems Integration Project. During the first phase, five CCTV camera deployments were implemented at the highest priority intersections in the county. Installation began in September 2004, with construction and acceptance testing completed in February 2005. In 2006, MCDOT completed an evaluation of these initial five CCTV installations. The system cost to install and implement five CCTV cameras was **$279,338**. This yields an average cost of **$55,860** per camera installation.[14]	

Traffic Control: Adaptive Signal Control

Adaptive signal control systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions.

Traffic Control: Adaptive Signal Control
Deployment
Three percent of traffic signals in the country's largest metropolitan areas are controlled by adaptive signal control. [15]
Costs
Unit Costs Data Examples
Roadside Control subsystem: • Signal Controller and Cabinet: $7K-$12K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Traffic Control: Advanced Signal Systems

Advanced signal systems include coordinated signal operations across neighboring jurisdictions, as well as centralized control of traffic signals, which may include some necessary technologies for the later development of adaptive signal control.

Traffic Control: Advanced Signal Systems	
Deployment	
Fifty (50) percent of signalized intersections in the country's largest metropolitan areas operate under centralized computer control. [16]	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Espanola, New Mexico the implementation of a traffic management system on NM 68 provided a decrease in total crashes of 27.5 percent. [17]
Mobility	In the City of Fort Collins, Colorado, the installation of an Advanced Traffic Management System reduced travel times up to 36 percent.[18]

Traffic Control: Advanced Signal Systems

Costs

Unit Costs Data Examples

Roadside Control subsystem:

- Signal Controller Upgrade for Signal Control: $2.1K-$5K

Transportation Management Center subsystem:

- Software, Integration for Signal Control: $104K-$149K

Roadside Telecommunications subsystem:

- Conduit Design and Installation – Corridor: $52K-$77K
- Fiber Optic Cable Installation: $21K-$54K

Sample System Costs of ITS Deployments

United States: Optimizing signal timing is considered a low-cost approach to reducing congestion. Based on data from numerous studies and the most recent Traffic Signal Report Card, the costs continue to be about **$3,000 per signal per update**. While this amount is reasonable, costs could be slightly more or less.[19]

United States: Well-trained technicians are needed to maintain traffic signal hardware so that the signal system is operating well and according to the timing updates. A current assumption is one traffic signal technician can maintain 30 to 40 signals. The average cost of a technician is **$60,000 per year** which includes salary, benefits (approximately 30 to 35 percent of salary), vehicles, parts/supplies, and other required items.[20]

New Mexico: The cost to deploy a new traffic management system in Espanola, New Mexico was $862,279. The system consists of eight signalized intersections on NM 68 and video detection equipment, a fiber optic communication system, a wireless communication system, traffic management system hardware and software, and system integration. The traffic management system connects to a traffic operations center located at the New Mexico Department of Transportation general office in Santa Fe. The system has expansion capabilities of at least 30 additional intersections.[21]

Washington: The Spokane Regional Traffic Management Center (SRTMC) was created as a regional partnership to provide area-wide ITS coverage during peak travel periods, to monitor and respond to incidents, and to share data. The Regional Traffic Management Center Enhancements project, that was implemented to integrate signal systems between jurisdictions and to improve incident response and management, cost **$1,238,679**.[22]

Benefit-Cost Studies

Virginia: Coordinated actuated traffic signal systems produced a 30 percent reduction in corridor travel times compared to actuated isolated systems, resulting in a benefit-cost ratio of 461.3.[23]

Pennsylvania: An optimized traffic signal timing project in Allegheny County, PA resulted in a benefit-cost ratio of 57:1 along the corridor.[24]

Lesson Learned: Incorporate contractual provisions to conduct on-site traffic signal demonstration testing and provide sufficient project oversight to ensure vendors meet agency requirements.

An advanced traffic management system (ATMS) project design and procurement should include rigorous performance requirements for vendors supplying traffic signal hardware and software. It is not only critical to select a proper vendor, it is also critical that the performance requirements for the vendors be well established within the procurement documents. In addition, the project manager and project engineers need to provide sufficient project oversight to be sure the vendors are meeting the requirements of the contract. A well-written contract cannot make up for little project oversight, nor will it protect the agencies' interests during failure of certain aspects of the project. Often, these failings result in litigation which, even when the agency wins, has absorbed time and money better spent elsewhere. In addition, it is often not possible to simply return large purchases when products fail to perform as promised.

When working with hardware and software vendors, the City of Fort Collins offers the following lessons learned:

- **Conduct all product testing and demonstrations in the location where the product has to work**. Having vendors show their product at their facility means little when the equipment will not work on-site. In contractual agreements, it is important to make sure vendors prove their products will do what they say they will do by testing their products on-site. It is also important for the implementing agency to learn, as much as possible, about vendors' products in order to test them appropriately. The electronics environment within transportation infrastructure is becoming very high-tech, very detailed, and very complicated, making it difficult to be knowledgeable of all facets of the equipment available for meeting customers' needs unless the product demonstration tests are conducted on-site with due diligence.
- **Be aware that vendors may over-promise and under-deliver.** Almost all the vendors offering products or services employed on the project promoted the impressive capabilities of their products and services. Frequently, products and services fell short of their touted capabilities. Some vendors' contracts had to be terminated because their products or services failed to perform as contracted, or even, in one case, failed to perform at all.

The agency should consider a two-step procurement process: pre-qualification and bid. This type of procurement requires the vendors to meet certain pre-qualifications before they are allowed to bid on the entire project. The agency can require the vendor to provide a demonstration or some other proof to determine if the hardware and software proposed will meet their needs before the vendor is allowed to compete for the full project. It is particularly important that a good client-vendor relationship be built where project goals are understood and effective communication is established.[25]

Traffic Control: Bicycle and Pedestrian

Pedestrian detectors, pedestrian-activated crosswalk lighting, specialized pedestrian signals (e.g., countdown WALK/DON'T WALK signals), and bicycle-actuated signals can improve the safety of all road users at signalized intersections and unsignalized crossings.

Traffic Control: Bicycle and Pedestrian
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Pedestrian Detection – Microwave: $0.5K • Pedestrian Detection – Infrared: $0.2K-$0.4K Roadside Information subsystem: • Light-Emitting Diode (LED) Countdown Signal: $0.261K-$0.361K • Pedestrian Crossing Illumination System: $22.8K-$35K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Traffic Control: Special Events

Arterial management systems can also smooth traffic flow during special events with unique operating schemes, incorporating elements such as special traffic signal operating plans, temporary lane restrictions, traveler guidance, and other measures.

Traffic Control: Special Events
Costs
Unit Costs Data Examples
Roadside Control subsystem: • Linked Signal System Local Area Network (LAN): $20K-$47K Roadside Information subsystem: • Dynamic Message Sign: $41K • Dynamic Message Sign – Portable: $15.9K-$21K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Lessons Learned: Use portable ITS equipment to monitor and control traffic flow at major signalized intersections located at entrance and exit points near planned special events.

Dutchess County in New York, home to approximately 300,000 residents, faces an influx every year of more than 500,000 people who, over the course of six days, attend the annual agricultural fair. The influx of visitors and vehicles burdens the county's transportation network, which consists of rural roads, two-lane state routes and several intersections. Although the county is a rural one, the traffic level is high. For example, the two-lane state road that leads to the fairground has two signalized intersections that operate near capacity on nonevent days. In the past, the county had severe traffic congestion that not only stalled entry and egress to the fairgrounds, but also spilled over to nearby jurisdictions, blocking access to a local hospital, backing up traffic on a bridge over the Hudson River and hampering the travel of commercial vehicles passing through the county to other destinations.

To improve the efficiency of transportation operations on the day of the event, the New York State Police (NYSP), which is responsible for traffic management on state roads, in coordination with the New York State Department of Transportation, developed a traffic plan that utilized ITS. Listed below are lessons learned and best practices using ITS to aid in the management of a planned special event in a rural area:

- **Apply portable ITS equipment to improve traffic flow at the entrance and exit points of a planned event.**
- **Deploy microwave detectors at signalized intersections for pedestrian detection and for allowing pedestrian crossing.**
- **Use CCTV and signal control software at signalized intersections for monitoring congestion and adjusting signal phases.**
- **Divert commercial vehicles headed through the event area to alternate routes.**

The FHWA report describes how a traffic plan and the use of portable ITS equipment improved traffic flow at a planned special event in a rural county in upstate New York and advanced transportation safety, efficiency and mobility goals.[26]

Lane Management

Lane management applications can promote the most effective use of available capacity during emergency evacuations, incidents, construction, and a variety of other traffic and/or weather conditions.

Lane Management
Deployment
Lane management systems have yet to be used widely on arterial streets. Only 11 percent of the country's largest metropolitan areas have high-occupancy vehicle restrictions or use reversible flow lanes on at least one of their arterial streets.[27]
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Closed Circuit Television (CCTV) Video Camera: \$8K-\$16K Transportation Management Center subsystem: • Labor for Lane Control: \$116K-\$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: \$52K-\$77K • Fiber Optic Cable Installation: \$21K-\$54K

Parking Management

Parking management systems with information dissemination capabilities, most commonly deployed in urban centers or at modal transfer points such as airports, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking.

Parking Management	
Deployment	
The percentage of agencies that adopted parking management systems increased from 5 percent in 2000 to 8 percent in 2010.[28]	
Benefits	
ITS Goals	**Selected Findings**
Mobility	The smart parking project found that more efficient management of transit station parking lots improved parking space utilization rates and increased BART ridership. Key findings from the analysis included decreased average commute time (47.5 minutes with smart parking and BART, and 50.1 minutes without smart parking) and reduced total vehicle miles traveled (on average, there were 9.7 fewer vehicle miles traveled per participant per month).[29]
Efficiency	A smart parking system outside San Francisco, California provided the ability to reserve parking spaces at a transit station, either pre-trip or en route, with space availability displayed on roadside DMS. Surveys of participants found sizable increases in transit mode share (5.5 more transit commutes per month), a decreased average commute time (an average of 5 percent for a 50-minute commute), and a reduction in total vehicle miles traveled per participant of 9.7 miles per month.[30]
Customer Satisfaction	Thirty percent of commuters would like to see an expansion of the Automated Parking Information System (APIS) that provides heavy-rail commuters with station parking availability information at en-route roadside locations.[31]
Costs	
Unit Costs Data Examples	
Parking Management Center subsystem: • Entrance/Exit Ramp Meters: $1K-$3K • Tag Readers: $1K-$3K • Database and Software for Billing and Pricing: $10K-$15K • Parking Monitoring System: $16K-$35K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Parking Management
Sample System Costs of ITS Deployments
Maryland, Washington, Illinois: A cross-cutting study was conducted to evaluate the deployment of advanced parking management systems in new parking facilities constructed in Baltimore, Seattle, and Chicago. The study found that these systems cost between **$250 to $800 per space** to install depending on the type and level of information provided, level of effort required to install sensors, ease of access to communications and power supplies, and the signage required to convey parking information to drivers at appropriate decision points. The BWI airport installation was estimated to cost **$450 per space**, while the operations cost for the Chicago Metra Park-and-Ride facility is estimated at **$1,700 annually** to power the seven electrical signs in the system.[32] **California:** A smart parking field test conducted for the California DOT and BART integrated traffic count data from entrance and exit sensors at the Rockridge BART station parking lot with an intelligent reservation system to provide accurate, real-time parking availability information. Information was available on two portable DMS along Highway 24. Commuters could also check parking availability and make reservations via telephone, mobile phone, Internet, or personal digital assistant. Although capital and operating costs of the field test were donated, the capital costs are estimated at **$150 to $250 per space** and O&M costs are estimated at **$40 to $60 per space**.[33] **Illinois:** In August, 2006, the Chicago Regional Transportation Authority (RTA) and Metra (the commuter rail system serving the Chicago Metropolitan area) implemented a pilot project to test the usefulness of a real-time parking information system for two of their commuter rail stations in suburban Chicago. The RTA/Metra parking management guidance system is comprised of two main components: parking monitoring and an en-route information system. The total cost of the Metra project (including construction of the signs as well as purchasing and installing the hardware and software) was approximately **$1 million**.[34]

Information Dissemination

Advanced communications have improved the dissemination of information to the traveling public. Motorists are now able to receive relevant information on location-specific traffic conditions in a number of ways including DMS, HAR, in-vehicle displays, and specialized information transmitted to individual vehicles.

Information Dissemination	
Deployment	
Permanent DMS, portable DMS, and HAR are used on 2 percent of arterial street miles in the country's largest metropolitan areas.[35]	
Benefits	
ITS Goals	**Selected Findings**
Energy and Environment	Simulation models show that real-time on-board driver assistance systems that recommend proper following distances can improve fuel economy by approximately 10 percent. The system would be more suitable for urban roadways where traffic signals and congestion are more frequent.[36]

Information Dissemination
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Dynamic Message Sign: $41K • Dynamic Message Sign – Portable: $15.9K-$21K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Enforcement

Automated enforcement systems, such as speed enforcement and traffic signal enforcement, improve safety, reduce aggressive driving, and assist in the enforcement of traffic signal and speed limit compliance.

Enforcement	
Deployment	
Automated speed enforcement and red light enforcement cameras on arterial streets are in use in 27 of the country's largest metropolitan areas.	
Benefits	
ITS Goals	**Selected Findings**
Safety	***Summary Finding:*** A 2007 literature review by the NHTSA documented studies of speed camera programs worldwide, which reported crash reductions from 9 to 41 percent.[37]
Safety	Analysis of red light enforcement camera programs in Phoenix, Arizona found reductions in right-angle and left-turn crashes of 14 percent and 1 percent, respectively, while rear-end crashes increased 20 percent. In Scottsdale, right-angle and left-turn crashes decreased by 17 percent and 40 percent, respectively, with rear-end crashes increasing 45 percent. In both cities, the programs had a positive economic impact due to the greater severity of right-angle and left-turn crashes. In Scottsdale, experience showed a larger impact on fatal and injury crashes and therefore a larger economic impact than in Phoenix.[38]
Safety	Cities with camera enforcement had a 24 percent lower rate of fatal red light running crashes during 2004-08 relative to what it would have been without camera enforcement. Further, the rate of all fatal crashes at signalized intersections in cities with enforcement programs was 17 percent lower than what it would have been without camera enforcement.[39]

Enforcement
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Portable Speed Monitoring System: $4.1K-$12.2K • Traffic Camera for Red Light Running Enforcement: $60K-$109K Roadside Information subsystem: • Variable Speed Display Sign: $3K-$4K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Chapter 3 Freeway Management

Source: ©iStockphoto.com/Strendyssel

There are numerous ITS strategies to improve the operation of the freeway system. Traffic surveillance systems use vehicle detectors and cameras to support freeway management applications. Traffic control measures on freeway entrance ramps, such as ramp meters, can use sensor data to optimize freeway travel speeds and ramp meter wait times. Lane management applications can promote the most effective use of available capacity on freeways and encourage the use of high-occupancy commute modes. Special event transportation management systems can help control the impact of congestion at stadiums or convention centers. In areas with frequent events, large changeable destination signs or other lane control equipment can be installed. In areas with occasional or one-time events, portable equipment can help smooth traffic flow. Advanced communications have improved the dissemination of information to the traveling public. Motorists are now able to receive relevant information on location-specific traffic conditions in a number of ways including dynamic message signs (DMS), highway advisory radio (HAR), even in-vehicle systems. (Other methods of providing traveler information, including those covering multiple modes or travel corridors, are discussed in the traveler information chapter.) Automated systems enforcing speed limits and aggressive driving laws can lead to safety benefits.

Categories

Surveillance

- Traffic
- Infrastructure

Ramp Control

- Ramp Metering
- Ramp Closures
- Priority Access

Lane Management

- High-Occupancy Vehicle Facilities
- Reversible Flow Lanes
- Pricing
- Lane Control
- Variable Speed Limits
- Emergency Evacuation

Special Event Transportation Management

- Occasional Events
- Frequent Events
- Other Events
- Temporary Traffic Management Center

Information Dissemination

- Dynamic Message Signs
- In-Vehicle Systems
- Highway Advisory Radio

Enforcement

- Speed Enforcement
- High-Occupancy Vehicle Facilities
- Ramp Meter Enforcement

Several other chapters of this report discuss ITS applications relevant to freeway management. The traveler information chapter discusses the provision of information on traffic conditions to travelers on a regional basis. For example, technologies such as 511 and regional traveler information Web sites can provide important information to freeway travelers. Successful implementation of these strategies often requires collaboration with other agencies in a region, contrasted with the use of freeway DMS under the direct control of the freeway management agency. The crash prevention and safety chapter describes road geometry warning systems which have been helpful in addressing safety challenges on freeway downgrades and exit ramps. The electronic payment and pricing chapter discusses pricing strategies that are used on a growing number of freeways.

The use of Traffic Surveillance Systems has increased substantially in the past decade. Video cameras cover approximately 45 percent of freeway miles as of 2010 from 15 percent in 2000, and Electronic Surveillance expanded from 18 percent in 2000 to 55 percent in 2010.

In addition to the individual ITS technologies profiled in this chapter, the Integrated Corridor Management (ICM) initiative, a major ITS initiative currently being conducted by the U.S. DOT, has the potential to improve freeway management strategies. The purpose of the ICM initiative is to demonstrate that ITS technologies can be used to efficiently and proactively manage the movement of people and goods in major transportation corridors by facilitating integration of the management of all networks in a corridor. The results of the initiative will help to facilitate widespread use of ICM tools and strategies to improve mobility through integrated management of transportation assets.[40] ICM Deployment demonstrations in Dallas and San Diego are being implemented in 2011 and 2012 with an independent national evaluation. Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/icms.

Findings

As of July 11, 2011, there were 193 evaluation summaries of Freeway Management applications in the Knowledge Resource databases, as shown in Figure 3-1. The Freeway Management category with the largest number of summaries is Information Dissemination (more than 97), followed by Surveillance (50 summaries), Lane Management (47 summaries), and Ramp Control (42 summaries), as shown in Figure 3-2.

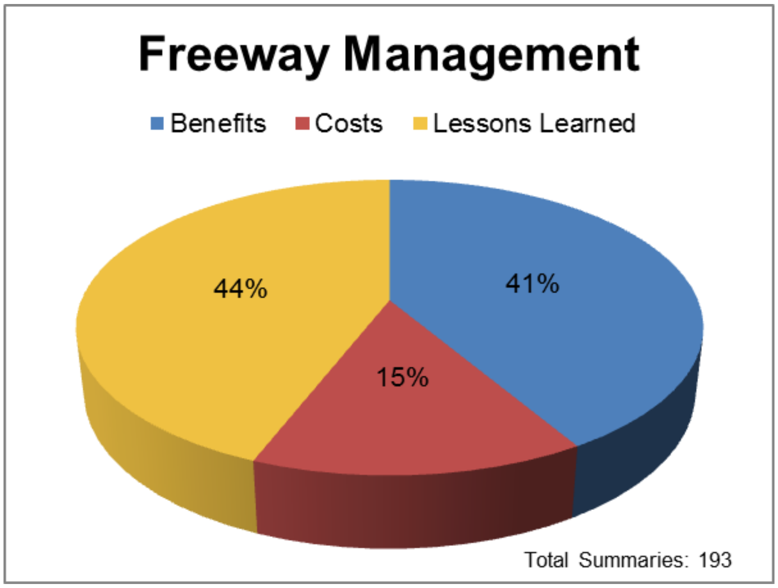


Figure 3-1. Freeway Management Summaries in the Knowledge Resources

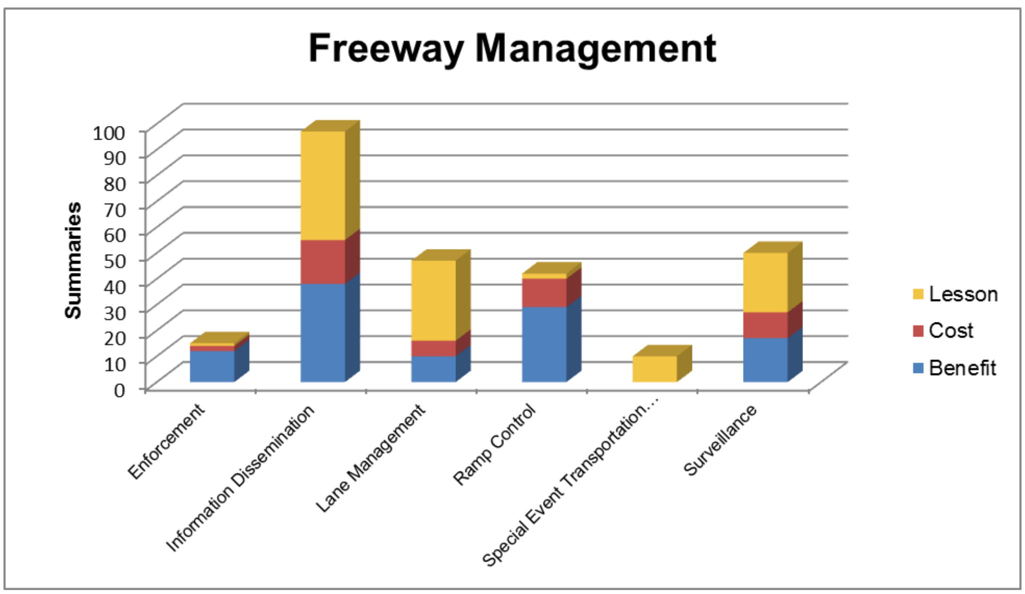


Figure 3-2. Summaries in the Knowledge Resources by Freeway Management Category

Benefits

A pilot test in the California Bay Area demonstrated that displaying real-time highway and transit trip times to the same destination and transit train departure times on changeable message signs encouraged motorists who typically do not use transit to switch to transit (1.6 percent motorist switched to transit when the time savings was less than 15 minutes, and 7.9 percent switched when the time savings was greater than 20 minutes).[41]

In the Minneapolis area, beginning in May 2005, HOV lanes on Highway 101 were converted into dynamically priced HOT lanes, resulting in an increase in peak period throughput by 9 to 33 percent. Surveys of motorists found broad support among all income groups for the program and satisfaction with the speed of the traffic flow.[42]

Several studies document safety improvements with the implementation of variable speed limits (VSL). These benefits stem from reduced speed variability and slower vehicle speeds during periods of hazardous traveling conditions. VSL signs installed on the Interstate loop (I-270/I-255) around St. Louis, Missouri helped encourage consistent speeds in congested conditions and reduced closing speeds of incoming traffic, resulting in a reduced crash rate of 4.5 to 8 percent, with a standard deviation of 3.4 percent.[43]

An evaluation study conducted in Scottsdale, Arizona showed that urban freeways equipped with automated speed enforcement technologies can reduce average speeds by about 9 mph and decrease the total number of injury crashes by 28 percent to 48 percent and of property-damage-only crashes by 46 percent to 56 percent.[44]

Table 3-1 presents qualitative ratings of the impact of freeway management ITS applications under each of the six ITS goals. Many of the strategies have been found effective in improving safety. Studies of ramp metering and information dissemination have shown mobility improvements. Ramp metering has also been found to enable the freeway system to accommodate larger traffic volumes. Ramp metering, information dissemination, and speed enforcement programs have been found, in surveys, to be well received by the traveling public. More study of the impact of using freeway ITS to manage traffic at special events is needed.

Table 3-1. Freeway Management Benefits Summary

Freeway Management Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Surveillance	Enabling technology.					
Ramp Control	◘	●	●			●
Lane Management	◘					
Special Event Transportation Management						
Information Dissemination	◘	◘				◘
Enforcement	●					●

● – substantial positive impacts	◘ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

There are numerous ITS strategies to improve freeway operations. The costs of these strategies vary based on many factors including whether or not the deployment is part of a larger agency project and maintenance and operations costs, as many States are experiencing.

The North Carolina DOT found using vehicle probes to monitor traffic cost less than remote traffic microwave sensors, which cost about $48,600 per mile. The South Carolina DOT also found that vehicle probes were a cost effective way to monitor traffic cost over standard side-fire radar detectors. Maintaining the radar detectors over 300 miles was the same as using vehicle probes over 1,200 miles. In addition, the probes provided additional data, having transmitted travel time and speed data.[45] The use of vehicle probe data has also improved mobility. For example, the New Jersey DOT found that vehicle probe data improved the efficiency of incident management, resulting in estimated savings of $100,000 per incident in user delay costs.[46] Using vehicle probe data enabled the New York State DOT to reduce traffic queues by 50 percent during the Thanksgiving holiday, which helped prevent traffic from backing up onto the freeway.[47]

In 2004, the Washington State DOT (WSDOT) developed a traveler information system in Vancouver at a cost of $511,300. The system consisted of three VMS, two HAR stations, and one Road Weather Information System (RWIS).[48]

Benefit-Cost Studies

The Analysis, Modeling and Simulation (AMS) of Integrated Corridor Management (ICM) strategies on the Interstate-15 Corridor in San Diego, California estimate that ICM deployment would have a benefit-cost ratio of 9.7:1 over a 10-year lifecycle. The benefits are attributed to savings in travel delay, resulting in lower vehicle-hours of travel, fuel consumption, and vehicular emissions. In addition, providing improved traveler information is expected to attract more arterial drivers to the freeway, resulting in improvements in arterial and overall system performance.[49]

The AMS of the ICM Test Corridor on I-880 in San Francisco between Oakland and Fremont found that converting an existing HOV lane to a HOT lane produced a benefit-cost ratio that ranged from 14:1 to 39:1.[50]

Deployment

Figure 3-3 shows results from the 2010 Freeway Management survey pointing toward continued growth in three key deployment indicators: percent freeway miles with real-time traffic data collection technologies, percent freeway miles covered by closed circuit television (CCTV), and number of DMS. These data were collected through surveys of the largest U.S. metropolitan areas from 1997 to 2010. The data show that significant progress has been made in deploying ITS technologies on freeways.[51]

As of 2010, surveillance technologies—consisting of loop detectors, radar detectors, and acoustic detectors—are used to collect data on traffic conditions on 55 percent of freeway miles in the country's largest metropolitan areas, up from 18 percent in 2000. The number of DMS deployed increased approximately 60 percent from 2000 to 2010, greatly expanding agency capability to communicate directly with freeway travelers. The percentage of freeway miles served by HAR nearly doubled in the same period; HAR now services almost two-thirds of all freeway miles.

Two other freeway management technologies have experienced slower growth. Ramp meters manage access to 13 percent of freeway miles, about the same level as in 2006 and lane control strategies used to manage travel cover about 9 percent of freeway miles, up from 4 percent in 2000.[52]

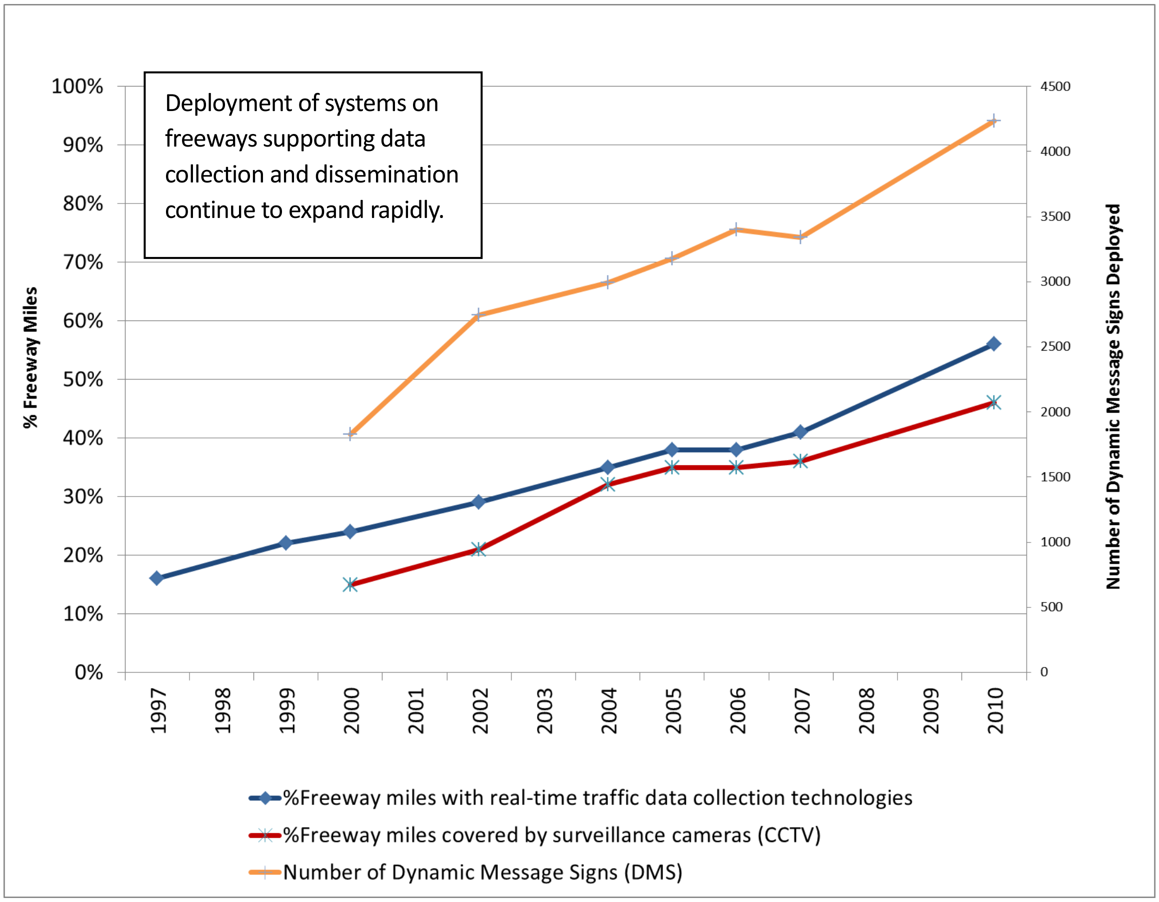


Figure 3-3. Freeway Deployment Trends for Major Metropolitan Areas

Selected Highlights from the ITS Knowledge Resources on Freeway Management

Surveillance

Traffic surveillance systems use vehicle detectors and video equipment to support the most advanced freeway management systems. These sensors can also be used to monitor critical transportation infrastructure for security purposes.

Surveillance
Deployment
Surveillance is used to collect information about traffic conditions on 55 percent of freeway miles in the country's largest metropolitan areas. [53]

Surveillance
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K • Closed Circuit Television (CCTV) Video Camera: $8K-$16K Transportation Management Center subsystem: • Hardware, Software for Traffic Surveillance: $134K-$164K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Ramp Control

Traffic control measures on freeway entrance ramps, such as ramp meters, can use sensor data to optimize freeway travel speeds and ramp meter wait times.

Ramp Control
Deployment
Twenty-two (22) percent of freeway agencies in the country's largest metropolitan areas have deployed ramp meters.[54]

Ramp Control: Ramp Metering

Traffic signals on freeway ramp meters alternate between red and green to control the flow of vehicles entering the freeway. Metering rates can be altered based on freeway traffic conditions.

Ramp Control: Ramp Metering
Costs
Unit Costs Data Examples
Roadside Control subsystem: • Ramp Meter: $21K-$42K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Ramp Control: Ramp Metering
Sample System Costs of ITS Deployments
California: Using an Analysis, Simulation, and Modeling (AMS) framework researchers estimated the potential costs in 2008 of implementing Integrated Corridor Management (ICM) strategies on the I-880 corridor located between Oakland and Fremont, California. The estimate per ramp meter (including the signal and controller) was **$40,000** with annual operating and maintenance cost of $2,000.[55]

Lane Management

Lane management applications can promote the most effective use of available capacity on freeways to encourage the use of high-occupancy commute modes.

Lane Management
Deployment
Lane control equipment is used on 2026 freeway miles in the country's largest metropolitan areas, with about half of these miles (1017 miles) used as high-occupancy vehicle (HOV) lanes and about 14 percent (277 miles) employing Variable Speed Limits.[56]

Lane Management: Pricing

Traffic surveillance, electronic payment, video, global positioning systems, and automated enforcement technologies can support the implementation of congestion pricing strategies, which adjust the cost of transportation facilities based on demand or the time of day.

Lane Management: Pricing
Costs
Unit Costs Data Examples
Roadside Information subsystem: examples include • Dynamic Message Sign: $41K-$101K Toll Plaza subsystem: examples include • Electronic Toll Reader: $2K-$4K • High-Speed Camera: $6K-$8K Toll Administration subsystem: examples include • Toll Administration Hardware: $4.3K-$6.4K • Toll Administration Software: $40K-$80K Roadside Telecommunications subsystem: examples include • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Lane Management: Pricing
Sample System Costs of ITS Deployments
California: Planning-level studies indicate that an effective combination of ICM strategies can be implemented for $7.5 Million per year (annualized capital and O&M).[57]

Lane Management: Lane Control

Lane control signs, supported by surveillance and detection technologies, allow the temporary closure of lanes to avoid incidents on freeways.

Lane Management: Lane Control	
Benefits	
ITS Goals	**Selected Findings**
Safety	Traffic surveillance, lane control signs, VSL, and DMS in Amsterdam, the Netherlands have led to a 23 percent decline in the crash rate.[58]
Costs	
Unit Costs Data Examples	
Roadside Control subsystem: • Software for Lane Control: $25K-$50K • Lane Control Gates: $66K-$100K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Lane Management: Variable Speed Limits

VSL systems use sensors to monitor prevailing traffic and/or road weather conditions, and post appropriate enforceable speed limits on DMS.

Lane Management: Variable Speed Limits	
Benefits	
ITS Goals	**Selected Findings**
Safety	A VSL system on the I-270/I-255 loop around St. Louis reduced the crash rate by 4.5 to 8 percent, with a standard deviation of 3.4 percent due to more homogenous traffic speed in congested areas and slower traffic speed upstream.[59]

Lane Management: Variable Speed Limits
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor • Environmental Sensor Station (Weather Station): $25K-$42K Roadside Information subsystem: • Dynamic Message Sign: $28K-$136K • Highway Advisory Radio: $15K-$36K Transportation Management Center subsystem: • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Special Event Transportation Management

Special event transportation management systems can help control the impact of congestion at stadiums or convention centers. In areas with frequent events, large changeable destination signs or other lane control equipment can be installed. In areas with occasional or one-time events, portable equipment can help smooth traffic flow.

Special Event Transportation Management
Deployment
Fifty-seven (57) of the country's largest metropolitan areas use portable transportation management systems, such as DMS, in various environments such as special event locations. Twenty-four (24) of these metropolitan areas use temporary transportation management centers (TMC) or satellite locations for existing TMCs to support management of special event traffic.
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Dynamic Message Sign: $28K-$136K • Dynamic Message Sign – Portable: $16K-$21K Roadside Detection subsystem: • Portable Traffic Management System: $66K-$83K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K

Special Event Transportation Management
• Labor for Traffic Information Dissemination: $116K-$142K (annually)
Roadside Telecommunications subsystem:
• Conduit Design and Installation – Corridor: $52K-$77K
• Fiber Optic Cable Installation: $21K-$54K

Information Dissemination

Advanced communications have improved the dissemination of information to the traveling public. Motorists are now able to receive relevant information on location-specific traffic conditions in a number of ways including DMS, HAR, in-vehicle displays, or specialized information transmitted to individual vehicles.

Information Dissemination
Deployment
HAR provides information to travelers on 21 percent of freeway miles in the country's largest metropolitan areas. Eighty-six (86) of these metropolitan areas use DMS to provide information to travelers on freeways.

Information Dissemination: Dynamic Message Signs

DMS are permanent or portable electronic traffic signs that allow operators to give travelers information on traffic conditions, incidents, weather, construction, safety, and special events.

Information Dissemination: Dynamic Message Signs
Costs
Unit Costs Data Examples
Roadside Information subsystem:
• Dynamic Message Sign: $28K-$136K
• Dynamic Message Sign – Portable: $16K-$21K
Transportation Management Center subsystem:
• Software for Traffic Information Dissemination: $18K-$22K
• Labor for Traffic Information Dissemination: $116K-$142K (annually)
Roadside Telecommunications subsystem:
• Conduit Design and Installation – Corridor: $52K-$77K
• Fiber Optic Cable Installation: $21K-$54K

Lessons Learned: In developing software for automated posting of messages on dynamic message signs, focus on the types of messages that are used often and changed frequently, and also include manual methods for posting.

A number of lessons learned were identified by observing sign operations during the evaluation with regard to using DMS for traveler information dissemination:

- **Validate travel time estimates before being used for traveler information.** The Condition Reporting System (CRS) software miscalculated travel times that were used for DMS messages, resulting in inaccurate travel times being displayed to the public. One iFlorida stakeholder suggested that the process used to produce travel times for DMS messages should be thoroughly validated before being used in the field.
- **In developing software for automating messages posted on DMS, focus on the types of messages that are used often and change frequently.** The CRS software included tools to generate travel time DMS messages automatically. Florida DOT (FDOT) operational policies for these signs meant that congestion messages were used most often during high traffic periods-exactly the time when sign messages changed frequently (because of changes in travel times). This required Regional Traffic Management Center (RTMC) operators to manage congestion sign messages manually during rush hour periods while travel time messages, used when congestion was not present, were generated automatically. The workload on RTMC operators might have been reduced if congestion messages were automated rather than travel time messages.
- **Include software tools for managing DMS travel time messages manually in the event that the automated travel times become unavailable or unreliable.** FDOT experienced significant reliability problems with their travel time network, so that travel time estimates were often unavailable. Although the CRS software was intended to include tools to estimate travel times based on historical values, these tools were not used. When the CRS failed, FDOT discovered that (a) static historical travel times worked well for most of the day and (b) RTMC operators could update signs manually to reflect current travel conditions when congestion occurred, although they made these updates by circumventing the CRS software.[60]

Information Dissemination: Highway Advisory Radio

HAR uses low-power permanent or portable radio stations to broadcast traffic- and travel-related information to motorists using AM radio.

Information Dissemination: Highway Advisory Radio	
Benefits	
ITS Goals	**Selected Findings**
Energy and Environment	Intelligent speed control applications that smooth traffic flow during congested conditions can reduce fuel consumption by 10 to 20 percent without drastically affecting overall travel times.[61]
Energy and Environment	In the Grand Canyon National Park (GRCA), the Park Dynamic Message Signs (PDMS) and Highway Advisory Radio (HAR), installed as part of a pilot shuttle bus program in 2008, were estimated to result in a reduction of between 66,000 to 99,000 vehicle-miles driven and a fuel savings of between 2600 and 2800 gallons.[62]

Information Dissemination: Highway Advisory Radio
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Highway Advisory Radio: $15K-$36K • Highway Advisory Radio – Sign: $4K-$8K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K
Sample System Costs of ITS Deployments
Washington: In Washington State, the implementation of the SR 14 traveler information system cost **$511,300.** The project was developed in two phases: the Columbia Gorge Traveler Information System Pilot Program and the SR 14 Traveler Information System Enhancements. • Phase 1 cost **$300,000** and included 2 VMS, a highway advisory radio (HAR) station and one RWIS station with a CCTV camera. • Phase 2 cost **$211,300** and included a HAR station and a VMS.[63]

Enforcement

Automated enforcement systems—such as speed enforcement, HOV lane enforcement, and ramp meter enforcement—improve safety and reduce aggressive driving.

Enforcement
Deployment
Few jurisdictions use automated systems to enforce traffic laws on freeways. Seven of the country's largest metropolitan areas use automated speed enforcement systems on freeways and one uses an automated system to enforce HOV restrictions.

Enforcement: Speed Enforcement

Automated enforcement technologies can assist with the enforcement of speed limit compliance. Still or video cameras, activated by vehicle detectors, can record vehicles traveling faster than the speed limit.

Enforcement: Speed Enforcement
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Portable Speed Monitoring System: $4.1K-$12.2K

Chapter 4 Crash Prevention and Safety

Source: ©thinkstockphotos.com/Jupiterimages

A major goal of the ITS program is to improve safety and reduce risk for road users including pedestrians, cyclists, operators, and occupants of all vehicles who must travel along a given roadway. In 2009, there were 33,808 fatalities on the Nation's roadways where 7,043 (20.8 percent of total fatalities) were intersection or intersection related.[64] Vehicle crashes at horizontal curves accounted for over 27 percent of fatalities in 2008.[65] Although the number of pedestrian and bicyclist fatalities have decreased, in 2009 there were 4,092 pedestrian fatalities and 630 pedal cyclists fatalities accounting for 14 percent of all traffic fatalities and 5 percent of all the people injured in traffic crashes during the year.[66]

Interstates and other freeway ramp curves can be dangerous locations because drivers must perceive the point at which to begin braking and slow down sufficiently to safely negotiate the ramp curve. Road geometry warning systems warn drivers of potentially dangerous conditions that may cause rollover or run-off-the-road crashes on ramps, curves, or downgrades, and provide overheight warnings at tunnels and overpasses. Highway-rail crossing warning systems can reduce the potential for collisions at railroad crossings including catastrophic crashes involving school buses or hazardous materials carriers. Intersection collision warning systems use sensors to monitor traffic approaching dangerous intersections and warn vehicles of approaching cross-traffic via roadside or

Categories

Road Geometry Warning

- Ramp Rollover Warning
- Curve Speed Warning
- Downhill Speed Warning
- Overheight/Overwidth Warning

Highway-Rail Crossing Warning System

Intersection Collision Warning

Pedestrian Safety

Bicycle Warning

Animal Warning

in-vehicle displays. Pedestrian safety systems can adjust traffic signal timing to provide an appropriate WALK phase or activate in-pavement lighting or roadside warning messages to alert drivers of pedestrians present. Bicycle warning systems can detect cyclists on narrow stretches of roadway and provide drivers with advanced notice when entering bridges and tunnels. In rural areas, animal warning systems can detect large animals near the roadway, alert travelers, and deter animals from crossing while traffic is present. Additional information on rural areas can be found at the Rural Safety Initiative available at the ITS JPO's Web site: http://www.its.dot.gov/rural/index.htm.

A benefit-cost analysis shows that dynamic curve warnings signs have an effectiveness rating of 30 percent.

Findings

As of July 2011, there were 56 evaluation summaries of Crash Prevention and Safety applications in the Knowledge Resources, as shown in Figure 4-1. The Crash Prevention and Safety category with the largest number of summaries is Road Geometry Warning (23 summaries), followed by Highway-Rail Crossing Warning Systems (14 summaries), Intersection Collision Warning (six summaries), Pedestrian Safety (three summaries), Animal Warning (four summaries), and Bicycle Warning (one summary), as shown in Figure 4-2.

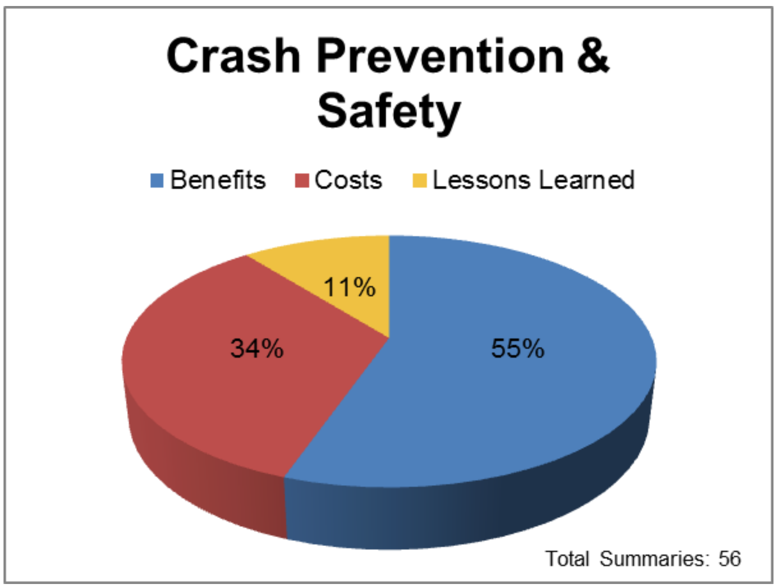


Figure 4-1. Crash Prevention and Safety Summaries in the Knowledge Resources

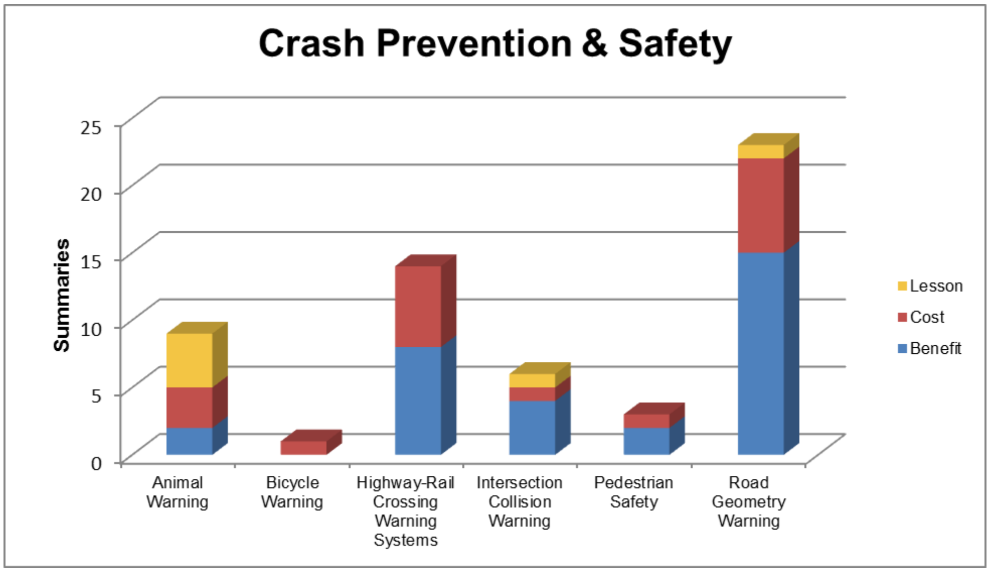


Figure 4-2. Benefits Summaries in the Knowledge Resources by Crash Prevention and Safety Category

Benefits

Road geometry warning systems can improve safety on highway ramps or curves that experience a high incidence of truck rollovers. Providing truckers with advanced notice of excessive approach speeds can reduce truck speeds by up to 8.3 mi/h. Several years of safety data collected at multiple sites show these systems can eliminate rollover crashes, and the impacts are sustainable. Downhill speed warning systems have also proven effective at mitigating risks to large trucks in areas with steep terrain. Currently, 26 agencies use dynamic curve warning systems. A recent simulation study shows that system lane departure warning, curve ahead warning, and speed limit warning systems could reduce critical events by 21 percent and decrease run-off-road crashes by 71 percent. [67]

The need to reduce crashes at intersections has fostered considerable research to develop and evaluate cost-effective countermeasures. These systems are currently being designed to transmit warning messages to in-vehicle systems and display warnings on roadside infrastructure. An intersection warning system in Minnesota reduced traffic conflicts and received very positive feedback from the public.[68]

A deer detection system reduced deer/vehicle crashes by 56 percent.

In rural locations, animal crossings can cause opportunities for vehicle-animal crashes. Just in the state of Minnesota, it is estimated that there are over 35,000 deer/vehicle crashes resulting in 3 to 11 deaths, over 400 personal injuries, and close to 4,000 reported property damages of one thousand dollars or more annually. A deer detection and warning system along Camden State Park reduced deer/vehicle crashes by 54 percent in a particularly problematic location. [69]

Table 4-1 illustrates that evaluations have shown the safety benefits for deployed crash prevention and safety systems. Several evaluations have documented customer satisfaction with road geometry and highway-rail crossing warning systems. A study also indicated mobility, fuel consumption, and emissions improvements through a highway-rail crossing warning system.

Table 4-1. Crash Prevention and Safety Benefits Summary

Crash Prevention and Safety Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Road Geometry Warning	●					●
Highway-Rail Crossing Systems	●	⦿			⦿	●
Intersection Collision Warning	⦿					
Pedestrian Safety	●					
Bicycle Warning						
Animal Warning	●					

● – substantial positive impacts	⦿ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Deployment

Crash prevention and safety systems are often deployed in non-urban settings to address specific safety issues at spot locations. The three most widely adopted systems are curve speed warning, ramp rollover warning, highway-rail crossing warning systems, and pedestrian safety systems. Next in popularity, and adopted by about half as many states, are downhill speed warning systems, intersection collision warning systems, and animal warning systems. Finally, bicycle warning systems are adopted by about a fourth as many states as the first three systems. The trend for adoption of crash prevention and safety systems in general continues to increase.

Selected Highlights from the ITS Knowledge Resources on Crash Prevention and Safety

Road Geometry Warning Systems

Road geometry warning systems warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous conditions that may cause rollovers; crashes on ramps, curves, or downgrades; and collisions with roadway infrastructure, such as overpasses.

Road Geometry Warning Systems
Deployment
Systems that warn drivers of potentially dangerous speeds in a variety of situations have been deployed in several states: approaching freeway ramps (11 states), curved freeways (11 states) and downhill grades (8 states). Currently, 26 agencies use dynamic curve warning systems. Overheight/overwidth warning systems that warn drivers of vehicles that are too tall or too wide to pass under bridges or through tunnels have been deployed in 23 states. Currently, 27 freeway management agencies use over-height warning systems.[70]

Road Geometry Warning Systems: Ramp Rollover Warning

Ramp rollover warning systems use roadside detectors and electronic warning signs to warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous approach speeds to freeway ramps.

Road Geometry Warning Systems: Ramp Rollover Warning
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Road Geometry Warning Systems: Curve Speed Warning

Curve speed warning systems use roadside detectors and electronic warning signs to warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous speeds on approaches to curves on highways.

Road Geometry Warning Systems: Curve Speed Warning	
Benefits	
ITS Goals	**Selected Findings**
Safety	***Summary Finding***: The analysis of a simulated Rural Highway Driver Warning System (RHDWS) that included lane departure warning, curve ahead warning, and speed limit warning showed a potential reduction of critical events by 21 percent, a decrease of 71 percent for runoff-road crashes, and contributed to smoother driving on the curvy highway.[71]

Road Geometry Warning Systems: Curve Speed Warning
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K (per mile)
Benefit-Cost Studies
A benefit-cost analysis shows that dynamic curve warning signs have a 30 percent rate of effectiveness and a benefit-cost ratio between 4.18 to 6.60.[72]

Road Geometry Warning Systems: Downhill Speed Warning

Downhill speed warning systems use roadside detectors and electronic warning signs to warn drivers, typically those in commercial trucks and other heavy vehicles, of potentially dangerous speeds in approaches to downhill grades.

Road Geometry Warning Systems: Downhill Speed Warning
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Road Geometry Warning Systems: Overheight/Overwidth Warning

Overheight/overwidth warning systems use roadside detectors and electronic warning signs to warn drivers of vehicles that are too tall or wide to pass under bridges or through tunnels.

Road Geometry Warning Systems: Overheight/Overwidth Warning	
Benefits	
ITS Goals	**Selected Findings**
Safety	An overheight warning system at a CSX bridge in Maryland decreased the number of tractor-trailer incidents from an average of nine per month to an average of three each month since the project was completed.[73]
Costs	
Sample System Costs of ITS Deployments	
Maryland: An overheight warning system on a CSX bridge that included reflective tubes strung between two 30-foot steel poles that strike vehicles that are too high to pass under the bridge, acting as an audible alert and steel poles with infrared height detectors on the eastbound and westbound approaches to the Md. 75 and Baldwin Road intersection, cost a total of $146,000.[74]	

Highway-Rail Crossing Systems

Highway-rail crossing systems use detectors, electronic warning signs, and automated enforcement technologies to warn roadway traffic of approaching trains and discourage drivers from violating railroad crossing traffic controls.

Highway-Rail Crossing Systems
Deployment
Sixteen (16) states have deployed systems that detect and warn drivers of approaching trains at highway-rail intersections. Currently, 48 arterial management agencies adjust signal timing automatically at intersections within 200 feet of a highway-rail intersection to avoid vehicle entrapment at train crossings, and six agencies use automated enforcement to detect drivers violating railroad crossing traffic controls.[75]
Costs
Unit Costs Data Examples
Roadside Rail Crossing subsystem: • Rail Crossing Four-Quad Gate, Signals: $76K-$86K • Rail Crossing Train Detector: $11K-$14K Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Intersection Collision Warning

Intersection collision warning systems use sensors to monitor traffic approaching dangerous intersections and warn vehicles of approaching cross traffic, via external signage or in-vehicle warnings.

<table>
<tr><th colspan="2">Intersection Collision Warning</th></tr>
<tr><th colspan="2">Deployment</th></tr>
<tr><td colspan="2">Seven (7) states have deployed intersection collision warning systems that use sensors to monitor traffic approaching intersections and warn drivers of approaching cross traffic.[76]</td></tr>
<tr><th colspan="2">Benefits</th></tr>
<tr><td>ITS Goals</td><td>Selected Findings</td></tr>
<tr><td>Safety</td><td>In Hennepin County, MN, an intersection warning system reduced traffic conflicts by 54 percent.[77]</td></tr>
<tr><td>Customer Satisfaction</td><td>An independent evaluation of an intersection warning system in Hennepin County, MN, reported very positive feedback from the general public:[78]
• 94.2 percent were aware of the sign
• 88.5 percent understood the meaning of the sign
• 79.4 percent had improved awareness of approaching traffic
• 65.2 percent are more likely to stop when the sign is flashing
• Half of survey respondents indicated they pay more attention when the sign is flashing</td></tr>
<tr><th colspan="2">Costs</th></tr>
<tr><td colspan="2">Unit Costs Data Examples</td></tr>
<tr><td colspan="2">Roadside Detection subsystem:
• Inductive Loops on Corridor: $2K-$6K
• Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor
Roadside Control subsystem:
• Signal Controller and Cabinet: $7K-$12K
Roadside Information subsystem:
• Dynamic Message Sign: $41K
Roadside Telecommunications subsystem:
• Conduit Design and Installation – Corridor: $52K-$77K
• Fiber Optic Cable Installation: $21K-$54K</td></tr>
</table>

Pedestrian Safety

Pedestrian safety systems can help protect pedestrians by automatically activating in-pavement lighting to alert drivers as pedestrians enter crosswalks. Other systems include countdown pedestrian traffic signals and pedestrian detectors that extend the WALK phase for pedestrians needing more time to cross a street.

Pedestrian Safety	
Deployment	
Fifteen (15) states have deployed pedestrian safety systems to protect pedestrians by alerting drivers when pedestrians enter crosswalks. Currently, 25 arterial management agencies use automatic pedestrian detection systems. Three (3) agencies use smart lighting systems that brighten when pedestrians are present.[79]	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Miami-Dade County, ITS pedestrian safety measures showed an increase in pedestrian safety by significantly reducing drivers right on red violations from 40 percent to 13 percent and increasing drivers yielding to pedestrians by up to 92 percent.[80]
Costs	
Unit Costs Data Examples	
Roadside Detection subsystem: • Pedestrian Detection – Microwave: $0.5K • Pedestrian Detection – Infrared: $0.2K-$0.4K Roadside Information subsystem: • Light-Emitting Diode (LED) Count-down Signal: $0.261K-$0.361K • Pedestrian Crossing Illumination System: $22.8K-$35K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Bicycle Warning

Bicycle warning systems can use detectors and electronic warning signs to identify bicycle traffic and notify drivers when a cyclist is in an upcoming segment of roadway to improve safety on narrow bridges and tunnels.

Bicycle Warning
Deployment
Four states have deployed bicycle warning systems that warn drivers of the presence of bicycles on narrow bridges and tunnels. Currently, 49 agencies use bicyclist-activated signals.[81]

Animal Warning

Animal warning systems typically use infrared or other detection technologies to identify large animals approaching the roadway and alert drivers by activating flashers on warning signs located upstream of high frequency crossing areas. These systems may also activate in-vehicle warning devices.

Animal Warning	
Deployment	
Six states have deployed animal warning systems that warn drivers of large animals approaching the roadway.	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Marshall, MN, a deer detection and warning system reduced the number of deer/vehicle crashes by 56 percent.[82]

Chapter 5 Road Weather Management

Source: ©iStockphoto.com/breckeni

Adverse weather conditions pose a significant threat to the operation of the Nation's roads. According to the National Research Council, motorists endure more than 500 million hours of delay each year as a result of fog, snow, and ice.[83] Rain—which occurs more frequently than snow, ice, and fog—leads to greater delay. Furthermore, an investigation of vehicle crashes from 1995 through 2008 show 24 percent of all crashes occur under adverse weather conditions resulting in more than 673,000 people injured and 7,100 killed.[84] The estimated cost of weather-related crashes ranges from $22 billion to $51 billion annually. These costs include travel delay, emergency services, property damage, medical and rehabilitation costs, productivity losses, insurance administration costs, legal and court costs, and the costs to employers.[85] Adverse weather not only affects safety but can also degrade traffic flow and increase travel times by as much as 50 percent under extreme conditions.[86]

There are several organizations working together to develop weather-related ITS (sometimes generally referred to collectively as RWIS or Road Weather Information Systems) to help local agencies and travelers better react to weather conditions affecting the roads. At the Federal level, the Federal Highway Administration's Office of Operations and Research and Innovative Technology Administration's ITS JPO run the Road Weather Management Program (RWMP).

Categories

Surveillance, Monitoring and Prediction

- Pavement Conditions
- Atmospheric Conditions
- Water Level

Information Dissemination

- Dynamic Message Signs
- Highway Advisory Radio
- Internet/Wireless/Phone

Traffic Control

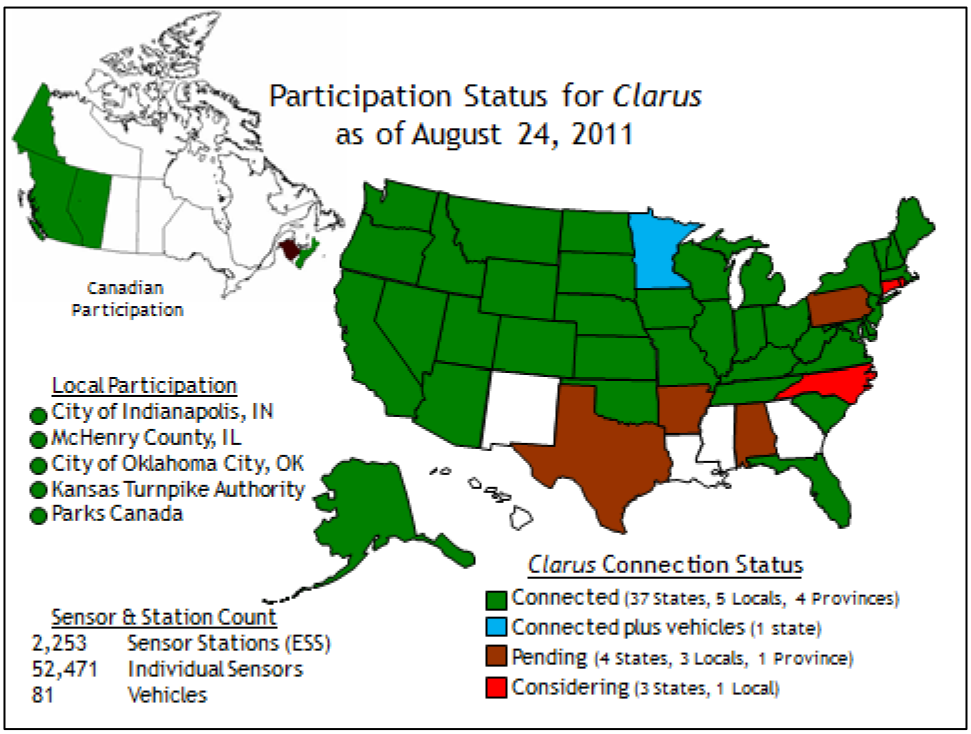
- Variable Speed Limits
- Traffic Signal Control
- Lane Use/Road Closures
- Vehicle Restrictions

Response and Treatment

- Fixed Winter Maintenance
- Mobile Winter Maintenance

The RWMP performs research to develop road weather strategies, tools, and technologies. More information can be found at http://www.ops.fhwa.dot.gov/Weather and http://www.its.dot.gov/connected_vehicle/road_weather.htm. In addition, there are several state organizations involved in road weather research such as the Aurora Program (http://www.aurora-program.org/) and AASHTO's Snow and Ice Pooled Fund Cooperative Program (SICOP) (http://www.sicop.net/?siteid=88). For more information on other road weather research organizations see http://www.ops.fhwa.dot.gov/weather/resources/resdev.htm.

Agencies that operate and maintain roadways use surveillance, monitoring, and prediction tools to mitigate the impacts of adverse weather or optimize activities such as maintenance in favorable weather. The standard method for monitoring road weather conditions is with fixed sensors, known as Environmental Sensor Stations (ESS), near and/or actually embedded in the road surface that report common atmospheric weather variables plus pavement and subsurface road temperature, road wetness and pavement chemical concentration. All 50 states and other local transportation authorities deploy ESS to some degree. However, before 2006 the data was not systematically shared among the various agencies. To improve data sharing, the U.S. DOT developed an experimental system called *Clarus* (http://www.clarus-system.com/) to collect, format, quality-check, display and distribute ESS road weather data from across North America. This "one-stop-shop" for observed road weather database makes ESS data more effectively used by members of both the weather and the transportation communities. As of August 24, 2011, 38 state DOTs, five local transportation agencies and four Canadian provinces were connected to Clarus, as shown in Figure 5-1.



Source: U.S. DOT Federal Highway Administration, Road Weather Management Program

Figure 5-1. Participation in Clarus Program

For prediction of weather and specifically impacts on road systems, agencies use a variety of methods including self-driven software tools, in-house agency meteorologists, and out-sourcing from private weather information service providers. First developed by the RWMP and now available in commercial versions, the Maintenance Decision Support System (MDSS) is a decision support tool that automatically combines weather model output with a road model, road maintenance rules of practice, and maintenance resource data. MDSS can be used by winter maintenance managers to obtain more objective road treatment recommendations.[87] (See www.ops.fhwa.dot.gov/weather/mitigating_impacts/programs.htm#p3.) By the end of 2011, the RWMP in collaboration with 8 mid-western states will complete development of several prediction and decision support prototype software tools in order to provide improved weather information services using *Clarus* System data. These applications include a seasonal load restriction decision support tool; a non-winter maintenance and operations decision support tool; a multi-state control strategy tool; and enhanced road weather content for traveler advisories.

USDOT's RWMP identified the integration of weather information into agency Transportation Management Centers (TMC) across the country as one of its key objectives. This Weather-Responsive Traffic Management (WRTM) project has shown that weather integration is beginning to take hold, but more remains to be done to encourage widespread adoption.[88] With the assistance of the FHWA's self-evaluation guide, a number of TMCs has adopted weather integration implementation plans. WRTM is organized around three strategies: advisory, control, and treatment.

Information dissemination capabilities enable advisory strategies to provide information on prevailing and predicted conditions to both transportation managers and motorists. Posting fog warnings on dynamic message signs (DMS) and listing flooded routes on Web sites are examples of these advisory strategies. The Sacramento, California Regional TMC has implemented and evaluated the performance of a weather alert notification system. Traffic control technologies enable agencies to enact control strategies that alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Reducing speed limits with variable speed limit (VSL) signs and modifying traffic signal timing based on pavement conditions are examples of control strategies. Response and treatment applications, like the MDSS, are designed to improve efficiency and the effectiveness of treatment strategies, typically snow and ice control operations involving the application of sand, salt, and anti-icing chemicals to pavements to improve traction and prevent ice bonding. Winter maintenance vehicles can be equipped with automatic vehicle location (AVL) systems and mobile sensors to monitor pavement conditions and optimize treatment application rates. In problem areas where the roadway can freeze unexpectedly, such as bridges in cold climates, fixed anti-icing/deicing systems can be installed and activated automatically based on ESS data.

Several other chapters of this report discuss ITS applications relevant to road weather management. The roadway operations and maintenance chapter discusses asset management technologies, such as AVL that can facilitate efficient winter road maintenance. Also, the traveler information chapter discusses technologies valuable for disseminating weather-related information to travelers.

Findings

As of July 2011, there were 127 evaluation summaries of Road Weather Management applications in the Knowledge Resource databases, as shown in Figure 5-2. The Road Weather Management category with the largest number of summaries is Information Dissemination-Advisory Strategies (62 summaries), followed by Surveillance, Monitoring, and Prediction (61 summaries), Response and

Treatment- Treatment Strategies (46 summaries), and Traffic Control – Control Strategies (25 summaries), as shown in Figure 5-3.

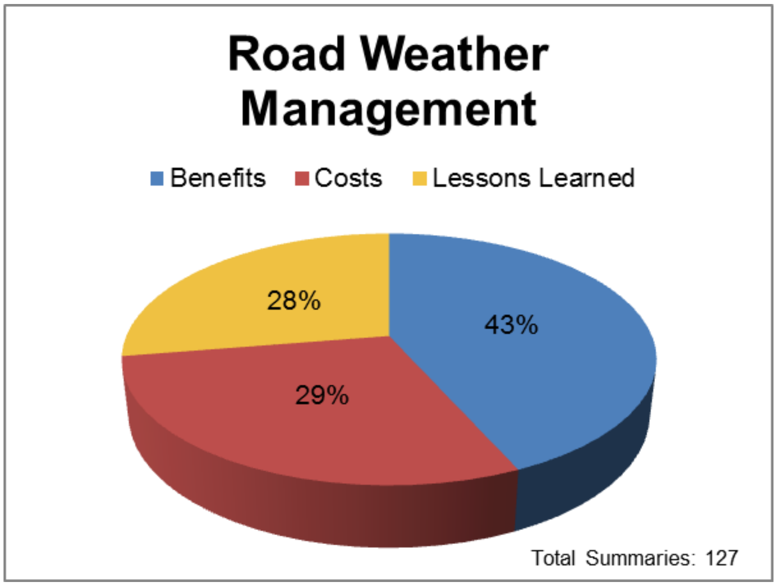


Figure 5-2. Road Weather Management Summaries in the Knowledge Resources

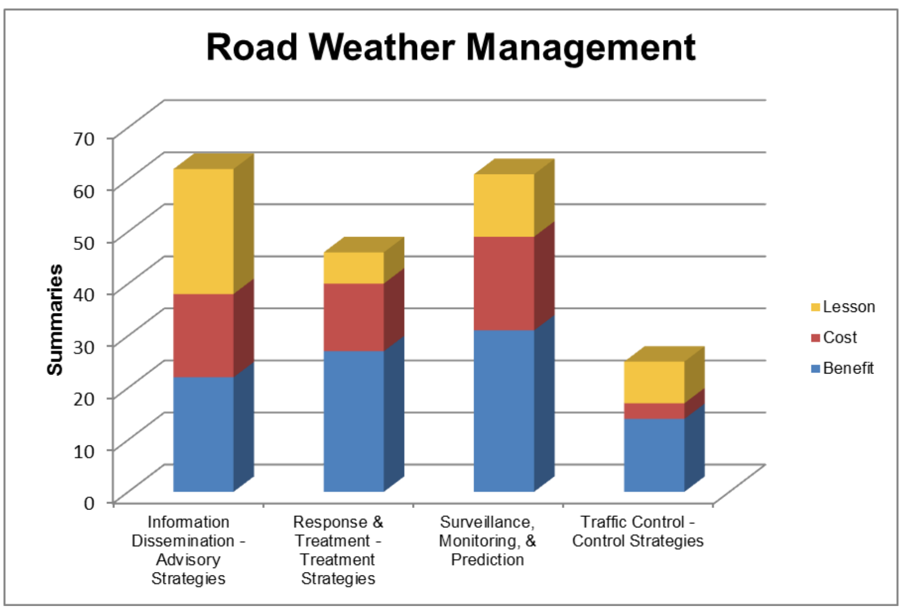


Figure 5-3. Summaries in the Knowledge Resources by Road Weather Management Category

Benefits

Evaluation data show that 80 to 94 percent of motorists who use traveler information websites think road weather information enhances their safety and prepares them for adverse road weather conditions.[89] Although quantitative impacts of road weather advisory systems are difficult to measure on a regional basis, warning systems that use flashers or DMS to alert drivers of reduced visibility or wind hazards have proven effective on short sections of roadway prone to these hazards.[90] Evaluation data show that drivers pay attention to these types of warning systems and will slow down or speed up as recommended to improve traffic speed uniformity and reduce crash risk.[91]

High-quality road weather information can benefit travelers, commercial vehicle operators, emergency responders, and agencies who construct, operate, and maintain roadways. RWIS are now a critical component of many agencies' winter maintenance programs. Accurate and timely road weather information helps maintenance managers react proactively before problems arise. A Western Transportation Institute study estimated that its weather operations program saved the State of Utah more than $2.2 million from reduced maintenance costs in the 2004-2005 winter season.[92] A similar study in the states of Iowa, Nevada, and Michigan showed winter maintenance costs reduced by $272,000 to $814,000.[93] A study in 2009 showed for New Hampshire, Minnesota and Colorado, MDSS usage saved $1.2 million to $1.7 million per winter.[94]

Table 5-1 presents qualitative ratings of the impact of road weather management ITS applications under each of the six ITS goals. All the strategies have been found effective in improving safety. Studies on the usage of surveillance technologies and treatment strategies have shown productivity improvements. Surveys have shown that both agency personnel and the general public are satisfied with road weather information dissemination.

Table 5-1. Road Weather Management Benefits Summary

Road Weather Management Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Surveillance, Monitoring, and Prediction	●			●		⊙
Information Dissemination (Advisory Strategies)	●					⊙
Traffic Control (Control Strategies)	⊙					
Response and Treatment (Treatment Strategies)	●			●	⊙	

● – substantial positive impacts	⊙ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

As with most ITS deployments, costs of road weather management systems vary depending on several factors, including system scope, complexity and particular technology or technologies under consideration. Often cost estimates are based on similar systems because precise records are not available and multiple organizations involved in the deployment make traceability from various funding sources difficult.

Based on three deployments studied under the MDSS pooled fund study, the cost per vehicle was estimated at $2,000 per Automatic Vehicle Location/Mobile Data Computer (AVL/MDC).[95] For several deployments, communications cost ranged from $40 to $60 per month per vehicle.[96] Data from five states show that the addition of various advanced technology applications such as radar, sensors, and control units can add $20,000 to $30,000 to the cost of a regular snowplow.[97]

The costs of integrating weather information into TMC operations vary greatly, depending on the extent of new technologies to be implemented, staff time expended, and the area of coverage. Kansas City Scout's implementation plan included $55,000 for the units and maintenance of six new RWIS. The installation costs were lower because the power and cabinet installation was completed for part of another project.[98] The State of Wyoming estimated it would cost $6.3 million for a significant RWIS expansion, AVL/MDC deployment, VSL expansion, a weather alert notification system enhancement, and the addition of Advanced Traffic Management System (ATMS) Decision Support.[99]

Benefit-Cost Studies

Several benefit-cost studies of road weather management technologies have been conducted and all found positive benefit-cost ratios. A benefit-cost analysis conducted as part of Michigan DOT's regional pre-deployment studies showed potential benefits in reduced travel time, crash reduction, and lower operating costs. The estimated benefit-cost ratios ranged from 2.8 to 7 depending on the region.[100] An additional study shows benefit-cost ratios of 1.8 to 36.7 resulting from the use of weather information to reduce winter maintenance costs in Iowa, Nevada and Michigan.[101]

Deployment

Owned and operated by state, provincial or local transportation agencies, nearly 2,500 ESS are deployed across North America and together comprise one of the largest weather observing networks. As of April 2011, 26 states use MDSS.[102]

As noted in the Freeway Management chapter, the results of the 2010 Freeway Management survey point toward continued growth in three key deployment indicators tracked in the Nation's largest metropolitan areas: percent freeway miles with real-time traffic data collection technologies, percent freeway miles covered by closed circuit television (CCTV), and number of dynamic message signs (DMS). All three of these technologies are used heavily in road weather management strategies, and the deployment trends make it likely that implementation of these core technologies will continue to expand over the next several years, increasing capacity to monitor the impacts of adverse weather and to communicate with motorists.

Selected Highlights from the ITS Knowledge Resources on Road Weather Management

Surveillance, Monitoring, and Prediction

Surveillance, monitoring, and prediction of weather and road conditions enable the appropriate management actions to mitigate the impacts of any adverse conditions.

Surveillance, Monitoring, and Prediction	
Deployment	
The use of sensors to track weather is popular among State DOTs: Thirty-eight (38) states use in-pavement or road sensors to track pavement conditions; the same numbers deploy ESS in rural areas, and fifteen (15) states use sensors to monitor water levels on roadways. As of April 2011, twenty-six (26) states use a (MDSS.	
Benefits	
ITS Goals	**Selected Findings**
Productivity	Through the Utah DOT Weather Operations Program, meteorologists based at the transportation management center use information from ESS in the field to provide detailed forecasts to winter maintenance personnel, saving $2.2 million per year in labor and materials for snow and ice control activities. This reduction was approximately 18 percent of the 2004-2005 labor and material costs.[103]
Costs	
Unit Costs Data Examples	
Roadside Detection subsystem: • Environmental Sensor Station (Weather Station): $25K-$42K • Closed Circuit Television (CCTV) Video Camera: $8K-$16K Transportation Management Center subsystem: • Road Weather Information System (RWIS): $9K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	
Sample System Costs of ITS Deployments	
Detailed weather implementation plans prepared selected TMCs to show the estimated costs of weather information integration strategies into TMC operations: **Kansas City, MO**: Six new RWIS devices are being installed by Kansas City Scout in conjunction with three pre-approved expansion plans. This reduced the cost because the power and cabinet installation were already included in the route expansions. Costs were estimated at $55,000 for the six RWIS with annual operating cost of $3,800 per unit (2010).[104] **Louisiana**: The cost of weather information integration into TMC operations was estimated at $314,500 for the first year, with $49,500 in annual maintenance costs. Among the costs were: 1) furnish, install, and integrate 12 RWIS at a cost of $25,000 each, 2) provide improved weather forecasts, 3) upgrade communications equipment between TMC staff and Motor Assistance Patrol operators, and 4) assume additional labor costs for the weather information coordinator.[105]	

Surveillance, Monitoring, and Prediction

Wyoming: The cost of weather information integration into TMC Operations was estimated at $6,270,000 for implementation costs, with $833,000 in annual O&M costs. The seven projects selected were:

- RWIS expansion at $2 million implementation cost; $400,000 per year in O&M.
- AVL/MDC at $800,000; with $100,000 in annual O&M.
- Weather Information Manager (WIM) at $100,000 annual O&M cost.
- VSL Expansion – at $3,000,000 initial cost, and $200,000 O&M.
- Weather Information Tool at $300,000 initial cost; $15,000 annual O&M.
- Weather Alert Notification – expand/enhance alert notification system at cost of $20,000 with $3,000 per year O&M.
- Advanced Traffic Management System (ATMS) Decision Support – Expand decision support tools at cost of $150,000 with $15,000 in annual O&M.[106]

Michigan: The Michigan Department of Transportation (MDOT) recently completed pre-deployment plans for five of the state's seven regions. As part of this process, MDOT performed benefit-cost analysis for the RWIS deployment in four regions: North, Bay, Grand, and Superior. The benefit-cost analysis of RWIS deployment included capital costs (which were annualized to compute the net benefits and benefit-cost ratios) and annual O&M costs for each region. The number of ESSs to be deployed was estimated at 15 in the Bay Region, 34 in the Superior Region, and 50 in the North Region. The costs were as follows (in 2007 dollars):

- North: Total Capital Cost: $4,020,000, Annual O&M Cost: $460,000
- Bay: Total Capital Cost-: $2,060,000, Annual O&M Cost-: $256,000
- Grand: Total Capital Cost-: $2,272,000, Annual O&M Cost-: $233,500
- Superior: Total Capital Cost-: $3,463,000, Annual O&M cost-: $358,000[107]

Iowa, Nevada and Michigan: The Iowa Department of Transportation (DOT) and the Aurora Program funded a research project to provide a benefit-cost assessment of weather information in winter maintenance. A model for winter maintenance costs was developed and applied to three case studies in Iowa, Nevada, and Michigan. The team calculated weather information costs per year as follows:

- Iowa's weather information costs included: RWIS maintenance contract at $130,000 per year; private sector weather forecast services at $298,000 per year; and other non-warranty costs such as vandalism, damage from animals, and accidental damage at $20,000 for a total of $448,00 per year (2006-07).
- Nevada's weather information costs included: RWIS maintenance cost of $89,901 per year and private sector weather forecast services at $98,682 per year for a total of $181,583 per year (2006-07).
- Michigan's weather information costs included private sector weather forecast services at $7,140 per year. Michigan DOT did not pay for RWIS maintenance costs during this winter season (20007-08).[108]

Surveillance, Monitoring, and Prediction
Benefit-Cost Studies
Michigan: Rural RWIS deployments show estimated benefit-cost ratios of 2.8 to 7.0 depending upon the region. A benefit-cost analysis conducted as part of Michigan DOT's regional pre-deployment studies showed potential benefits in reduced travel time, crash reduction, and lower operating costs.[109] **Iowa, Nevada, and Michigan:** Use of weather information shows benefit-cost ratios of 1.8 to 36.7, with winter maintenance costs reduced by $272,000 to $814,000.[110] **Utah:** Utah DOT's Weather Operations/RWIS program provides a benefit-cost ratio of 11:1 from reduction in winter maintenance costs. The model estimated the value and additional savings potential of the Utah DOT weather service to be from 11 to 25 percent and from 4 to 10 percent of the labor and materials costs for winter maintenance, respectively.[111]

Lessons Learned: Invest in high accuracy road weather information to ensure greater usage and reduce winter maintenance costs.

The Iowa Department of Transportation (DOT) and the Aurora Program funded a research project to provide a benefit-cost assessment for weather information in winter maintenance. Cases studies in Iowa, Nevada, and Michigan collectively showed that winter maintenance costs decreased with increased use of weather information and with improved accuracy. Therefore, agencies should consider expanding the use of current resources and investing in improving the accuracy of their weather information to realize cost savings.

The research team provided the following recommendations concerning the use of weather information in winter maintenance:

- **Use the most accurate weather sources for winter maintenance within budget limits and other constraints.** The research team found that accuracy of weather information had a greater effect on maintenance costs than frequency of its use. Hence, the improvement of weather information accuracy is critical to achieving more savings in winter maintenance. If accuracy programs exist with fee-based service, provide feedback to service providers to solve problems or find better alternatives.
- **Invest in technology enabling high accuracy road weather information and ensure high usage of existing road weather services.** RWIS and customized weather services were found to provide more accurate information. Agencies should leverage existing infrastructure (such as existing ITS sites with available power and communications) when choosing RWIS installation sites to help reduce costs. Agencies should compare weather information sources by criteria such as accuracy, ease of access, and cost to rank the sources and provide recommendations.
- **Focus the weather information toward the road environment.** Pavement temperature, pavement condition, and bridge temperature are important information for developing better maintenance strategies.[112]

Information Dissemination

Information dissemination technologies help road weather managers notify travelers of any adverse conditions.

Information Dissemination	
Benefits	
ITS Goals	**Selected Findings**
Efficiency	An evaluation of four adverse weather events in the Sacramento region found that its Weather Notification System issued on time alerts 88.9 percent of time, but message coverage was incomplete. **Timeliness of Alerts.** Across the four event periods analyzed, alerts were used in a timely and accurate way. In 16 out of 18 times (88.9 percent) alerts were issued "on time," defined as within +/- 10 minutes of the time when the weather condition broke its defined threshold value at the beginning of the event. In the other two cases, one alert was issued a half hour after the start of the event and in the other case, no alert was issued. **Timeliness of Message Activation.** Fifteen individual sensor-reported weather events that exceeded threshold and/or lasted longer than 16 minutes should have resulted in posted weather warning messages; 13 of them did, and two had no messages posted. For the events with some message coverage, coverage ranged from 27 to 100 percent of the duration of the event. Out of the 13 events with message coverage, 11 had coverage over 75 percent of the duration of the event. **Adequacy of Message Coverage.** The number of changeable message signs (CMS), extinguishable message signs (EMS) and light emitting diode (LED) signs used was significantly less than the number of signs recommended in the RTMC policy guidelines. For the fog event, only 2 out of 8 opportunities to activate primary signs were used. For the three wind events, 12 out of 43 (28 percent) opportunities were used. The ratio of messaging improved over time, with 7 out of 17 (41 percent) used in the April event. **Timeliness of Message Deactivation.** For 14 sensor-reported events for which messages were activated, the period from the end of the event to message deactivation ranged from 18 minutes to 8 hours and 44 minutes, with an average lag time of 4 hours and 14 minutes. The experience shows that there were a number of periods during which messages were left active much longer than needed or desired.[113]
Costs	
Unit Costs Data Examples	
Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K • Portable Dynamic Message Sign: $15.9K-$21K • Highway Advisory Radio: $15K-$36K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Information Dissemination
Sample System Costs of ITS Deployments
Washington: Implementation of the SR 14 traveler information system cost **$511,300**. The equipment installed provides information to the Southwest Region TMC in Vancouver, Washington to aid WSDOT personnel in managing the roadway. Weather information from the RWIS station is available to WSDOT maintenance crews and is provided to the public via the WSDOT website. • Phase 1 cost $300,000 and included 2 VMS, a HAR station and one RWIS station with a CCTV camera. • Phase 2 cost $211,300 and included a HAR station and a VMS.[114] **Pennsylvania:** The Pennsylvania (PA) Turnpike Commission expanded its statewide advanced traveler information system (ATIS) to better inform motorists of traffic, weather, and emergency conditions along the PA Turnpike. The overall project cost was $8.2 million.[115]

Lessons Learned: Use the self-evaluation guide and integration planning process to create wider awareness of the benefits of weather integration to improve TMC operations.

The FHWA's RWMP selected four TMCs to conduct a self-evaluation and participate in a weather integration planning process. The four comprehensive weather integration plans that were produced serve to guide each TMC's future integration plans but also offer clear examples for the benefit of weather integration for other TMCs.

Lessons that were common across each of the TMCs include the following:

- **Use the self-evaluation and integration planning process to increase awareness of the value of weather integration.** However, understand that TMC managers and staff may require considerable assistance in moving forward to incorporate new ways to integrate the weather. The self-evaluation alone may not be sufficient if the TMC lacks the motivation to make real changes in operations based on weather integration.
- **Recognize that constrained resources, both financial and in staff time, constitute a serious challenge to the successful promotion of weather integration in TMCs.** TMC personnel are stretched to fulfill their daily obligations and tasks, so that taking on a new set of responsibilities, including modifying policies and procedures to support new ways of operating with weather information, may not be a high enough priority.
- **Engage operations and maintenance as well as other stakeholders in the weather integration planning process to develop teamwork.** The most effective weather integration depends on a seamless sharing of information and decision making across operations and maintenance, but the historical arrangements in TMCs often present major institutional and cultural barriers that hinder information sharing.[116]

Traffic Control

Traffic control technologies improve traveler safety under poor weather conditions. A variety of technologies allow these control measures to be taken quickly in response to developing adverse weather.

Traffic Control	
Benefits	
ITS Goals	**Selected Findings**
Safety	The Wyoming Department of Transportation (WYDOT) implemented a VSL system along the Elk Mountain corridor during February 2009 with the goal of improving safety and reducing closure frequency and durations. The VSL system included 20 VSL signs at ten locations. The year after the VSL system was implemented in February 18, 2009 was the period when Elk Mountain Corridor had the fewest crashes of any during the 10 years prior. During this time the total number of incidents and the number of injury crashes fell to 0.999 and 0.208 per Million Vehicle Miles Traveled (MVMT) respectively. These are the lowest crash rates in the last decade. However, the number of fatal crashes remained consistent in the last ten years and was equal to three fatal crashes per year on average.[117]
Costs	
Unit Costs Data Examples	
Roadside Control subsystem: • Fixed Lane Signal: $4K-$5K • Signal Controller and Cabinet: $7K-$12K Roadside Detection subsystem: • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor • Environmental Sensor Station (Weather Station): $25K-$42K Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K • Highway Advisory Radio: $15K-$36K Transportation Management Center subsystem: • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Response and Treatment

A variety of ITS applications are being deployed in the United States to support roadway treatments necessary in response to weather events. These applications may provide for automated treatment of the road surface at fixed locations, such as anti-icing systems mounted on bridges in cold climates. They may also enhance the efficiency and safety of mobile winter maintenance activities, for example, through AVL technologies on snow plows supporting a computer-aided dispatch system.

<table>
<tr><th colspan="2">Response and Treatment</th></tr>
<tr><th colspan="2">Deployment</th></tr>
<tr><td colspan="2">As of April 2011, twenty-six (26) states use MDSS. Twenty (20) states use automatic bridge anti-icing systems, and 13 states equip a portion of their snow plow fleet with AVL, communications, and sensors to track distribution of chemical treatments.[118]</td></tr>
<tr><th colspan="2">Benefits</th></tr>
<tr><td>ITS Goals</td><td>Selected Findings</td></tr>
<tr><td>Productivity</td><td>A U.S. DOT JPO sponsored evaluation of the benefits of a MDSS in the winter season of 2006-2007 found the following benefits:
The MDSS provides enhanced notification capability of storm events with its Geographical Information System (GIS) radar and National Weather Service (NWS) platform, which enabled the system to track storm events across the state.
The MDSS consolidated a set of treatment recommendations that crews used in their decision-making for pavement treatment operations.
Although Maine DOT relied primarily on the crews to obtain information about conditions on the road, such as observations of pavement temperature, the MDSS extended crew observations with trend forecasts. [119]</td></tr>
<tr><td>Productivity</td><td>A U.S. DOT JPO sponsored evaluation of the benefits of MDSS for the city of Denver showed over $94,000 in labor savings per year from use of MDSS.[120]</td></tr>
<tr><td>Energy and Environment</td><td>Winter maintenance personnel from several agencies indicated that the use of RWIS decreases salt usage and anti-icing techniques limit damage to roadside vegetation, groundwater, and air quality (in areas where abrasives are applied).[121]</td></tr>
<tr><th colspan="2">Costs</th></tr>
<tr><td colspan="2">Unit Costs Data Examples</td></tr>
<tr><td colspan="2">Roadside Control subsystem:
Automatic Anti-icing System – Short Span: $19K
Automatic Anti-icing System – Long Span: $38K-$380K
Roadside Detection subsystem:
Closed Circuit Television (CCTV) Video Camera: $8K-$18K
Transportation Management Center subsystem:
Road Weather Information System (RWIS): $9K
Roadside Telecommunications subsystem:
Conduit Design and Installation – Corridor: $52K-$77K
Fiber Optic Cable Installation: $21K-$54K
900 MHz Spread Spectrum Radio: $8.4K (per link)
Wireless: $1.2K-$1.8K (annually)</td></tr>
</table>

Response and Treatment

Sample System Costs of ITS Deployments

Colorado: The estimated cost of MDSS implementation was $1,497,985.[122]

- It was assumed that MDSS was deployed on all 307 sheds, with two computers installed per shed, with a total installation cost of $76,406.
- The in-vehicle computer hardware investment was estimated at $ 835,800 per year for 1393 trucks equipped with MDCs costing $2000 per unit. Each MDC can be used for 5 years, and the maintenance cost per year is 10 percent of the capital cost.
- The communication cost of MDC was $40 per month, 5 months per winter season (assuming the winter season from November to March) for a total of $278,600.
- The training costs were estimated at $163,324, and administrative costs were estimated at 10 percent of the total cost of the implementation.

Indiana: Indiana DOT (INDOT) implemented MDSS statewide for the FY2009 at a cost of $529,000 for the equipment and vendor-provided training. The cost of the system included 120 AVL/MDC units that were procured and installed into the INDOT fleet across the state, cellular air cards for use in the AVL/MDC systems, and operational costs.[123]

Minnesota: The estimated cost of MDSS implementation was $496,952.[124]

- It was assumed that MDSS was deployed on all 150 sheds, with two computers installed per shed, with an installation cost of $41,082.
- The in-vehicle computer hardware investment was estimated at $180,000 per year for 300 MDCs costing $2000 per unit. Each MDC can be used for 5 years, and the maintenance cost per year is 10 percent of the capital cost. Two trucks are assumed to be used in each shed.
- The communication cost of MDC is $40 per month, 5 months per winter season (assuming the winter season from November to March) for a total of $60,000.
- The training costs were estimated at $116,480. Administrative costs were estimated at 25 percent of the total costs discussed.

New Hampshire: The estimated cost of MDSS implementation was $332,879.[125]

- It was assumed that MDSS was deployed on all 127 routes, with one computer installed with MDSS software on each route, with an installation cost of $32,878.
- The in-vehicle computer hardware investment was estimated at $152,400 for 254 MDCs costing $2000 per unit. Each MDC can be used for 5 years, and the maintenance cost per year is 10 percent of the capital cost. Two trucks are assumed to be used on each route.
- The communication cost of MDC is $40 per month, 5 months per winter season (assuming the winter season from November to March).
- The training costs were estimated at $30,226. Administrative costs were estimated at 25 percent of the total costs.

Benefit-Cost Studies

Colorado, Minnesota, New Hampshire: Sixteen (16) states have joined the MDSS Pooled Fund Study led by the South Dakota DOT to develop an enhanced version of the federal MDSS prototype. Three states were selected for a case study of the benefits and costs of MDSS. The benefit-cost ratios ranged from 1.33 to 8.67.[126]

Chapter 6 Roadway Operations and Maintenance

Source: ©iStockphoto.com/kozmoat98

Many State DOTs are implementing ITS to better manage roadway maintenance efforts and to enhance safety and mobility on the transportation system. ITS applications in roadway operations and maintenance focus on integrated management of roadway facilities, maintenance vehicle fleet, and field equipment in order to enhance mobility, safety, and efficiency of travel. Systems and processes are required to monitor, analyze, and disseminate roadway/infrastructure data for operational, maintenance, and managerial uses. ITS can help secure the safety of workers and travelers in a work zone while facilitating traffic flow through and around the construction area.

Information dissemination technologies can be deployed temporarily, or existing systems can be updated periodically, to provide information on work zones or other highway maintenance activities. Several ITS technologies can help State DOTs with asset management including fleet tracking and automated data collection for monitoring the condition of highway infrastructure. ITS applications in work zones include

Categories

Information Dissemination

- Portable Dynamic Message Signs
- Highway Advisory Radio
- Internet/Wireless/Phone

Asset Management

- Fleet Management
- Infrastructure Management

Work Zone Management

- Temporary Traffic Management
- Temporary Incident Management
- Lane Control
- Variable Speed Limit
- Speed Enforcement
- Intrusion Detection
- Road Closure Management

the temporary implementation of traffic management or incident management capabilities. These temporary systems can be stand-alone implementations or they may supplement existing systems in work areas during construction. Other applications for managing work zones include measures to control vehicle speeds and notify travelers of changes in lane configurations or travel times and delays through the work zones. In fact, work zone management systems are the most widely studied example of the information dissemination technologies mentioned above. ITS may also be used to manage traffic along detour routes during full road closures to facilitate rapid and safe reconstruction projects.

Work zone ITS deployment costs ranged from $100,000 to $2.5 million with the majority of systems costing in the $150,000 to $500,000 range.

Findings

As of July 2011, there were 112 evaluation summaries of Roadway Operations and Maintenance applications in the Knowledge Resource databases, as shown in Figure 6-1. The Roadway Operations and Maintenance category with the largest number of summaries is Work Zone Management (76 summaries), followed by Information Dissemination (43 summaries), and Information Dissemination – Advisory Strategies and Asset Management (17 each), as shown in Figure 6-2.

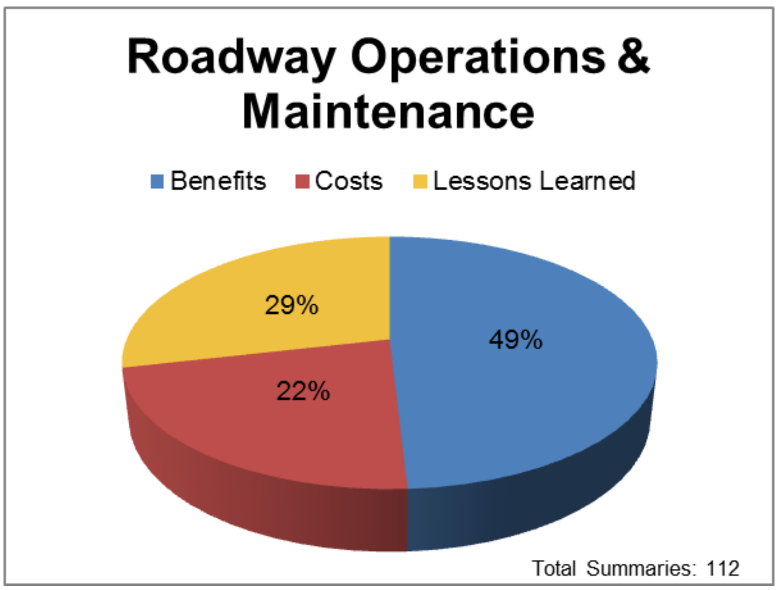


Figure 6-1. Roadway Operations and Maintenance Summaries in the Knowledge Resources

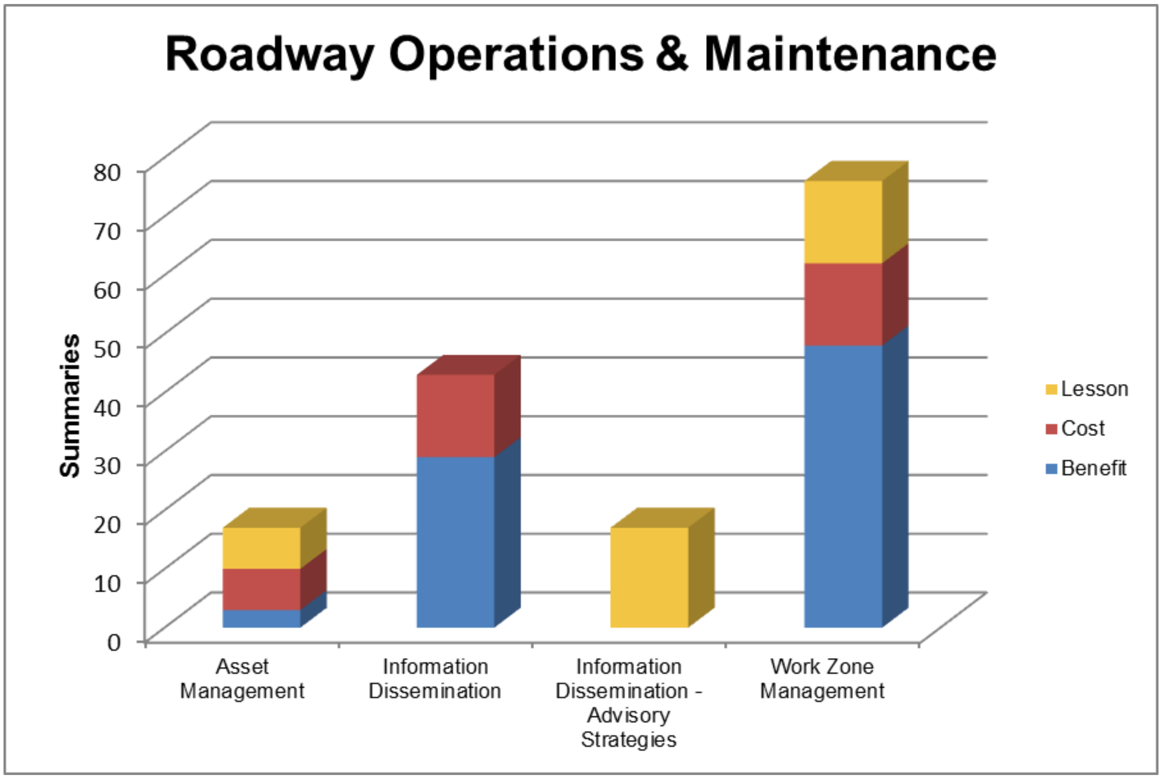


Figure 6-2. Summaries in the Knowledge Resources by Roadway Operations and Maintenance Category

Benefits

ITS can improve safety and mobility in work zones. Evaluation data shows that areas equipped with speed monitoring displays can decrease vehicle speeds by 4 to 6 mi/h[127] and reduce the number of speeding vehicles by 25 to 78 percent.[128] In addition to controlling traffic speed, smart work zones improve driver behavior. Evaluation data show that dynamic lane merge systems help reduce driver confusion at merge points and reduce aggressive driving.[129]

Speed monitoring displays can decrease vehicle speeds by 4 to 6 mi/h and reduce the number of speeding vehicles by 25 to 78 percent.

In rural areas, ITS technologies can improve the efficiency and effectiveness of operations and maintenance activities. With improved communication links between operation centers and field equipment, maintenance personnel can spend more time improving roadway conditions instead of traveling to remote sites to manually update or confirm the operation of field devices.[130]

As depicted in Table 6-1, evaluations have documented the ability of work zone management systems to positively impact transportation operations in five of the six ITS goal areas: safety, mobility, efficiency, productivity, and customer satisfaction. Highlights of these research findings are presented later in this chapter. Several studies have shown that providing information to travelers regarding work zone and other maintenance activities can reduce related congestion, while the automated work zone information systems (AWIS) have reduced delay from 46 to 55 percent in three locations studied.[131]

Table 6-1. Roadway Operations and Maintenance Benefits Summary

Roadway Operations and Maintenance Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Information Dissemination		◘				
Asset Management						
Operations and Fleet Management						
Work Zone Management	●	●	◘	◘		◘

● – substantial positive impacts	◘ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

A review of work zone ITS deployments from 17 states showed that the costs vary greatly depending on several key factors: (1) purchasing vs. leasing system equipment, (2) temporary vs. permanent components of the project (e.g., equipment used in a work zone is later deployed as permanent equipment on the same or different project), and (3) size and function of the system. Costs ranged from $100,000 to $2.5 million with the majority of systems costing in the $150,000 to $500,000 range.[132]

Deployment

The use of ITS applications in work zones is popular among state DOTs. Work zone management is also performed by many Traffic Management Centers (TMCs). A 2010 survey of state and local transportation agencies in major metropolitan areas show that 39 percent of the TMCs on freeways and 34 percent of TMCs on arterials manage work zones with ITS technologies in order to coordinate lane closures, monitor work zone traffic, etc.

Selected Highlights from the ITS Knowledge Resources on Roadway Operations and Maintenance

Information Dissemination

Information dissemination technologies can be deployed temporarily or existing systems can be updated periodically to provide information on work zones or other highway maintenance activities. Examples of these systems include dynamic message signs (DMS), highway advisory radio (HAR), Internet Web sites, wireless devices, and telephone services.

Source: ©thinkstockphotos.com/Comstock

Information Dissemination	
Deployment	
In a 2010 survey, Web pages are reported as the most widely used method of information dissemination, with 90 percent of freeway management agencies and 40 percent of arterial management agencies having Web sites to disseminate information.[133]	
Benefits	
ITS Goals	**Selected Findings**
Mobility	In Washington, D.C. an ITS work zone program implemented on I-295 decreased delay up to 90 percent with an average decrease in delay of 52 percent when drivers were advised to take alternate routes.[134]
Costs	
Unit Costs Data Examples	
Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K • Dynamic Message Sign – Portable: $15.9 K-$21K Roadside Detection subsystem: • Portable Traffic Management System: $66K-$83K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	

Asset Management

Several applications help State DOTs with asset management include fleet tracking applications, as well as automated data collection applications for monitoring the condition of highway infrastructure.

Asset Management	
Benefits	
ITS Goals	**Selected Findings**
Productivity	In an assessment by the University of Kansas, the application of AVL in highway maintenance fleet management has a benefit-cost ratio that ranges from 2.6:1 using conservative assumptions, to 24:1 (or higher) using moderate assumptions.[135]
Costs	
Sample System Costs of ITS Deployments	
United States and Canada: AVL is widely used to track and manage assets. Cost data available for several advanced winter maintenance technologies include AVL ranging from $1,250 to $5,800 per vehicle; fixed automated spray technology (FAST) ranging from $22,000 to $4 million; and a large-scale multi-agency, 400-vehicle winter weather management system costing $8.2 million.[136]	

Lessons Learned: Establish a well defined process for monitoring and maintenance before expanding the base of field equipment.

With iFlorida Model Deployment, there was a significant increase in the number, types, and geographic distribution of field equipment that the Florida Department of Transportation (FDOT) District 5 (D5) was required to maintain. In January 2004, D5 was maintaining about 240 traffic monitoring stations. In 2007, this had increased to about 650 stations. FDOT identified a number of lessons learned that might benefit other organizations planning on a significant expansion of their traffic monitoring field equipment:

- **Ensure that the requirements for new field equipment include steps to integrate the equipment into the monitoring and maintenance process.** The requirements should include tools and/or procedures for monitoring the equipment to identify failures that occur. In the case of the arterial toll tag readers, the deployment contractor provided no such tools and weak documentation. FDOT had to develop procedures for monitoring the equipment after it had been deployed, and it took several months before FDOT had developed an efficient process for doing so.
- **Plan for the increased demands on maintenance staff and contractors as new systems are brought online.** If possible, avoid bringing several new systems online at the same time. In the case of the arterial toll tag readers, almost half of the readers had failed before manual monitoring began. When monitoring did begin, it required a significant amount of FDOT staff time to poll each individual reader each day to identify readers that had failed. The same held true with the other deployed devices-FDOT staff was required each day to review the status of each field device and copy status information into spreadsheets used to monitor system status. Thus, even though FDOT had taken steps to reduce the demands on its maintenance staff by requiring warranties on much of the iFlorida equipment, monitoring the equipment for failures still required a significant amount of FDOT staff time. The amount of time required was larger when systems were first brought online, as FDOT developed procedures to integrate the new equipment into its monitoring and maintenance programs. [137]

Work Zone Management


Source: ©thinkstockphotos.com/Hemera 1

ITS applications in work zones include the temporary implementation of traffic management or incident management capabilities. These temporary systems can be stand-alone implementations or they may supplement existing systems in the area during construction. Other applications for managing work zones include measures to control vehicle speeds and notify travelers of changes in lane configurations or travel times and delays through the work zones. Systems for work zone incident management can also be used to more quickly detect incidents and better determine the appropriate degree of response needed, thereby limiting the amount and duration of additional capacity restrictions. ITS may also be used to manage traffic along detour routes during full road closures to facilitate rapid and safe reconstruction projects.

Work Zone Management	
Deployment	
A 2010 survey of state and local transportation agencies in major metropolitan areas shows that TMCs play a important role, with 39 percent of the TMCs on freeways and 34 percent of TMCs on arterials being used to manage work zones with ITS technologies in order to coordinate lane closures and monitor work zone traffic.[138]	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Kalamazoo Michigan, the activation of the Dynamic Lane Merge System in a work zone reduced the number of forced merges seven fold and reduced the number of dangerous merges three fold.[139]
Mobility	In a work zone simulation of four-to-two lane closure in Washington, DC, metro area, the variable speed limit sign (VSL) configuration resulted in a mean savings of 267 vehicle-hours of delay.[140] In Texas, during major incidents or high construction impact periods, the work zone traffic management system diverted an average of 10 percent of mainline traffic to alternate routes, with the highest diversion of traffic at 28 percent.[141]
Customer Satisfaction	In Little Rock Arkansas, 82 percent of the drivers surveyed agreed that the Automated Work Zone Information System improved their ability to react to slow or stopped traffic.[142]

Work Zone Management
Costs
Unit Costs Data Examples
Roadside Detection subsystem: • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor • Closed Circuit Television (CCTV) Video Camera: $5K-$14K • Portable Traffic Management System: $66K-$83K Roadside Information subsystem: • Dynamic Message Sign – Portable: $15.9K-$21K • Highway Advisory Radio: $15K-$36K • Highway Advisory Radio Sign: $4K-$8K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K
Sample System Costs of ITS Deployments
United States: Based on a study of 17 states, The costs of work zone ITS in the study ranged from $100,000 to $2.5 million with the majority of systems costing in the $150,000 to $500,000 range.[143]

Lessons Learned: Coordinate the schedules for ITS deployment and roadway construction to maximize use and benefits of the system.

In 2004, the North Carolina Department of Transportation (NCDOT) designed an ITS work zone solution on a rural section of I-40 west of Winston Salem. The goal of the system was to monitor traffic conditions and improve mobility and safety through the work zone. The work zone was about 4 miles long between the I-40/NC 801 interchange in Davie County and I-40/SR 1101 interchange in Forsyth County and also included a bridge rehabilitation project on I-40 about five miles east of the work zone. The majority of the construction was restricted to night work. NCDOT offers the following lessons when implementing ITS applications as an integral part of the work zone management plan.

- **Link the schedule for ITS deployment to the construction schedule to maximize use and benefits of the system.** The ITS system was deployed several weeks after the construction work zones were already set up and construction had begun. The most significant traffic impacts had occurred during this time, reducing the overall benefit the ITS applications had on the safety and mobility of traffic through the work zone. To achieve the maximum benefit of the ITS system, all applications should be operational prior to any lane restrictions.
- **Involve the construction contractor in the design and implementation of ITS applications to the fullest extent possible.** The construction contractor should be involved in the design and implementation of any and all ITS solutions being considered as part of the work zone management plan. Local NCDOT representatives cited the need to involve the construction contractor to the extent possible so they would be fully aware of the goals and objectives for the system.[144]

Chapter 7 Transit Management

Source: ©iStockphoto.com/prominx

The transit industry in the United States consists of over 173,000 vehicles (65,000 buses, 69,000 paratransit, and 39,000 rail and other types), providing 4.6 billion revenue vehicle miles of service, resulting in 55 billion passenger miles of travel, and $12.2 billion in passenger fares collected. Despite service cutbacks due to the economic downturn, in the past 10 years the transit industry has grown by over 20 percent—faster than either highway or air travel.[145] [146] During this time ITS has matured and is becoming part of standard practice in transit operations across the country in order to meet the increased passenger demand in a cost effective way and provide safer and more reliable service. Agencies are moving beyond the implementation of first generation stand-alone systems. Trends include deploying transit ITS systems that integrate automated vehicle location (AVL) and computer-aided dispatch (CAD), automatic passenger counters (APC), electronic payment and smart card systems, and real time information. Transit agencies are actively participating in Integrated Corridor Management (ICM) systems. Transit agencies are also at the forefront in providing open source real time data for third party application developers, and there is a growing trend to provide transit data to Internet map and routing providers (e.g. Google maps, Bing Maps, Map Quest) for multimodal trip planning applications.

Categories

Operations and Fleet Management

- Automatic Vehicle Location and Computer-Aided Dispatch
- Transit Signal Priority
- Maintenance
- Planning
- Service Coordination

Information Dissemination

- In-Vehicle Systems
- In-Terminal/Wayside
- Internet/Wireless/Phone

Transportation Demand Management

- Ride Sharing/Matching
- Dynamic Routing/Scheduling

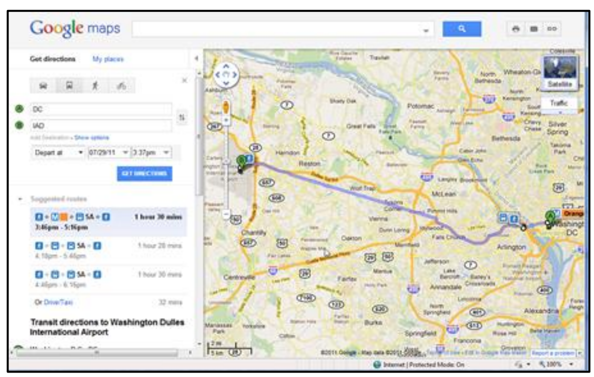
Safety and Security

- In-Vehicle Surveillance
- Facility Surveillance
- Employee Credentialing
- Remote Disabling Systems

Transit operations and fleet management ITS applications improve transit reliability through implementation of AVL and CAD systems which can reduce passenger wait times. The systems enhance security and improve incident management through improved vehicle-to-dispatch communications, enabling quicker response to aggressions, accidents and vehicle breakdowns. Speedy response to these types of incidents minimizes vehicle downtime and improves service reliability. Information on current vehicle location and schedule status can also support transit signal priority, which improves transit trip times and schedule adherence. Data records from AVL/CAD systems, along with automated passenger counters, are enabling a transition to improved transit planning and management strategies which rely on large quantities of data regarding system operations.[147] Vehicle monitoring technologies can allow transit vehicles to perform self-diagnostic tests and automatically alert maintenance personnel of potential problems, either immediately via AVL/CAD systems or through routine downloads at vehicle maintenance facilities.

Public access to bus location data and schedule status information is increasingly popular on transit agency Web sites. Passengers can confirm scheduling information, improve transfer coordination, and reduce wait times. In addition, electronic transit status information signs at bus stops help passengers manage their time, and on-board systems such as next-stop audio annunciators help passengers in unfamiliar areas reach their destinations.

Providing easily accessible real time information on transit services to travelers for both automobile and transit services is key to making travelers aware of the options that they have to travel. Prior to 2006, most transit agencies implemented their own custom trip planner systems and web interface software. With the release of Google Transit and the General Transit Feed Specification (GTFS) for transit data, and other open source platforms such as OpenTripPlanner, there has been a major change in the level of effort and costs required to implement transit and multimodal trip planners by both large and small agencies. The Federal Transit Administration (FTA)-sponsored Web-based Multi-Modal Trip Planning System (MMTPS) in North Eastern Illinois, implemented from 2004 to 2010, demonstrates this change. The MMTPS aimed to integrate driving itineraries, transit trip planners, and real-time monitoring systems to provide side-by-side comparisons of trip itineraries using transit, driving, or any combination of non-motorized modes including biking and walking. The goal was to create a comprehensive decision support tool for choosing travel options that incorporates convenience, efficiency, and cost from the traveler's perspective. The cost of the MMTPS and its development of a custom application was just over $4 million. A small transit agency has the tools now to provide many of the same features by converting schedule and route information to the GTFS feed and providing it to Internet Service Providers. The costs involve anywhere from 12 hours to 2 person months of labor and an hour or two per change of schedules. Implementing an integrated regional system takes more effort but is still a fraction of the cost of a custom system.[148]



Source: Google Maps

ITS is now considered an established core element of bus rapid transit (BRT). These transit lines typically supplement infrastructure-based improvements with transit ITS to provide service qualities approaching those of rail transit facilities. Infrastructure-based improvements to BRT lines include enhanced shelters, level boarding facilities, and priority treatments such as dedicated transit lanes or queue-jump lanes at congested intersections. ITS technologies typically deployed include transit signal priority and AVL/CAD for enhanced schedule performance, station and access control systems to dedicated rights of way, and improvements to traveler information that include in-vehicle annunciators and the provision of wayside arrival time information at major stops along the line. Pioneering BRT systems also are implementing collision warning and obstacle detection, precision docking, and lane-keeping assistance systems.[149]

ITS applications can also support transportation demand management activities including carpooling and ridesharing services, and enable flexible, door-to-door paratransit service that is typically provided for disabled travelers. Computer databases and Internet technologies can facilitate ride sharing and carpool matching services to reduce peak period travel along major commuter routes. Paratransit services increase public access to transit resources where coverage is limited or provide service to those who cannot access standard service. ITS can improve these services through data collection technology and software supporting better coordination of service providers and scheduling of trips, or by supporting innovative strategies, such as route deviation or zone-based demand-responsive feeder service to fixed routes. These latter strategies enable transit systems to provide access for those living in close proximity to scheduled transit services but unable to reach them. Use of ITS technologies to support paratransit services represents another growing area of transit ITS deployment. Applications for human services transportation that improve scheduling and service coordination among multiple providers can be cost-effective and provide enhanced service to travelers. Several of these concepts are included in the Mobility Services for All Americans (MSAA) initiative discussed below.

Transit ITS services include a number of other ITS applications that can help transit agencies increase safety and security, as well as enhance the operational efficiency of the Nation's transit systems. Advanced software and communications enable data as well as voice to be transferred between transit management centers and transit vehicles for increased safety and security, improved transit operations, and more efficient fleet operations. Transit management centers in several cities have the ability to monitor in-vehicle and in-terminal surveillance systems to improve quality of service and improve the safety and security of passengers and operators.

Source: ©thinkstockphotos.com/John A. Rizzo

Several ITS technologies discussed elsewhere in this document have significant impacts on public transit systems. Electronic fare payment systems offer significant potential for transit agencies to streamline cash-handling processes and the potential for simplifying traveler access to multiple transit systems in a region. Also of interest are advanced traveler information systems (ATIS), which can include transit information, as in the case of the multi-modal trip planner discussed above. ITS data archiving can provide important information for transit planning and management. Finally, several vehicle-based collision avoidance technologies have been tested on transit vehicles and show promise for lessening the likelihood of crashes involving transit vehicles.

Two major ITS initiatives initiated in the mid-2000's are beginning to see impacts across the country concerning ITS technologies for transit: MSAA and Integrated Corridor Management (ICM). Formal evaluation results of operational tests of these initiatives are expected in the near future.

The goal of the MSAA initiative is to improve transportation services and simplify access to employment, healthcare, education, and other community activities by means of the advanced technologies of ITS and through extending transportation service partnerships with consumers and human service providers at the Federal, State, and local levels. Several ITS technologies profiled in this chapter will be deployed in support of this initiative including integrated vehicle dispatching and scheduling, AVL, communication systems, electronic payment systems/financial tracking and billing systems, and ATIS.[150] On March 12, 2010, four rural transit agencies in and around Paducah, Kentucky held a Grand Opening for their Travel Management Coordination Center (TMCC), as part of the MSAA Initiative.

Transit ITS continues to evolve, supporting the next generation of Transit ITS applications and the needs of the ITS JPO's ITS Strategic Plan 2010 – 2014. Connected vehicles and the continued shift to a mobile world provide new opportunities. The Integrated Dynamic Transit Operations bundle of applications track of the connected vehicle program will explore development of transit applications utilizing real time data. Potential applications that will be explored include: Connection Protection (T-Connect); Dynamic Transit Operation s (T-Disp), and Dynamic Ridesharing (D-Ride).

Additional information on the MSAA, the ICM, and the ITS Strategic Plan 2010-2014 is available at the ITS JPO's Web site: http://www.its.dot.gov/index.htm .

Findings

As of July 2011, there were 177 evaluation summaries of Transit Management applications in the Knowledge Resource databases, as shown in Figure 7-1. The Transit Management category with the largest number of summaries is Operations and Fleet Management, with 134 summaries, followed by Information Dissemination (57 summaries), Transportation Demand Management (39 summaries), and Safety and Security (17 summaries), as shown in Figure 7-2.

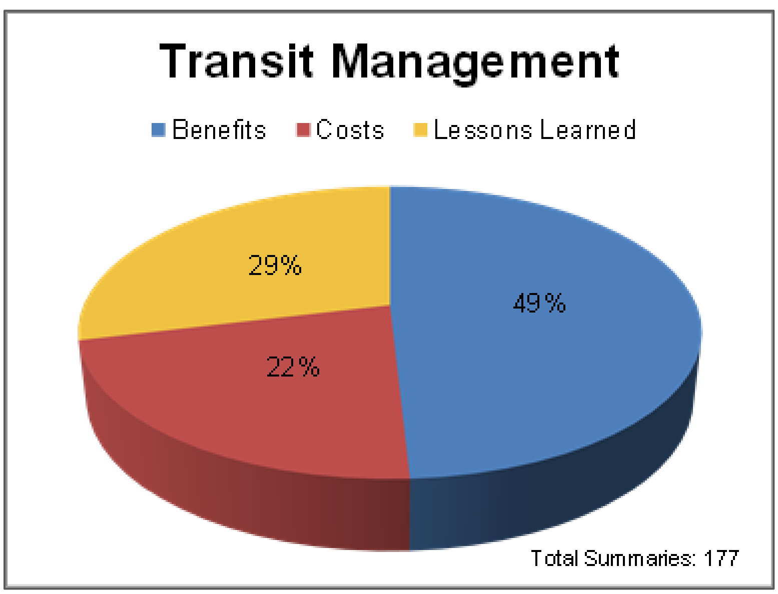


Figure 7-1. Transit Management Summaries in the Knowledge Resources

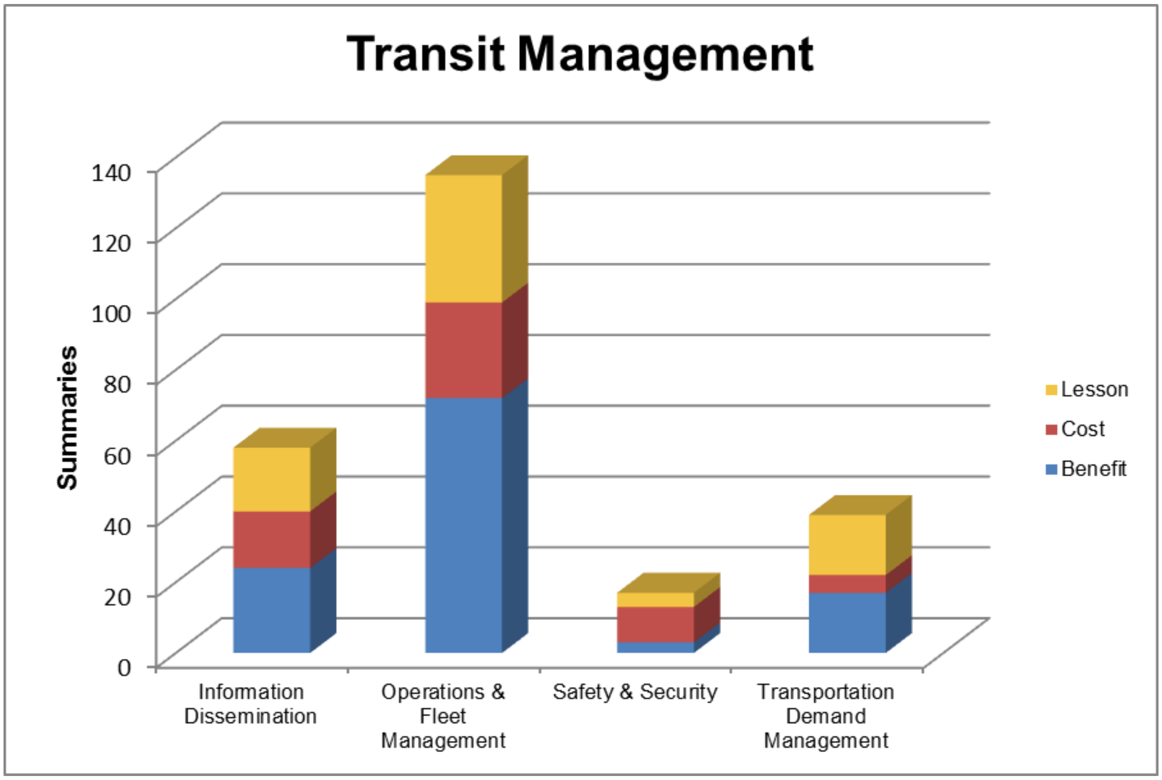


Figure 7-2. Summaries in the Knowledge Resources by Transit Management Category

Benefits

Fleet management applications can improve both the experience of transit riders and the efficiency of transit operations by enabling more efficient planning, scheduling, and management of transit assets and resources. Transit agencies have reported reductions in fleet requirements ranging from two to five percent as a result of improved fleet utilization.[151] For large agencies even small percentage gains can represent large amounts of actual operating cost savings.[152] Deployment of AVL/CAD and scheduling software has enabled cost savings for paratransit providers through better planning of trips. In rural Pennsylvania this resulted in a nine percent increase in overall on-time performance and over a five percent decrease in non-revenue miles traveled.[153] An innovative application of these technologies has also demonstrated that agencies operating fixed routes can provide the option of demand-responsive services.

Improving schedule reliability improves travelers' experiences by reducing wait time anxiety and simplifying successful connections to other transit services. Data from transit systems in Portland, Oregon; Milwaukee, Wisconsin; and Baltimore, Maryland show that AVL/CAD systems have improved schedule adherence by 9 to 23 percent. The systems enable better monitoring of transit system status by transit dispatchers and allow appropriate responses to early arrivals, bus bunching, and other operational challenges as they arise.[154]

Figure 7-3 shows the range of documented experiences with improvements in transit travel times after the implementation of transit signal priority, with improvements ranging from 1.5 to 15 percent.[155] Several studies show a range of measurements, typically representing measurements during peak periods and off-peak periods, or results for a variety of signal priority scenarios tested. Transit signal priority is often implemented on a conditional basis intended to help transit vehicles improve schedule performance by granting signal priority when vehicles are behind schedule. This practice can lead to a reduced need for recovery time in the scheduled trip and improve transit travel times. Archived data from AVL/CAD systems can also facilitate these types of schedule improvements.

The implementation of remote vehicle diagnostic systems can have significant impacts on maintenance costs and improve service reliability. In Reno Nevada, the integrated remote vehicle diagnostics implemented with the system was a major contributor to the 50 percent decrease in missed trips for mechanical reasons.

In Pennsylvania an AVL/CAD for demand-response service vehicles resulted in a nine percent increase in overall on-time performance and over five percent decrease in non-revenue miles traveled.

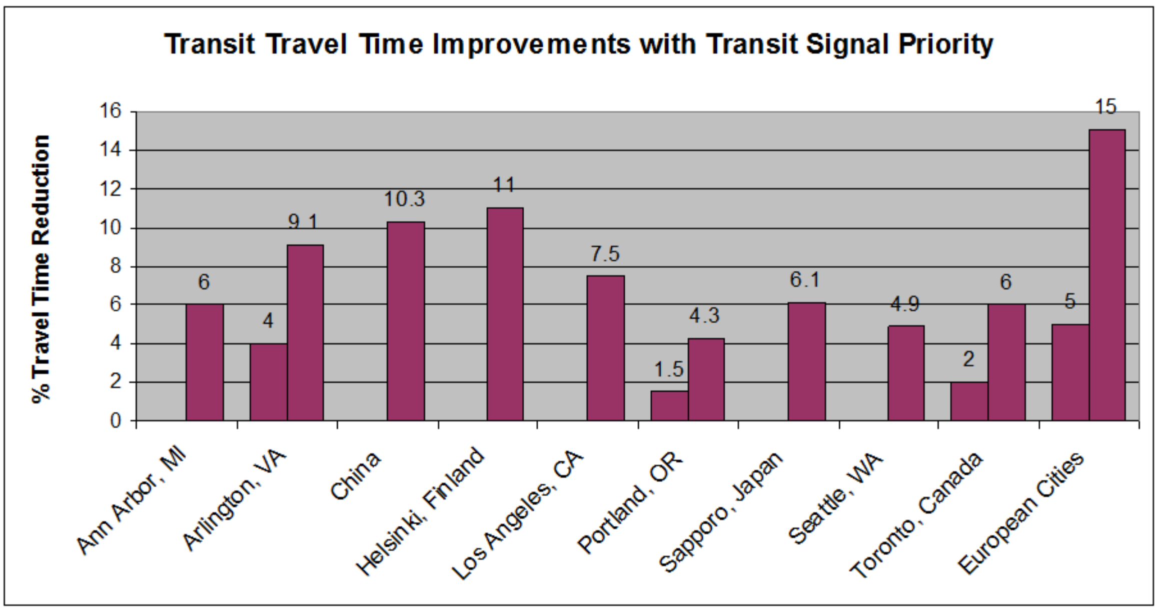


Figure 7-3. Transit Travel Time Improvements with Transit Signal Priority

Table 7-1 lists qualitative ratings for the impact of ITS applications for transit under each of the ITS goal areas identified by the U.S. DOT. These ratings demonstrate that each of the transit ITS applications have positive impacts on travelers' experiences. Applications supporting transit operations and fleet management provide substantial cost savings to transit operators, reduce transit vehicle emissions and energy consumption, and improve traveler mobility. Technologies supporting paratransit systems—listed under transportation demand management—have cost savings benefits for paratransit operators and improve customer experiences.

Table 7-1. Transit Management Benefits Summary

Transit Management Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Operations and Fleet Management		●	◉	●	◉	●
Information Dissemination						●
Transportation Demand Management				●		◉
Safety and Security	◉			◉		◉

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

Based on survey results from over 100 transit agencies and equipment suppliers, the trend in mobile data terminals (MDTs) is an increase in functionality and lower unit, installation, maintenance, and repair costs. MDTs are multifunctional on-board devices that support two-way communication between the vehicle and the control center. The majority of MDTs are used to download driver manifests, collect driver data such as sign on/sign off and start run/end run, count passengers boarding and alighting, and to function as an emergency alarm.

Capital costs for MDTs typically range between $1,000 and $4,000 per unit with installation costs frequently between $500 and $1,000.[156]

The costs to implement an AVL/CAD system seem to increase with fleet size. A rule of thumb to use for both vehicle and system costs is $8,000 to $10,000 per vehicle.

A rule of thumb to estimate total costs for an AVL/CAD system is $8,000 to $10,000 per vehicle.

Costs to implement a transit or multimodal trip planner have dropped significantly since the release of Google Transit and the Google Transit Feed Specification (GTFS) standard for transit data.

A comprehensive cost assessment of BRT components was conducted in 2007 and updated in 2009 and found that on-board security systems typically cost approximately $8,000 to $10,000 per vehicle.[157]

Deployment

Transit agencies are continuing to adopt ITS technologies at a rapid rate (reaching saturation levels for some technologies) in order to take advantage of the improved operational efficiencies and user services that they enable. Figure 7-4 shows deployment trends for three key transit management technologies from 2000 to 2010, based on a survey of the country's large metropolitan areas (with a population of over 1 million).[158] In these large regions, in the 10 years from 2000 to 2010:

- The percentage of fixed route buses equipped with AVL increased from approximately 31percent to 66 percent.
- The percentage of demand responsive vehicles equipped with CAD increased from 28 percent to 88 percent.
- The percentage of fixed route buses equipped with electronic real-time monitoring of system components increased from 15 percent to 35 percent.
- The percentage of bus stops with displays of dynamic traveler information (an emerging technology) increased from less than 1 percent in 2007 to 3 percent in 2010.[159]

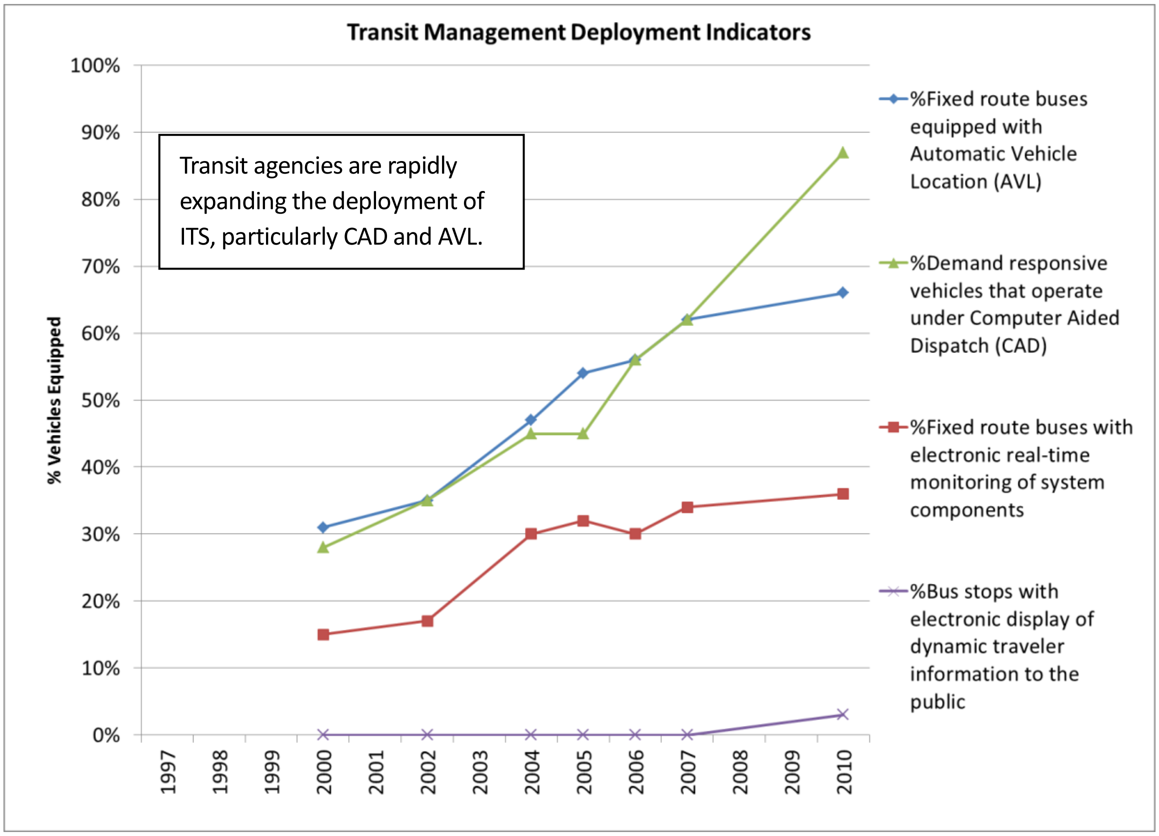


Figure 7-4. Deployment Trends for Transit Management Technologies, 2000 – 2010

The American Public Transportation Associations (APTA) reports the equipment installed on all transit vehicles operating in the country based on a sample from the APTA Public Transportation Vehicle Database. It reports that between 2001 and 2010 equipment installed on buses for automatic vehicle location or GPS has increased from 21 to 60 percent; automatic passenger counters have increased from 2.8 percent to 31.7 percent; automated stop announcement equipment has increased from 10 to 48 percent; and security cameras or CCTV have increased from 13 to 53 percent.[160] Technology is becoming part of standard operations among transit agencies.

The 2010 Deployment Survey and APTA's Public Transportation Fact Book are the sources of deployment statistics presented later in this chapter.

Selected Highlights from the ITS Knowledge Resources on Transit Management

Operations and Fleet Management

Transit operations and fleet management technologies improve transit reliability through implementation of AVL and CAD systems. These systems may also be implemented with in-vehicle self-diagnostic equipment to automatically alert maintenance personnel of potential problems. Automated passenger counters can provide additional data to support service planning. Service coordination technologies can help assure connections between transit services at transfer points through a service commonly known as connection protection. Transit signal priority systems, through coordination with arterial management systems, can improve service quality and transit agency productivity. Integrated Corridor Management is extending the transit operations and fleet management to consider overall corridor performance across all modes.

Operations and Fleet Management	
Deployment	
The use of ITS to support fleet management has experienced wide acceptance among transit agencies in major metropolitan areas. The 2010 ITS Deployment Survey shows that 66 percent of fixed-route transit buses in the country's larger metropolitan areas are equipped with AVL; 80 percent of demand-responsive paratransit vehicles operate under CAD; 36 percent of fixed-route transit buses are equipped with technology to monitor vehicle components in real time. Also, 48 percent of transit agencies in these metropolitan areas use archived data for operation planning and analysis, 38 percent use archived data for performance measurement and 24 percent for capital planning and analysis. APTA's Public Transportation Fact Book also reports that for buses operated by all transit agencies 60.1 percent are equipped with AVL or GPS, and 31.7 percent have automatic passenger counters.	
Benefits	
ITS Goals	**Selected Findings**
Mobility	***Summary Finding*:** Studies from transit systems in Portland, Oregon; Milwaukee, Wisconsin; and Baltimore, Maryland show that AVL/CAD systems have improved schedule adherence by 9 to 23 percent.[161]
Productivity	In Reno, Nevada, the Regional Transportation Commission of Washoe County, implanted and evaluated a comprehensive Transit ITS system from 2002-2007. They found that the AVL/CAD system lead to nearly a four percent increase in on-time performance for paratransit services and the ability to accurately track on time performance and address schedule issues in the fixed route system. Improved scheduling also led to a reduction in percent overtime operating hours from 12.4 percent in 2005 to 8.4 percent in 2008. The advanced systems also allowed the agency to handle over a 10 percent increase in ridership with no additional staff increases. The integrated remote vehicle diagnostics implemented with the system also was a major contributor in 50 percent decrease in missed trips for mechanical reasons. This reduction in missed trips led to improved reliability and user service as well since passengers were not left waiting at bus stops.[162]

Operations and Fleet Management	
Efficiency	By implementing ITS within an integrated service concept Bus Rapid Transit can reduce transit running times by 38 to 69 percent and improve service reliability producing increased ridership from 35 to 77 percent.[163]
Productivity	Pace Suburban Bus of Northern Illinois found in a case study deployment of the Transit Operations Decision Support Systems (TODSS) core requirements (second generation AVL/CAD with integrated functions, incident and situation identification, prioritization and decision support) that TODSS reduced false and low priority incident reports sent to dispatchers by 60 percent. This allowed dispatchers to focus on higher priority incidents resulting in better performance.[164]

Costs

Unit Costs Data Examples

Transit Management Center subsystem:

- Upgrade for Automated Scheduling, Run Cutting, or Fare Payment: $20K-$40K
- Integration for Automated Scheduling, Run Cutting, or Fare Payment: $224K-$498K
- Transit Center Labor: $112K-$448K (per site for 3 staff, annually)

Transit Vehicle On-Board subsystem:

- Cell-Based Communication Equipment: $0.14K-$0.24K
- Global Positioning System (GPS)/Differential GPS (DGPS) for Vehicle Location: $0.4K-$2K
- Trip Computer and Processor: $0.1K-$0.11K
- Automatic Passenger Counting System: $0.83K-$8.3K (per vehicle with installation, low cost is for add on to existing equipment, high costs is for standalone)

Sample System Costs of ITS Deployments

Worldwide: Cost data were obtained from various BRT projects either underway or planned and made available to transit professionals and policy makers in planning and decision making related to implementing different components of BRT systems. The data are representative of BRT development costs. On-board performance monitoring systems typically cost approximately **$2,000 per vehicle** and AVL systems cost around **$8,000 per vehicle**.[165]

United States: Recent contract awards suggest the capital costs to implement bus AVL systems range from **$10,000 to $20,000 per vehicle**. This is based upon a review of 27 contact awards from 2001 to 2007.[166]

California: The experience of San Luis Obispo Transit in implementing an ITS Transit system including AVL, DMS, and real-time passenger information showed that deployment of Advanced Public Transit Systems (APTS) in mid-size transit systems costs **$150,000**.[167]

Montana: The Billings MET Special Transit, a paratransit service, spent approximately **$43,500** to add AVL technology to its fleet of 15 vehicles.[168]

Lessons Learned: Plan for cellular and other communications technologies to evolve and the need to transition to new systems every few years.

The Triangle Transit Authority experience in implementing a bus AVL system in Raleigh Durham North Carolina highlights this important lesson. In 2000 TTA implemented an AVL system based on Cellular Digital Packet Data (CDPD) cellular mobile data communications. By late 2005 CDPD was phased out in favor of Code Division Multiple Access (CDMA) technology. This required significant upgrades to the AVL system. Communications technologies will continue to evolve with the release of the 3G and 4G and mesh network technologies. In addition, the changing radio spectrum must also be considered by transit agencies. This leads to the following:

- **Anticipate and plan for cellular technology to evolve and transition to new communication technologies.** Prepare to retrain staff including operators, dispatchers, supervisors, maintenance technicians, information technology staff, customer service, and marketing personnel.
- **Communicate proactively with cellular service providers and technology vendors.** Consultants are an additional resource applied selectively by agencies, for areas where staff have less experience with regard to technology upgrades.
- **Budget for periodic minor upgrades required to maintain compatibility with cellular data service as it evolves and improves.** Carefully select the systems integrator, apply strong project management for implementation, and understand that substantial ongoing effort will be need to manage AVL system operations.[169]

Operations and Fleet Management: Transit Signal Priority

Transit signal priority systems use sensors to detect approaching transit vehicles and alter traffic signal timing to improve transit performance. For example, some systems extend the duration of green signals for public transportation vehicles when necessary.

Transit Signal Priority	
Deployment	
The percentage of signalized intersections in the country's larger metropolitan areas that are equipped with transit signal priority has remained relatively flat from 2007 to 2010 at two percent. However, 25 percent of the agencies in these metropolitan areas have adopted transit signal priority in one or more corridors. APTA reports that the percentage of buses in all the country's transit agencies equipped with transit signal priority devices (note that these apply only to vehicle triggered signal priority) has risen from 0.7 percent in 2001 to 5.2 percent in 2010. Interestingly, 25.5 percent of all light rail vehicles are equipped with transit signal priority devices.	
Benefits	
ITS Goals	**Selected Findings**
Mobility	***Summary Finding*:** Experience in 13 cities in the U.S. and abroad show 1.5 to 15 percent improvement in bus travel time due to transit signal priority. This range represents experience with a variety of transit service types under varying traffic conditions. Several studies show significant reductions in travel time variability, with a corresponding improvement in on-time performance. [170]
Mobility	In Snohomish County, Washington State, implementation of a transit signal priority system on two test corridors reduced average transit corridor travel time by 4.9 percent, and had insignificant negative impacts on local cross street traffic.[171]

Transit Signal Priority	
Customer Satisfaction	Surveys found that riders on Vancouver's 98 B-line BRT service, which implemented transit signal priority to improve schedule reliability, rated the service highly with regard to on-time performance and service reliability (an average of 8 points on a 10-point scale).[172]
Costs	
Unit Costs Data Examples	
Roadside Control subsystem: • Signal Controller Upgrade for Signal Control: $2.1K-$5K • Roadside Signal Preemption/Priority: $4K-$5K (per intersection) Transit Vehicle On-Board subsystem: • Signal Preemption Processor: $0.2K-$0.4K • Signal Preemption/Priority Emitter: $0.4K-$1.8K • Preemption/Priority Transponder: $0.06K Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K (per mile) • Fiber Optic Cable Installation: $21K-$54K	

Lessons Learned: Anticipate and address challenges to consistently operating a transit signal priority (TSP) system.

Experience from a cooperative project between Sacramento County and the Sacramento Regional Transit District in deploying a transit signal priority system shows that it is important to include testing and budget time and resources to deploy and operate TSP. For emitter systems:

- **Allocate sufficient time to calibrate TSP emitters.** The proper performance depends on the geometry and conditions of each intersection and there must be multiple test runs and a trial and error process to calibrate the emitters for the system.
- **Install TSP emitters that require minimal input from the vehicle operator. Initial emitters required the operator to activate the emitters for TSP use.** They were eventually replaced with emitters hardwired to the door mechanism.
- **Establish "test signals" to verify proper functioning of the TSP emitters.** In order to quickly identify faulty emitters it is recommended that a test signal be placed at the exit door of the bus depot.
- **Anticipate and plan for challenges in consistently assigning emitter-equipped buses to the TSP routes.** Vehicle assignments were made by maintenance staff and it was difficult to ensure that the vehicles equipped with the emitters were assigned to the correct routes on a consistent basis.[173]

Information Dissemination

Information dissemination Web sites allow passengers to confirm scheduling information, improve transfer coordination, and reduce wait times. Electronic transit status information signs at bus stops help passengers manage their time and on-board systems such as next-stop audio annunciators help passengers in unfamiliar areas reach their destinations. More and more transit agencies are also providing mobile applications or making their real time data available to others through open interfaces to allow others to develop apps.

Information Dissemination	
Deployment	
One of the fastest growing areas of technology deployment within transit agencies is the use and dissemination of real time transit information. In the largest metropolitan areas the distribution of real time information now exceeds the distribution of static traveler information in channels of distribution. Close to 86 percent of agencies use webpages to distribute real time information (versus 29 percent that distribute static information via webpages). Twenty two (22) percent are distributing real time information alerts via Email or mobile device texts. Thirty one (31) percent are distributing alerts via email (but not through mobile devices). Close to 44 percent of the agencies are distributing real time information via telephone systems. An emerging technology is the provision of dynamic traveler information at bus stops: the percentage of bus stops within these regions with displays of dynamic traveler information has increased from 1 percent in 2007 to 3 percent in 2010. APTA also reports that due to ADA requirements the percentage of all the country's buses with automated stop annunciators has increased from 10.2 percent in 2001 to 48.4 percent in 2010.	
Benefits	
ITS Goals	**Selected Findings**
Customer Satisfaction	***Summary Finding*:** Evaluation data show that passengers who use real-time bus or tram departure information signs find them useful. At the Acadia National Park in Maine, 90 percent of visitors using the signs said they made travel easier.[174] Several surveys in Helsinki, Finland found 66 to 95 percent of travelers regarded similar signs useful.[175]
Customer Satisfaction	An evaluation of the SmartBus ITS implementation program for the Chattanooga Area Regional Transportation Authority found that two thirds of bus tracking website users said that they used transit more frequently because of the availability of real-time information.[176]
Customer Satisfaction	Bus arrival predictions at bus stops make customers think transit service has improved. London's transit agency found in an assessment of its Countdown System, that 65 percent of those interviewed "felt like they waited for a shorter period of time when [the] Countdown [system] was present, with the perceived waiting time dropping from 11.9 to 8.6 min," Additionally, 64 percent thought service had improved, despite the fact that "service reliability had actually decreased when the Countdown System was implemented.[177]
Mobility	In the Bay Area, Changeable Message Signs that displayed highway and transit trip times and departure times for the next train influenced 1.6 percent of motorists to switch to transit when the time savings was less than 15 minutes, and 7.9 percent of motorists to switch to transit when the time savings was greater than 20 minutes. Overall this resulted is an average of 9.7 fewer vehicle miles traveled and decreased the average commute time by 2.6 minutes.[178]
Energy and Environment	In Nagoya, Japan a personal integrated travel assistance system to help commuters make environmentally sound decisions regarding their travel behavior was developed and tested. It was found that it helped commuters choose environmentally friendly routes and modes reducing carbon dioxide emissions by 20 percent. For those in the study, car usage decrease by 20.1 percent, walking and bicycling increased by 82.2 percent and use of transit increased by 103 percent. [179]

Information Dissemination
Costs
Unit Costs Data Examples
Transit Management Center subsystem: • Transit Center Hardware: $6K-$8K • Transit Center Software, Integration: $810K-$1710K • Transit Center Labor: $112K-$4448K (per site for 3 staff, annually) Transit Vehicle On-Board subsystem: • Cell-Based Communication Equipment: $0.14K-$0.24K • Global Positioning System (GPS)/Differential GPS (DGPS) for Vehicle Location: $0.4K-$2K • Trip Computer and Processor: $0.1K-$0.11K Remote Location subsystem: • Transit Status Information Sign: $3K-$7K
Sample System Costs of ITS Deployments
Chicago: The cost of Implementing a multimodal or transit trip planner has dropped significantly since Internet Mapping Sites such as Google Transit, Bing Maps, Map Quest and OpenTripPlannner have added transit and routing features for agencies to use. It cost **$4,187,800** to develop and implement the custom multimodal trip planner for the Chicago region from 2004 to 2010. In contrast Portland's TriMet implemented a system within the OpenTripPlanner and estimates an initial investment of **$69,000 for developer time and another $69,000 to for a routing engine and interface**. Also one state DOT reported that for a regional consolidator of information (similar to the Chicago system), it would cost using the Google Transit Feed Specification (GTFS) **$325 per agency plus $7.50 per stop, and $450 per route**. Annual maintenance would be 35 percent of the creation costs plus $300 per agency)[180] **Chicago:** The RTA/Metra parking management guidance system for two commuter rail stations in suburban Chicago including parking monitoring within the parking facilities and an en-route information system was approximately **$1 million**. Development of the concept of operations cost **$100,000** and the engineering design and specifications cost approximately **$100,000**. [181] **Worldwide:** A comprehensive cost assessment of BRT components was conducted in 2007 and updated in 2009 and found that on-board security systems typically cost approximately **$8,000 to $10,000 per vehicle**. In vehicle video display systems cost roughly **$2,000 to $4,000 per vehicle (2 displays per vehicle),** and passenger annunciators cost **$2,500 to $3,500 per vehicle** with annunciator displays costing **$1,000 to $1,500 per vehicle**. Electronic displays at BRT stations or stops range from **$4,000 to $10,000 per display.**[182]

Transportation Demand Management

Transportation demand management services, such as ride sharing/matching and dynamic routing/scheduling, increase public access to transit service.

Transportation Demand Management	
Deployment	
A significant number of transit agencies in major metropolitan areas use ITS technologies to improve transportation demand management efforts. The 2010 ITS deployment survey showed that in the large metropolitan areas, the percentage of demand responsive vehicles equipped with AVL and computer aided dispatch has increased from 28 percent in 2000 to 88 percent in 2010. In these areas 48 percent of the agencies also use archived data for operational planning and analysis adjusting service as called for. Results from the 2007 ITS deployment survey also showed that 33.3 percent of transit agencies in the country's largest metropolitan areas offer ride sharing and carpool matching services; 19.4 percent use AVL and CAD to support dynamic routing and scheduling; and 40.7 percent use ITS technologies to coordinate passenger transfers between vehicles or between transit systems.	
Benefits	
ITS Goals	**Selected Findings**
Efficiency	The Area Transportation Authority of North Central Pennsylvania implementing a comprehensive ITS system to support both its fixed route and paratransit services. As a result demand-response service vehicles experienced a nine percent increase in overall on-time performance (to over 80 percent) and over five percent decrease in non-revenue miles traveled (to 18 percent putting ATA below the national average). Reservationists also reported reduced times spent on each call and the ability to schedule more same day trips.[183]
Productivity	Coordinating human transportation services for the transportation disadvantaged improves customer service and lowers costs. In Aberdeen South Dakota consolidating transit services previously provided by non-transit entities (senior and medical centers and various government programs) allowed the agency to expand service hours and increase the number of trips provided while reducing the average trip cost by 20 percent, from about $5 to $4.[184]
Productivity	Route-deviation service can be less expensive than pure demand-responsive paratransit service while providing the additional important benefit of providing easy access to traditional transit routes for some patrons requiring door-to-door service. Experience with the Omnilink system in Prince William County, Virginia suggests that with less than 20 passengers per hour, adding 10 minutes of recovery time allows accommodation of one or two deviations per hour for routes taking approximately 35 minutes to drive without deviations.[185]
Customer Satisfaction	In Reno, Nevada, the Regional Transportation Commission of Washoe Count, implanted and evaluated a comprehensive Transit ITS system from 2002-2007. They found that the AVL/CAD system lead to nearly a four percent increase in on-time performance for paratransit services, and a 45 percent reduction in complaints by paratransit riders. [186]

Transportation Demand Management
Costs
Unit Costs Data Examples
Transit Management Center subsystem: • Transit Center Hardware: $6K-$8K • Transit Center Software, Integration: $810K-$1710K • Upgrade for Automated Scheduling, Run Cutting, or Fare Payment: $20K-$40K • Integration for Automated Scheduling, Run Cutting, or Fare Payment: $224K-$498K • Transit Center Labor: $112K-$4448K (per site for 3 staff, annually) Transit Vehicle On-Board subsystem: • Cell-Based Communication Equipment: $0.14K-$0.24K • Global Positioning System (GPS)/Differential GPS (DGPS) for Vehicle Location: $0.4K-$2K • Trip Computer and Processor: $0.1K-$0.11K • Automatic Passenger Counting System: $0.83K-$8.3K (per vehicle with installation, low cost if for add on to existing equipment, high costs is for standalone)
Sample System Costs of ITS Deployments
Montana: The Billings MET Special Transit System—a paratransit service that operates within the Billings, Montana city limits—deployed a computer-aided scheduling and dispatching software system at a cost of **$83,575**. A software maintenance fee is charged at **$11,835 per year**.[187] **New Mexico:** Client Referral, Ridership, and Financial Tracking (CRRAFT), a Web-based system that integrates human services transportation with the daily operating procedures and administration of multiple rural transit agencies, cost about **$1 million** to implement.[188] Operating costs for CRRAFT are about **$95,000 annually**.[189] Building on the success of CRRAFT, the Alliance for Transportation Institute developed a plan and implemented smart card technology—the Intelligent, Coordinated Transit Smart Card Technology Project (ICTransit Card)—to provide cost-effective, seamless, and convenient transportation services in a rural setting. The cost of the ICTransit Card system is approximately **$635,700**.[190] Operating costs for the ICTransit Card system are about **$93,000 annually** with about $40,000 shared with the annual operations for CRRAFT.[191]

Safety and Security

Advanced software and communications enable data as well as voice to be transferred between transit management centers and transit vehicles for increased safety and security. Transit management centers can monitor in-vehicle and in-terminal surveillance systems, sometimes including video, to improve quality or the safety and security of passengers and operators. Silent distress alarms enable drivers to notify dispatch of on-board security situations and remote disabling systems can prevent hijacking of transit vehicles.

<table>
<tr><th colspan="2">Safety and Security</th></tr>
<tr><th colspan="2">Deployment</th></tr>
<tr><td colspan="2">ITS technologies are used by many metropolitan transit agencies to enhance transit safety and security. In 2010 transit agencies in large metropolitan areas rated security cameras (4.67 out of 5) on a benefit scale from different types of ITS technologies just behind communications (4.82 out of five). Ten of the agencies surveyed are planning to implement security cameras between 2010 and 2013. APTA also reports that the percentage of all of the country's busses with security cameras has increased from 13 percent in 2001 to 53 percent in 2010.</td></tr>
<tr><th colspan="2">Benefits</th></tr>
<tr><td>ITS Goals</td><td>Selected Findings</td></tr>
<tr><td>Productivity</td><td>In Monterey Bay California, Monterey-Salinas Transit reported that by installing cameras on the interior and exterior of all of their buses, they improved perceptions of safety and security for both passengers and drivers, improved relations with local police by providing surveillance data for any incidents occurring on MST property or on or near buses, improved inventory control, and a way to provide evidence in cases of insurance claims or driver complaints. They estimate that $70,000 in insurance claims had been saved as a result of the cameras. [192]</td></tr>
<tr><th colspan="2">Costs</th></tr>
<tr><td colspan="2">Unit Costs Data Examples</td></tr>
<tr><td colspan="2">Transit Management Center subsystem:
• Video Monitors for Security System: $1K-$3K
• Hardware for Security System: $10K-$15K
• Labor for Security System: $320K-$391K (per site for 3staff, annually)
Transit Vehicle On-Board subsystem:
• Security Package: $3.3K-$6K
Remote Location subsystem:
• Closed Circuit Television (CCTV) Camera: $2K-$5K
• Transit Status Information Sign: $4K-$8K</td></tr>
<tr><td colspan="2">Sample System Costs of ITS Deployments</td></tr>
<tr><td colspan="2">United States: Based on the results of a high-level scan on the use and adoption of advanced technology by public transit agencies, a video monitoring system costs approximately $10,000 per vehicle. However, the addition of other integrated systems such as automated passenger counters, event recorders, voice annunciators, and equipment health monitoring may only cost a few thousand dollars more.[193] For Bus Rapid Transit vehicles, costs for cameras in an on board video monitoring system may range from $8,000 to $10,000 per vehicle. Costs for a viewing station range from $10,000 to $15,000.[194]</td></tr>
</table>

Lessons Learned: Enhance overall transit safety and security programs by implementing video assessment systems.

Experience gained for the i-Florida model deployment along I-4 points to the need to build in video assessment procedures in security systems:

- **Incorporate diagnostic tools to identify and verify problems in the transmission of video in a transit bus security system.** The deployment of the LYNX Bus Security System occurred with few surprises. Operators reported receiving high-quality video images from buses while on the instrumented portion of I-4. However, they found it difficult to consistently verify that the system was operating correctly. Buses were on the instrumented portion of I-4 at regular but infrequent intervals. Operators had to periodically check the system to see if video was present as a method for gauging whether the system was working.
- **Beware of rapid advances in video communications technologies while considering the deployment of a bus security system.** The rapid advance of broadband communications technology has meant that this project, which was a cutting-edge application in 2003 when it was first considered, is no longer cutting-edge.

Florida DOT (FDOT) reported that the video transmission worked well, when the system was operational. However, the system was rarely operational, as reported in the project's evaluation report, lacking the proper diagnostic and verification tools that would have enhanced the reliability of the system to attain the safety and security goals the system was meant to serve.[195]

Chapter 8 Transportation Management Centers

Source: ©thinkstockphotos.com/Kim Steele

Transportation management centers (TMCs), often called traffic management centers or traffic operations centers (TOCs), coordinate ITS operations. TMCs can be owned or operated by a single transportation agency or multiple agencies and perform an array of functions including data acquisition, command and control, computing, and communications for many types of ITS applications.

TMCs are integral to a variety of management and operations strategies discussed in the remainder of this report: traffic surveillance, traffic incident management, emergency management, electronic payment and pricing, traveler information, and information management. While some of these strategies can be implemented in a stand-alone manner, others cannot, and each is enhanced through participation in a TMC. Careful planning is needed to gain the best performance through participation in a TMC. For example, TMCs provide an opportunity for centralized collection of data collected by ITS; however, TMC performance requirements are necessary during archived data management systems development for the successful development of such a system.

Coordination through a TMC can also improve the performance of the various strategies discussed earlier in this report. TMCs are often the venue for the instantaneous

Categories

Temporary TMC

- Seasonal
- Special Events
- Work Zones

Permanent TMC

- Freeway
- Arterial
- Transit
- Rural
- Multi-Agency/Co-located

communication and coordination among various transportation organizations that enable improved system performance. For example, inclusion of road weather management personnel in TMC operations can facilitate the implementation of a variety of traffic management strategies, in addition to snow and ice control, to mitigate the impact of inclement weather.

TMCs can be operated under several different scenarios. TMCs operated by a single agency have the simplest model focusing resources on agency-specific goals, coordination requirements, and explicit performance measures. Joint TMCs, however, are more complex. Joint operation of TMCs by multiple agencies complicates the task of TMC stakeholders and decision-makers charged with developing realistic planning and performance measures needed to rationalize TMC investments.

To date, most evaluation efforts that discuss TMC operations focus on specific programs such as incident management, emergency management, or traffic control. Since evaluation data that explicitly quantifies the impacts of integrated systems is limited, evaluators charged with determining the potential impacts of these deployments typically rely on estimation, simulation, and surveying techniques to approximate system impacts.[196] Reports also include lessons learned to help improve operational procedures, strategies, and policies.

Findings

As of July 2011, there were 118 evaluation summaries of Transportation Management Center applications in the Knowledge Resource databases, as shown in Figure 8-1. The Transportation Management Center category with the largest number of summaries is Permanent TMCs, as shown in Figure 8-2.

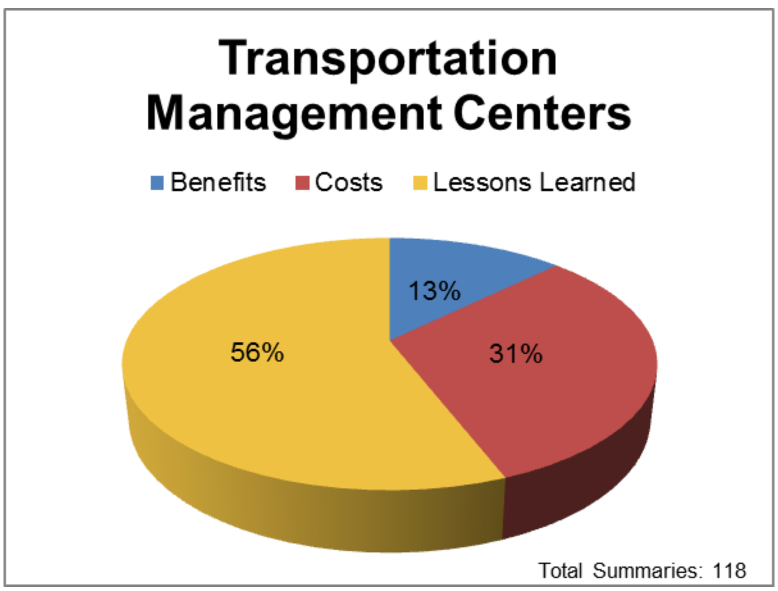


Figure 8-1. Transportation Management Center Summaries in the Knowledge Resources

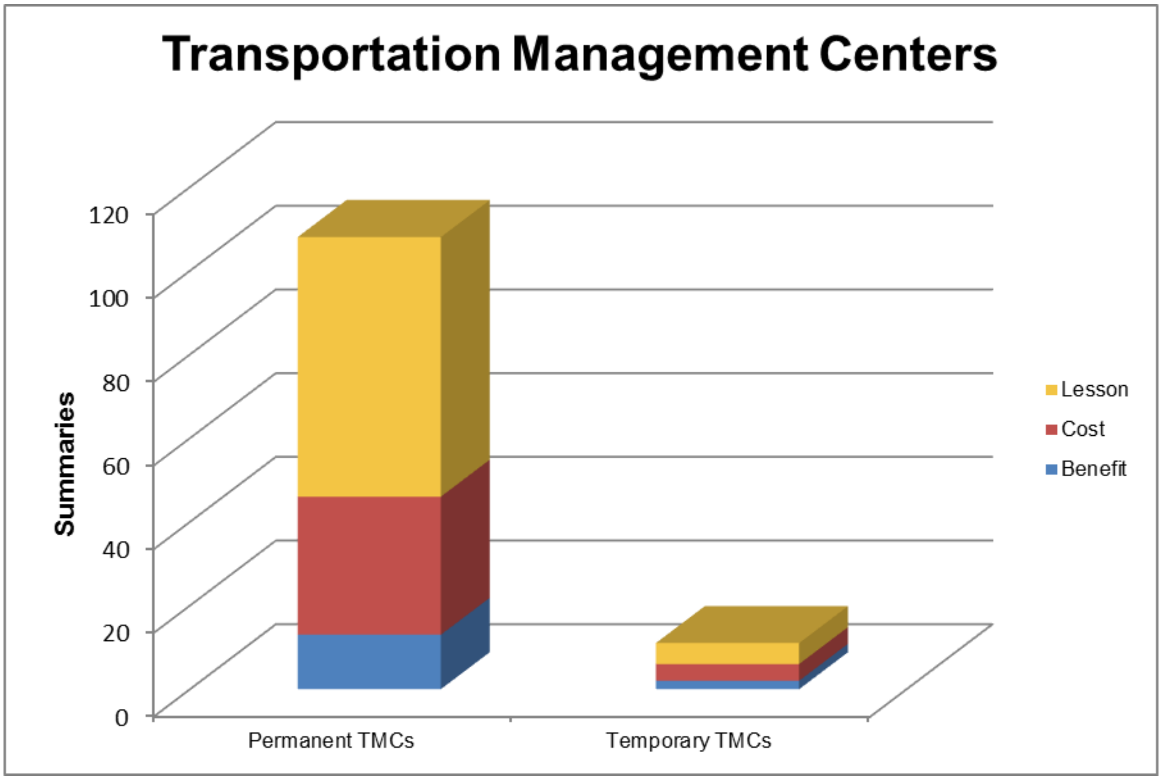


Figure 8-2. Summaries in the Knowledge Resources by Transportation Management Center Category

Benefits

A TMC integrates a variety of ITS applications to facilitate the coordination of information and services within the transportation system. Some of these applications perform more effectively because they are supported by other applications within a TMC. As such, while it is difficult to isolate the impacts of a TMC and evaluate them using explicit performance measures, experts agree that without the enhanced operational coordination that a TMC offers, the result would be increased congestion, reduced traffic safety, and noteworthy inconvenience to the traveling public.

A TMC can be implemented as either a virtual system accessible via remote device(s) or a physical system where single or multiple stakeholder operators are located in a permanent structure and have centralized access to multiple applications. Co-locating stakeholder operators can improve interagency coordination and communications resulting in improved efficiency and productivity throughout the transportation network. For example, if one operator's system experiences failures, other operators may be able to implement mitigation responses to ease the impacts on the traveling public.

Overall, the benefits of a TMC vary greatly depending on its purpose, configuration, service responsibilities, performance, and level of integration. Integrated transportation management systems facilitated by a TMC have the potential to produce the following benefits:

- Improved traffic management, advisory strategies, and control actions
- Improved timeliness and accuracy of information provided to the traveling public

- Increased efficiency of maintenance operations
- More effective use of personnel and resources
- Enhanced institutional, procedural, and operational integration and coordination[197]

Costs

The cost of TMCs can vary greatly. Primary cost drivers include the size of the facility, the number of agencies present, and the number of functions performed by the facility.[198] Planners typically examine the following cost categories to help assure costs are accounted for early and budgets can be adequately funded.

TMC annual O&M costs can range from $50,000 to $1.8 million per year.

TMC facilities, communications, and hardware

The cost of a TMC can depend on the size and complexity of building construction, number of agencies housed, and functionality supported. As illustrated in Figure 8-3, the capital cost of physical components can range from $1.8 million to $11.0 million per facility,[199] and have annual operations and maintenance (O&M) costs that range from $50,000 to $1.8 million per year.[200] The higher costs reflect the complexity of a large facility that supports multiple agencies and integrates multiple functions. The lower costs are for a smaller facility that supports a single agency or agency function. Other cost drivers for TMC include: central hardware and software systems, telecommunications, labor (staffing), and operations and maintenance.

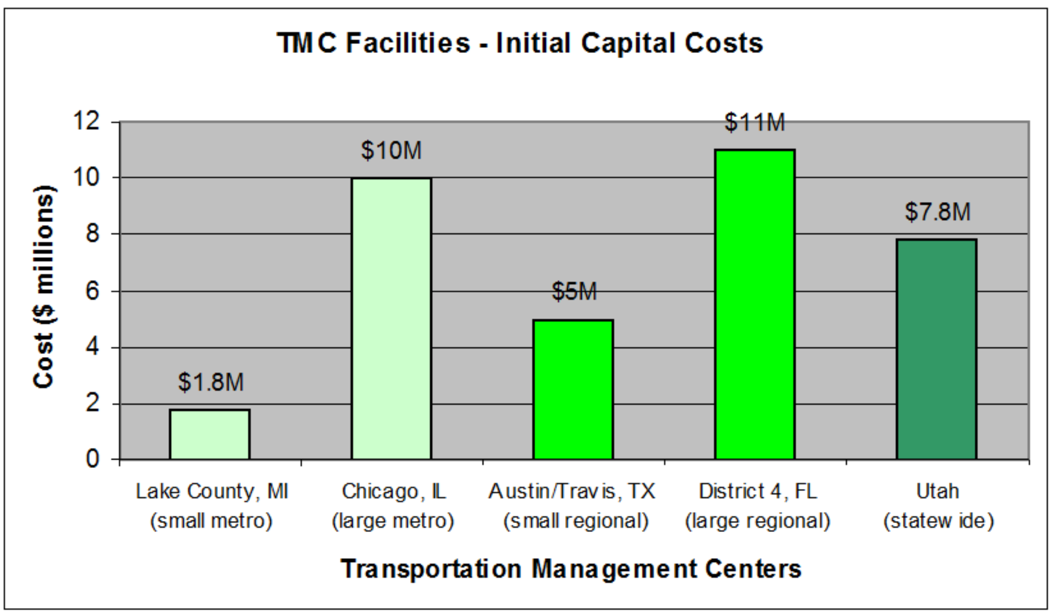


Figure 8-3. TMC Initial Capital Costs

Deployment

Figure 8-4 and Figure 8-5 show the functional capabilities of TMCs operated by freeway and arterial management agencies. The results are based on a 2010 survey of 122 freeway management agencies and 290 arterial management agencies. Capabilities reported by more than half of both types of TMC include incident management, dissemination of data to travelers and other agencies, network surveillance and data collection, as well as traffic management for special events and evacuation. Incident response dispatch and management of work zones were also important functions of freeway TMCs. Emergency response functions in the form of evacuation management and emergency services traffic control are next in frequency and were reported by more than a third of TMCs. In all, the surveyed TMCs perform one or more of 16 different functions on freeways. Traffic signal coordination or control, special event traffic management, and roadway surveillance were reported by more than 60 percent of the arterial TMCs. In general, the pattern of functions is similar to that for freeway TMCs.[201]

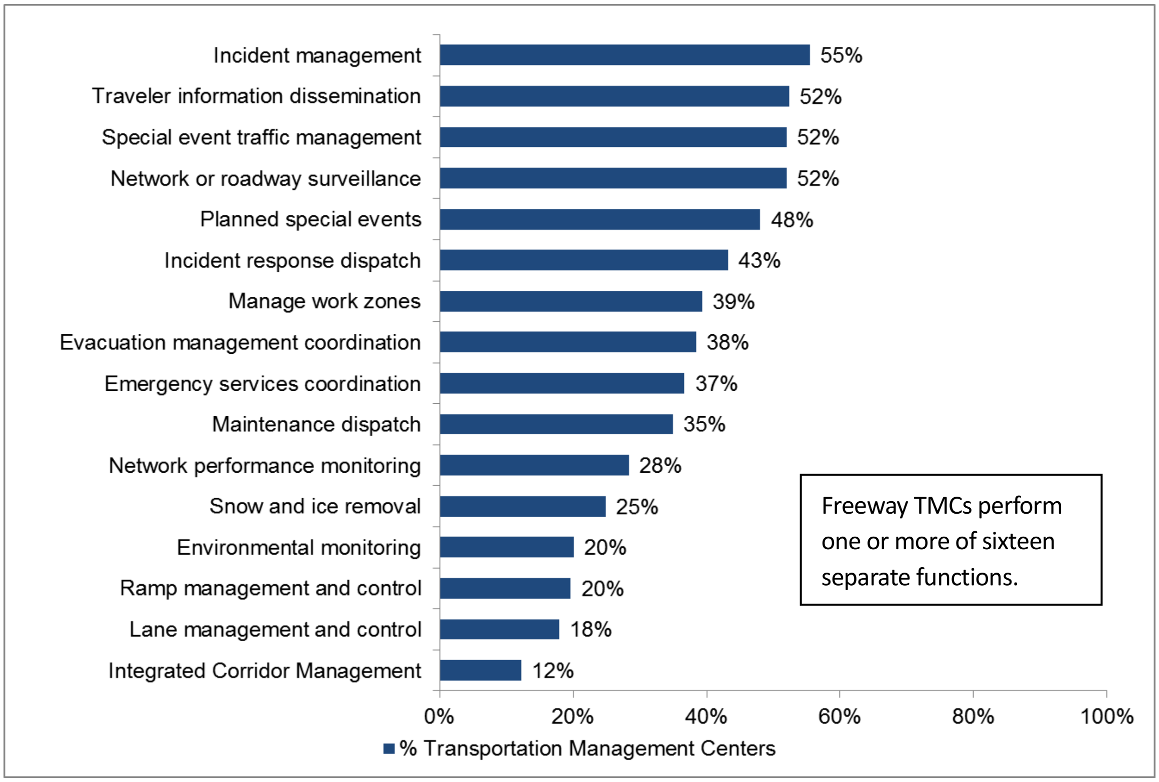


Figure 8-4. Functions Performed by Transportation Management Centers on Freeways

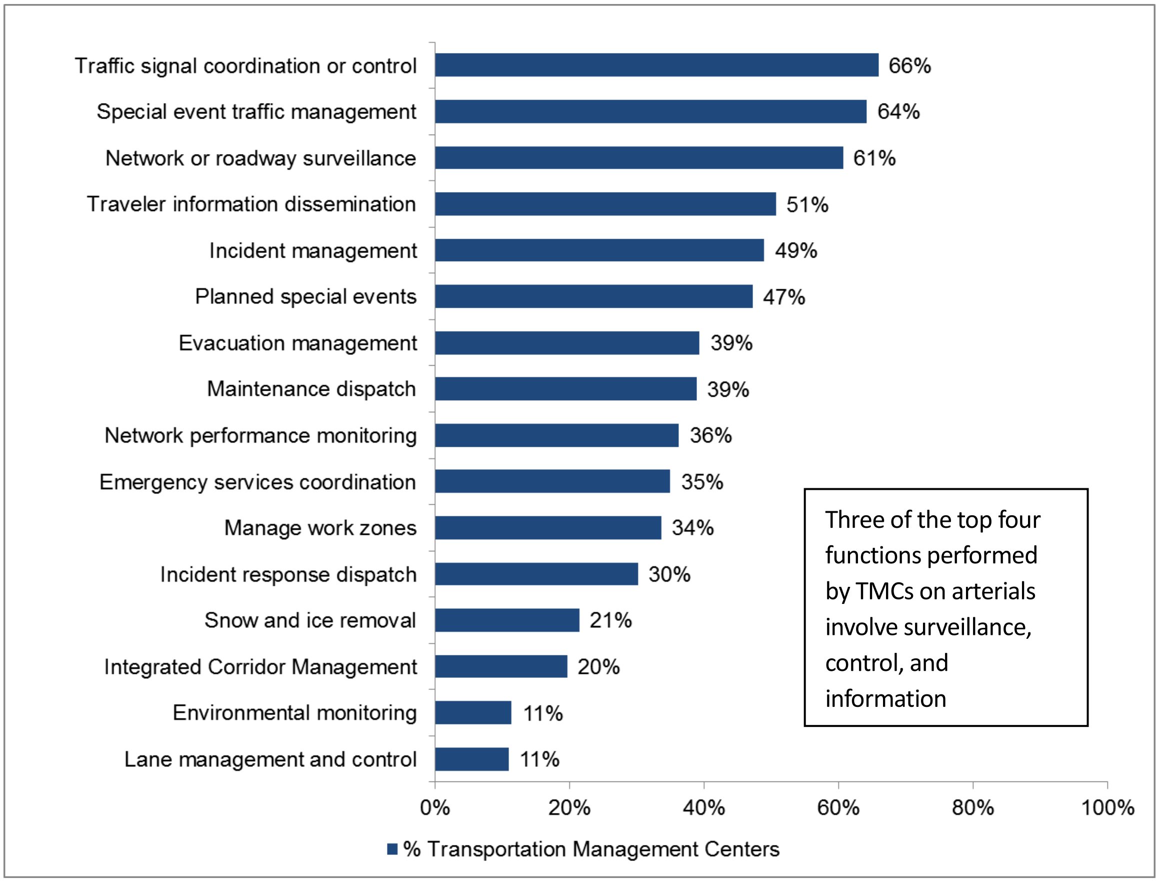


Figure 8-5. Functions Performed by Transportation Management Centers on Arterials

Selected Highlights from the ITS Knowledge Resources on Transportation Management Centers

Transportation Management Centers

TMCs are physical facilities used to coordinate the activities of ITS operations. They can be owned or operated by a single agency or multiple transportation agencies and perform an array of functions including data acquisition, command and control, computing, and communications for many types of ITS applications.

Transportation Management Center	
Benefits	
ITS Goals	**Selected Findings**
Mobility	New York State DOT TMC operators and New York State Thruway Authority staff were able to reduce traffic queues by 50 percent using vehicle probe data available through the I-95 Corridor Coalition.[202]

Transportation Management Center	
Mobility	The Miami-Dade traffic incident management team has had continued success by reducing the average time to clear blocked lanes to 32 minutes, which is the equivalent of an 11 percent reduction in comparison to the previous fiscal year (2008), and by 36 percent from the baseline of 50 minutes.[203]
Productivity	In Salt Lake City, Utah, staff meteorologists stationed at a TOC provided detailed weather forecast data to winter maintenance personnel, reducing costs for snow and ice control activities, and yielding a benefit-cost ratio of 10:1.[204]
Efficiency	In Sacramento, the regional TMC helps integrate weather information integration strategies and issues on-time alerts 88.9 percent of time.[205]

Costs

Unit Costs Data Examples

Transportation Management Center subsystem:

- Basic Facilities and Communications for Large Area: $4,606K-$10,529K
- Basic Facilities and Communications for Medium Area: $4596K
- Basic Facilities and Communications for Small Area: $4021K
- Video Monitors, Wall for Incident Detection: $35K-$63K
- Software for Incident Detection: $85K-$104K
- Labor for Incident Detection: $815K-$997K for multiple staff (annually)
- Hardware, Software for Traffic Surveillance: $134K-$164K
- Integration for Traffic Surveillance: $224K-$273K
- Software for Traffic Information Dissemination: $18K-$22K
- Integration for Traffic Information Dissemination: $85K-$103K

Sample System Costs of ITS Deployments

TMC facility, software, telecommunications, labor, and operations maintenance costs vary widely depending on the scale and scope of the TMC, as shown by the following examples:

Illinois: Facility development: $1.8 million for the Lake County, Illinois TMC for advanced signal control) [206]

Florida: $11 million for the Florida DOT District IV TMC, shared by four agencies, and supports incident and emergency management, traffic surveillance, interactive traveler information services, and transit management.[207]

Washington: The Spokane Regional Traffic Management Center (SRTMC) was created as a regional partnership to provide area-wide ITS coverage during peak travel periods, to monitor and respond to incidents, and to share data. The Regional Traffic Management Center Enhancements project, implemented to integrate signal systems between jurisdictions and to improve incident response and management, cost $1,238,679.[208]

Colorado: The Colorado Transportation Management Center (CTMC) Integration Project was the result of FY01 congressionally designated funds intended to improve transportation efficiency; promote safety; increase traffic flow; reduce emissions; improve traveler information; enhance alternate modes; promote tourism and build on existing ITS. Total project investment was $6,753,160.[209]

Lessons learned: Assess security risks, threats, vulnerabilities, and identify countermeasures to ensure operations of Transportation Management Centers.

As part of the iFlorida Model Deployment, the Florida Department of Transportation (FDOT) conducted a vulnerability assessment for the District 5 (D5) Regional Traffic Management Center (RTMC). The purpose of the assessment was to identify potential weaknesses at the FDOT D5 RTMC and to suggest counter measures that would eliminate or lessen the impact of vulnerabilities. Key countermeasures, which are likely to apply to many other TMCs, are:

- **Include standoff distances that help maintain a clear space around the TMC building.** The main vulnerabilities observed during the vulnerability assessment were related to the inability to maintain a clear space around the building.
- **Develop and enforce security check procedures for persons entering the TMC.** Vulnerabilities related to the failure for some staff to follow security procedures must not be overlooked. For example, people sometimes entered the TMC by tailgating authorized personnel and people without an appropriate badge displayed were seldom challenged.
- **Verify and ensure that security patches are applied to TMC servers and password protection is used**. Three common problems were discovered during the cyber-security review of the D5 TMC. First, a number of servers were identified that did not have the most recent security patches installed. Second, several servers were identified as running unnecessary services. Since each service running on a server provides a potential entry point for cyber-attack, the fewer services running the better. Third, some software systems were installed using the default password and the password had not been updated. Since default passwords are well known, they should be changed to prevent unauthorized users from accessing a system. A second cyber-security review indicated that FDOT had corrected most of the vulnerabilities discovered during the initial cyber-security review. [210]

Lessons learned: Consider including in-house ITS expertise and task order project configuration for complex ITS projects.

Colorado DOT (CDOT) believes the Colorado Traffic Management Center (CTMC) Integration Project was a success. Goals and objectives were met or surpassed. Deficiencies in ITS infrastructure, functionality, automation, information dissemination, data sharing; and amount, accuracy and timeliness of data were addressed. The project dovetailed with related activities but most importantly was an important building block and catalyst for the Colorado ITS program. Momentum generated by federal funds has allowed CDOT to develop order-of-magnitude improvements in devices; data collection and dissemination; communications; interfaces with partners; and operations, maintenance and program management. Lessons learned from the implementation of the CTMC Integration Project include the following:

- **Include in-house expertise in ITS specialty areas for successful ITS projects.** CDOT believes that having current levels of in-house expertise throughout the duration of the ITS Program would have been beneficial and would have lessened or avoided difficulties at the outset. Addition of these skill sets ultimately allowed CDOT to subdivide technical responsibilities for completion of multiple task orders between several capable and knowledgeable individuals. CDOT believes in-house skills in ITS-related technical areas are an indispensable resource definitely required for success in complex ITS projects.
- **Consider task order (or phased) project configuration.** Although task order project configuration is not necessarily more efficient for a contractor (if one is involved), it provides a better mechanism for the owner to track progress and control schedules and costs. Task order and/or phased software iteration configuration in the CTMC project provided much better control than did previous ITS projects that dictated delivery of one large product at the end of the schedule.
- **Ensure open communications to ensure project success.** Frequent communications engender trust and are critical to success in a complex systems engineering project environment.
- **Consider opportunities to share resources with local agencies.** For example, on other projects including local agency participation, the agency contributed to the project in terms of purchasing, in-kind services, assistance in obtaining related services or contracts, or the provision of ancillary materials. [211]

Chapter 9 Traffic Incident Management

Source: ©iStockphoto.com/slobo

Managing traffic incidents is a proven strategy for addressing significant portions of the Nation's traffic congestion problems. Approximately 25 percent of all delay is the result of incidents on roadways.[212] Traffic crashes are the most time-consuming of these incidents, but the more numerous cases of stalled vehicles, roadway debris, and other incidents also contribute significantly to the problem.

Traffic incident management programs are widely deployed in metropolitan areas and are being extended into rural areas through a growing number of statewide programs. These programs make use of a variety of ITS technologies to successfully detect, manage, and clear traffic incidents; improving safety for travelers by reducing the risk of secondary crashes; and reducing time lost and fuel wasted in traffic backups.

These programs also utilize ITS deployed for traveler information, freeway management, and arterial roadway management, and increasingly coordinate their activities with Transportation Management Centers, the police, and emergency medical services.

Categories

Surveillance and Detection

- Detectors
- Imaging/Video
- Wireless Enhanced 9-1-1
- Mayday/Automated Collision Notification
- Call Boxes
- Traveler Reported

Mobilization and Response

- Automatic Vehicle Location/Computer-Aided Dispatch
- Response Routing
- Service Patrols

Information Dissemination

- Dynamic Message Signs
- Highway Advisory Radio

Clearance and Recovery

- Investigation
- Imaging/Video
- Temporary Traffic Control

In 2008-2009, the Miami-Dade traffic incident management team reduced the average roadway clearance time by 11 percent from the previous year.

A variety of surveillance and detection technologies can help detect incidents quickly including inductive loop, microwave, acoustic vehicle detectors, and camera systems providing video surveillance of roadways monitored by operators. Information from wireless enhanced 9-1-1 systems, Mayday and automated collision notification (ACN) systems, as well as roadside call boxes can also help incident management personnel identify incidents quickly. Mobilization and response may include automated vehicle location (AVL) and computer-aided dispatch (CAD) systems, as well as response routing systems to help incident response teams arrive swiftly. Service patrols, which preceded the emergence of ITS technologies, are now frequently incorporated into traffic incident management programs. The patrol vehicles and staff, supported by an array of other ITS components, enable significant reductions in the time to respond to and clear incidents.

Several components of incident management systems help travelers safely negotiate travel around incidents on the roadway and facilitate the rapid and safe clearance of incidents and reopening of travel lanes. In some locations, incident management personnel can directly post incident-related information to roadside traveler information devices such as dynamic message signs (DMS) or highway advisory radio (HAR). On-site or transportation management center-based personnel can also relay messages to traveler information, freeway management, or arterial management systems, providing incident information to travelers via additional means including 511 systems and traveler information Web sites. Several technologies are available to speed the investigation of incident scenes and record necessary information for later analysis. Temporary traffic control devices help ensure the safety of incident responders and provide for the safe travel of vehicles around incident sites.

Traffic incident management programs are typically implemented concurrently with freeway management systems, but it is important to keep in mind that arterials can be included in incident management programs as well, and are increasingly deploying technologies that support incident management. For example, the percentage of arterial management agencies that deployed video imaging detector systems (VIDS) and Dynamic Message Systems (DMS) from 2007 to 2010 more than doubled.[213]

Many of the techniques used to address traffic incidents are also used to manage operations during planned special events, which the freeway management chapter discusses in more detail. In addition, the emergency management chapter discusses ITS applied to larger scale emergencies such as hazardous materials incidents and evacuations for man-made or natural disasters.

Findings

As of July 2011, there were 168 evaluation summaries of Traffic Incident Management applications in the Knowledge Resource databases, as shown in Figure 9-1. The Traffic Incident Management category with the largest number of summaries is Mobilization and Response (98 summaries), followed by Surveillance and Detection (69 summaries), Information Dissemination (66 summaries), and Clearance and Recovery (18 summaries), as shown in Figure 9-2.

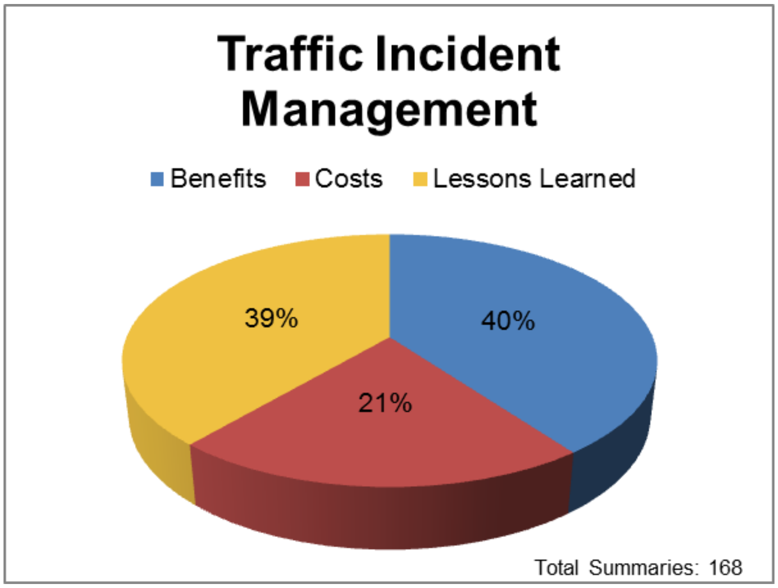


Figure 9-1. Traffic Incident Management Summaries in the Knowledge Resources

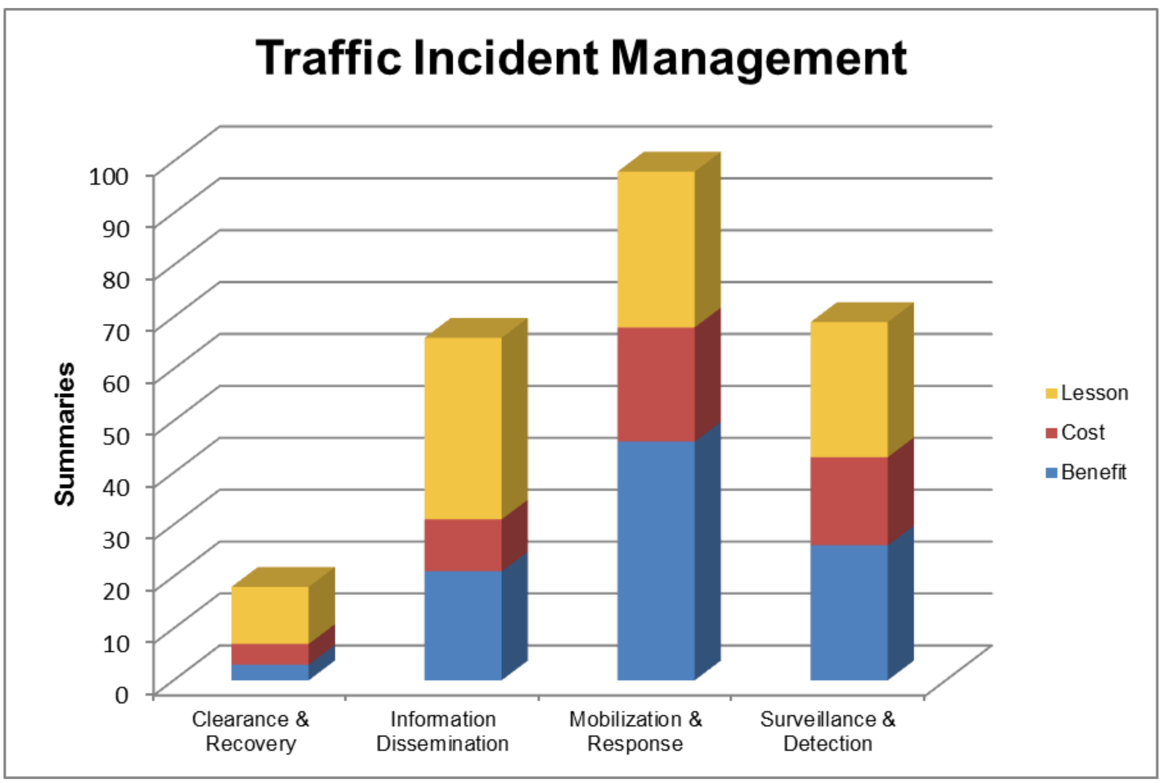


Figure 9-2. Summaries in the Knowledge Resources by Traffic Incident Management Category

Benefits

Traffic incident management programs have demonstrated success under each of the goals of ITS, as summarized in Table 9-1. The most significant finding may be that incident management programs have the ability to significantly reduce the duration of traffic incidents. For example, the service patrol in Hampton Roads, Virginia, decreased the average incident duration by 70.7 percent[214] and the service patrol in Northern Virginia on average decreased incident duration by 15.6 percent for crashes, 25 percent for roadway debris, and 17.2 percent for breakdowns.[215] Figure 9-3 shows the average reductions in duration achieved by service patrols across different states.[216] Reducing incident duration improves safety by reducing the likelihood of secondary incidents, supporting the mobility and economic productivity of travelers by lowering incident-related delay and associated costs, and impacting the environment through reduced fuel consumption by idling vehicles.

Table 9-1. Traffic Incident Management Benefits Summary

Traffic Incident Management Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Traffic Incident Management	●	●	●	●	●	●

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Service patrols are among the most effective tools available in incident management for reducing incident duration, and they are perhaps the most prominent and widely evaluated component of traffic incident management programs. Reports assessing customer satisfaction with the programs are unanimously positive.

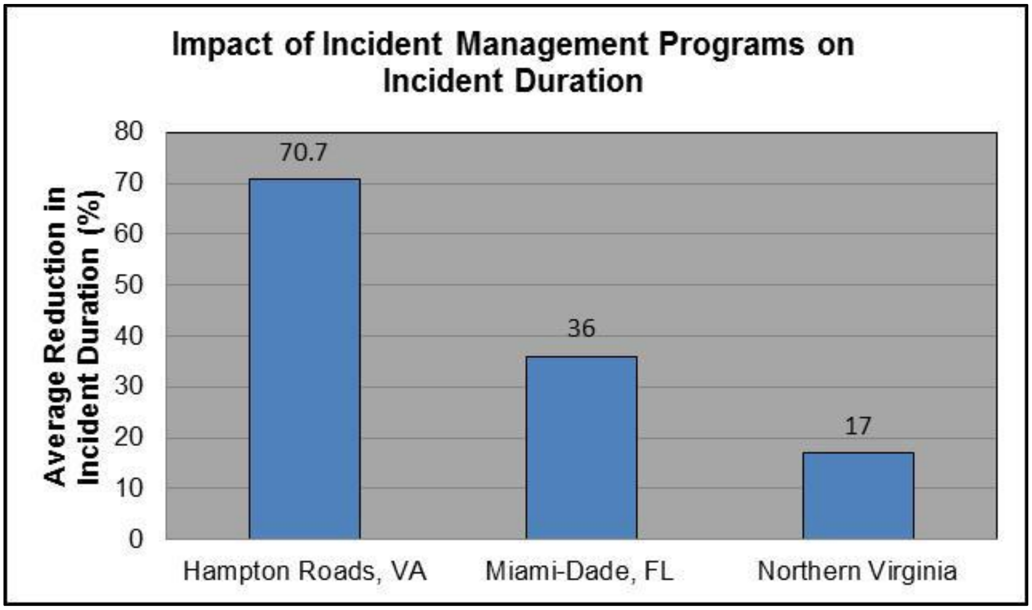


Figure 9-3. Impact of Incident Management Programs on Incident Duration.

Costs

State DOTs can spend between $5.6 million and $13.6 million per year on service patrols. Regional service patrols cost often from $1.5 million to $2.5 million per year. For large, densely populated areas such as Los Angeles, California, the cost can be upwards of $20.5 million per year, in contrast to less populated areas, such as in the Salt Lake City, Utah area in which the cost is as low as $0.4 million. The cost of service patrols vary considerably depending on population, number of freeway miles covered, and the types and hours of services provided.[217]

Costs for regional service patrols are often in the range from $1.5 million to $2.5 million per year.

Benefit-Cost Studies

Safety data demonstrate that an important safety outcome of service patrols is the reduction of secondary crash risk, particularly because secondary incidents are frequently more severe than primary incidents, and have a higher percentage of fatal and Property Damage Only (PDO) crashes than primary crashes. An analysis of safety data in the St. Louis metro area from 2000 to 2008 found that the ability of the St. Louis Motorist Assist program to lower secondary crashes annually by 1,082 was a key factor in its highly positive benefit-cost ratio of 38.25:1.[218] In view of these results, it is not surprising that 41 states have deployed service patrols and expanded coverage to nearly 50 percent of freeway miles in these states.

Deployment

The use of ITS technologies to improve traffic incident management is common in major metropolitan areas. Figure 9-4 shows trends for the deployment of key traffic incident management technologies based on changes in coverage of surveillance technologies on freeways and arterial streets from 1997 to 2010. These data are from a survey of major metropolitan areas conducted over this period. Surveillance of arterial streets lags behind that of freeways, although some cities, such as St. Louis, have deployed arterial service patrols in addition to their freeway service patrols.

Service patrols cover almost half (48 percent) of freeway miles in major metropolitan areas.

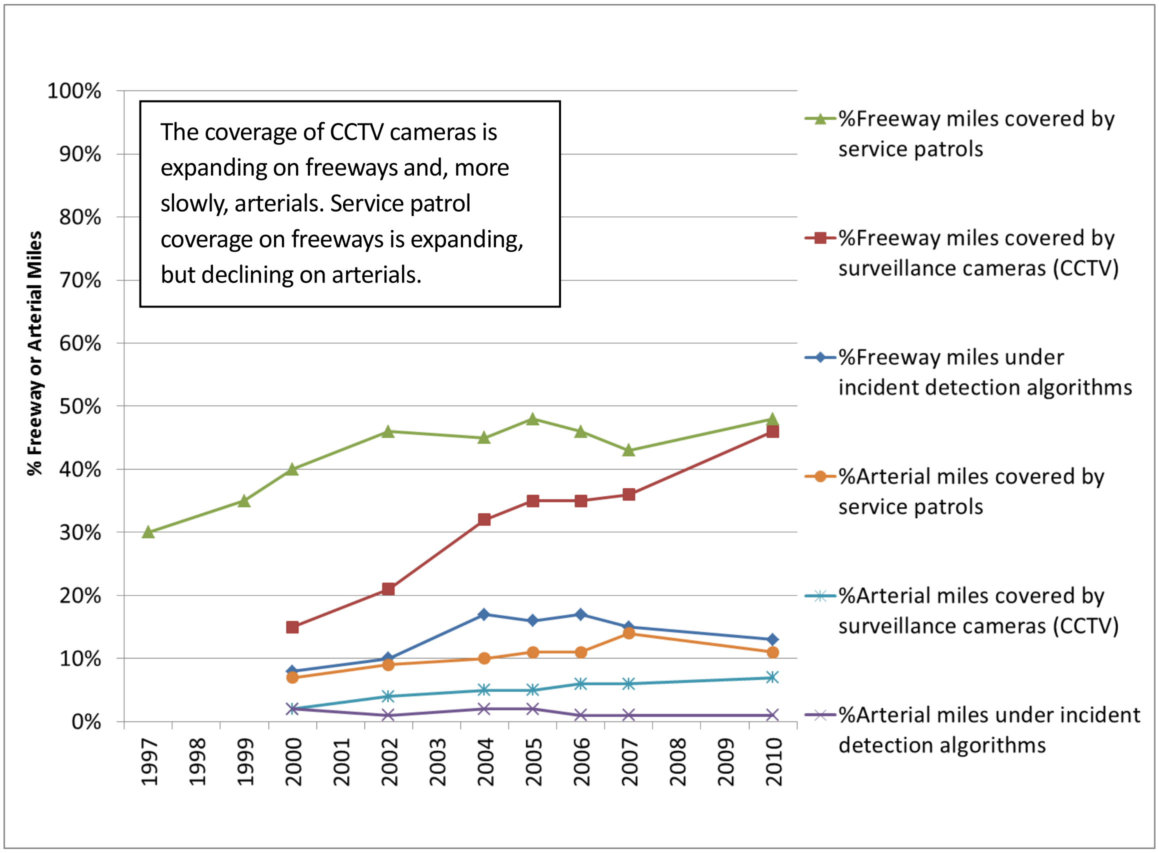


Figure 9-4. Deployment Trends for ITS Technology on Freeways and Arterials Supporting Incident Management

Selected Highlights from the ITS Knowledge Resources on Traffic Incident Management

Surveillance and Detection

A variety of surveillance and detection technologies can help detect incidents quickly including inductive loop or acoustic vehicle detectors, and camera systems that provide frequent still images or full-motion video. Information from wireless 9-1-1 systems, Mayday, ACN systems, and roadside call boxes help incident management personnel identify incidents quickly.

Surveillance and Detection	
Deployment	
Traffic surveillance cameras monitor nearly 50 percent of freeway miles, and approximately 8 percent of arterial miles in the country's largest metropolitan areas.	
Benefits	
ITS Goals	**Selected Findings**
Customer Satisfaction	Motorists who had received assistance from the Arterial Service Patrol in Missouri overwhelmingly responded positively to a mail-in survey, reporting that they found the program to be valuable and effective, and the operators to be knowledgeable, courteous, and professional.[219]
Costs	
Unit Costs Data Examples	
Roadside Detection subsystem: • Inductive Loops on Corridor: $2K-$6K • Remote Traffic Microwave Sensor on Corridor: $8K-$11K per sensor • Closed Circuit Television (CCTV) Video Camera: $8K-$16K Transportation Management Center subsystem: • Software for Incident Detection: $85K-$104K • Labor for Incident Detection: $815K-$997K for multiple staff (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K	
Sample System Costs of ITS Deployments	
New Mexico: The new traffic management system in Espanola implemented in June 2006 consists of eight signalized intersections and video detection equipment, a fiber optic communication system, a wireless communication system, traffic management system hardware and software, and system integration. The system connects to a traffic operations center located at the New Mexico DOT general office in Santa Fe. The cost of deployment was $862,279.[220]	

Lessons Learned: Be aware of the potential of ITS surveillance and detection systems to support law enforcement.

The Minnesota Traveler Information Guidance and Emergency Routing (TIGER) project sought to improve mobility and safety along the Interstate-94 (I-94)/Highway 10 corridor by deploying ITS technologies for traffic surveillance, incident management, traffic signal control, traveler information systems, and interconnected traffic management centers. Among the findings of the preliminary evaluation of the TIGER project was the unexpected benefit that ITS surveillance technologies produced for law enforcement. In one case, patrol vehicles were in pursuit of a high-speed motorcycle traveling along the I-94 corridor. The patrol vehicles were unable to keep pace with the motorcycle, but the surveillance cameras tracked the suspect vehicle, eventually finding an opportunity for patrol cars to be prepositioned in time to successfully apprehend the suspect. In the second example, a patrol officer pulled his vehicle over to assist a disabled vehicle on the roadside. Finding that the disabled vehicle was not occupied, the officer determined that the vehicle had been stolen. In coordination with the dispatcher, the officer checked the camera feed from a nearby interchange and sighted the presence of individuals walking toward a truck stop. The dispatcher monitored the individuals, who were attempting to get gas to refuel the car, until another patrol officer arrived and the suspects were arrested.[221]

Mobilization and Response

Mobilization and response may include AVL and CAD systems, as well as response routing systems, to help incident response teams arrive swiftly.

Mobilization and Response	
Deployment	
In the country's largest metropolitan areas, nearly 80 percent of emergency vehicles (fire, rescue, and/or emergency medical services) are under AVL/CAD used in fleet management. The percentage of emergency vehicles with navigation capability has expanded from 3 percent in 2000 to more than 40 percent in 2010.	
Benefits	
ITS Goals	**Selected Findings**
Safety	A traffic management system implemented in June 2006 in Espanola, New Mexico resulted in a 27.5 percent reduction in total crashes compared with previous years.[222]
Mobility	***Summary Finding***: Traffic incident management programs have reported reductions in incident duration from 15 to 70 percent.[223]
Productivity	***Summary Finding***: Freeway service patrols in Hampton Roads, Virginia and St. Louis, Missouri realized annual savings in motorist delay of $455,856, and in congestion costs of $1,130,000, respectively, and an arterial service patrol in St. Louis County reduced congestion costs per year by $1,034,000.[224]
Customer Satisfaction	***Summary Finding***: Service patrols are well-received by the public. Operating agencies often receive thank you letters from grateful motorists assisted by service patrols.[225]

Mobilization and Response
Costs
Unit Costs Data Examples
Transportation Management Center subsystem: • Labor for Incident Response: $116K-$142K (annually)
Sample System Costs of ITS Deployments
Missouri: Motorist Assist is the freeway service patrol that covers all freeway segments in the St. Louis metro area, and was one of the state's first ITS freeway management programs to use cameras, communication equipment, message boards and traffic sensors. In FY08/09, Motorist Assist used 12 trucks and operators per shift to patrol 160 center lane miles every day from 5:00 AM to 7:30 PM, patrolling over a million miles, and make over 31,000 stops each year, with operating costs of **$2,015,378** in 2008 and **$2,075,839** in 2009.[226] **Virginia**: The Northern Virginia Safety Service Patrol (NOVA SSP) provides service for approximately 198 centerline miles of the NOVA freeway system with a one vehicle per one route ratio. The NOVA SSP has one manager and 28 patrollers and supervisors, and deploys 35 patrol vehicles, 6 pickup trucks, 2 flatbeds, 2 small self-loading wreckers, 2 large wreckers, and 4 incident command vehicles. The annual operating cost is **$1,193,511** (for FY03/04).[227]
Benefit-Cost Studies
Virginia: The benefit-cost ratio for the safety service patrol (SSP) in Hampton Roads, Virginia was 4.71:1. A Return on Investment (ROI) study of the SSP in Hampton Roads, Virginia analyzed 33,877 incidents that had occurred during the evaluation period. The study includes a comparison of the average duration for incidents that occurred on SSP routes to those of similar incidents and conditions that had occurred on non-SSP routes.[228] **Missouri:** The Missouri DOT and St. Louis County deployed an arterial service patrol to accommodate increases in traffic volume on arterials during the "New I-64 Project" in which different segments of Interstate-64 were fully closed. An interim evaluation of the service estimated the benefit-cost ratio as 8.3:1, demonstrating the value of using arterial service patrols as part of a mobility strategy for major construction projects.[229]

Information Dissemination

Information dissemination systems help travelers navigate safely around incidents. Incident management personnel can provide incident-related information directly to travelers.

Information Dissemination
Deployment
Most of the nation's traffic incident management agencies use roadside systems to notify travelers of traffic incidents on both freeways and arterial streets. Virtually all of the surveyed traffic incident management agencies in the country's largest metropolitan areas disseminate traffic incident information on freeways using DMS, and almost two-thirds use HAR to do so.

Information Dissemination
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K • Portable Dynamic Message Sign: $15.9K-$21K • Highway Advisory Radio: $15K-$36K Transportation Management Center subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Labor for Traffic Information Dissemination: $116K-$142K (annually) Roadside Telecommunications subsystem: • Conduit Design and Installation – Corridor: $52K-$77K • Fiber Optic Cable Installation: $21K-$54K

Clearance and Recovery

Several technologies are available to speed the investigation of incident scenes and record necessary information for later analysis. Temporary traffic control devices help ensure the safety of incident responders and provide for the safe travel of vehicles around the incident site.

Clearance and Recovery
Deployment
Fifty-four (54) percent of law enforcement agencies in the country's largest metropolitan areas use automated measuring equipment to investigate major traffic incidents.
Costs
Unit Costs Data Examples
Transportation Management Center subsystem: • Automated Incident Investigation System: $12K

Lessons Learned: Follow agency protocol for software development and release when designing and developing an Integrated Incident Management System.

Since March 2003, an Integrated Incident Management System (IIMS) has been operating in all five boroughs of New York City (NYC). The IIMS facilitates information sharing and coordination among responders and traffic agencies for the purpose of increasing the speed of incident response and recovery and reducing secondary crash risks. The IIMS allows first responders to send pictures and incident information from the scene to secondary responders (e.g., Departments of Transportation and Sanitation, Police, and Fire and Rescue). First responders have "mobile units" in their vehicles consisting of an integrated system with a computer, touch screen display, keyboard, digital camera and digital imaging systems. The responder transmits images and information from the scene to incident management centers. These centers have stored information from Geographic Information Systems (GIS) and satellite imagery that provide nearly instant, detailed information about the location. The centers analyze the incident information and then assign and dispatch resources to the scene. The centers can make faster and more accurate decisions in regards to resource allocation, leading to faster clearance times. When developing this complex, integrated system, the project developers followed the model used by the lead agency, the NYSDOT, which employs a two-tiered model for software development that involves a testing stage and a production stage. Additional capabilities and features are added during the testing stage. Following the model used by an agency helps to ensure that the system will meet agency standards and operating requirements. This practice will also help to facilitate the system being mainstreamed as an agency service that receives operations and maintenance support.[230]

Chapter 10 Emergency Management

Source: ©iStockphoto.com/tillsonburg

In the United States, there are over 400 tropical storms, hurricanes, tornadoes, and hazardous materials (HAZMAT) incidents that require evacuation each year. In order to improve safety and minimize loss of life, prompt action is required from multiple agencies before, during, and after each event. Responders must reach the scene, victims must be evacuated, and clearance and recovery resources must arrive on time. Smaller scale emergencies occur each day in communities across the nation, requiring emergency responders to travel quickly and safely to fires, traffic crashes, or crime scenes. ITS applications for emergency management aim to improve public safety by giving agencies the tools and equipment they need to plan for and implement response actions quickly and efficiently.

Safe and secure transport of HAZMAT includes vehicle tracking, roadside detection, driver authentication, and route planning. Vehicle-mounted hardware provides the capability to track HAZMAT shipments and support the notification of management centers when a shipment deviates from its intended route. Roadside detectors can monitor for the presence of hazardous shipments in sensitive areas and, if electronic tag information is available on the detected vehicle, confirm that the shipment is on the expected route. Driver authentication technology can confirm that the individual operating a HAZMAT vehicle is authorized to do so and report operation by unexpected drivers to public safety entities. ITS

Categories

Hazardous Materials Management

- Tracking
- Detection
- Driver Authentication
- Route Planning

Emergency Medical Services

- Advanced Automated Collision Notification
- Telemedicine

Response and Recovery

- Early Warning System
- Response Management
- Emergency Vehicle Signal Preemption
- Evacuation and Re-Entry Management
- Emergency Traveler Information

can also provide assistance to commercial vehicle operators via electronic route planning services, ensuring compliance with HAZMAT shipment restrictions along planned travel routes.[231]

Eighty percent of emergency management vehicles in major metropolitan areas operate under computer-aided dispatch.

Advanced automated collision notification (ACN) and telemedicine address the detection of and response to incidents such as vehicle collisions or other incidents requiring emergency responders. In rural areas, response time for emergency medical services is greater than in metropolitan areas, resulting in more severe consequences for those in need of medical assistance. Advanced ACN systems can notify emergency personnel and provide them with valuable information on the crash including location, crash characteristics, and possibly relevant medical information regarding the vehicle occupants. Telemedicine systems provide a link between responding ambulances and emergency medical facilities, enabling doctors to advise emergency medical personnel regarding treatment of patients en route to the hospital. ACN systems are also discussed in the collision notification chapter of this report.

A variety of sensors deployed on the transportation infrastructure can help provide an early warning system to detect large-scale emergencies including natural disasters (hurricanes, earthquakes, floods, blizzards, tsunamis, etc.) and technological and man-made disasters (hazardous materials incidents, nuclear power plant accidents, and acts of terrorism including nuclear, chemical, biological, and radiological weapons attacks). In the event of a large-scale emergency, ITS applications can assist with response management through services such as the tracking of emergency vehicle fleets using automated vehicle location (AVL) technology and two-way communications between emergency vehicles and dispatchers. When responding to emergencies of any scale, emergency vehicle signal preemption implemented through coordination with arterial management agencies, can speed the safe arrival of emergency responders on scene. Evacuation operations often require a coordinated emergency response involving multiple agencies, various emergency centers, and numerous response plans. Integration with traffic and transit management systems enables emergency information to be shared between public and private agencies and the traveling public. This communication and cooperation also enables the use of the variety of ITS information dissemination capabilities to provide emergency traveler information. The freeway management chapter discusses how lane management techniques such as reversible flow lanes are often used for evacuation during emergencies.

Improvements in the command and control of emergency management can lead to increased cooperation among agencies. An interoperable communications network and the use of common terminology between agencies can lead to more reliable and effective emergency operations. Studies of ITS deployed to enhance emergency response have shown the potential of these technologies to assist organizations in improving emergency response actions.

The Emergency Transportation Operations initiative, undertaken by the U.S. DOT's ITS Joint Program Office (JPO) and completed in 2008, supported the development of new of tools, techniques, technical guidance, and standards necessary for state and local agencies and their private sector partners to improve emergency management. Effective real-time management of transportation during major incidents results in more timely responses to highway and HAZMAT incidents, and shorter incident durations. This initiative aimed to improve the management of all forms of transportation emergencies through the application of ITS technologies, including in-vehicle communication and information systems that provide access to essential real-time data about incidents and transportation conditions on all routes throughout the affected region.[232] Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/eto.

The Federal Highway Administration (FHWA) produced a primer for emergency response managers and transportation officials entitled "Using Highways during Evacuation Operations for Events with Advance Notice." The primer serves as a guide for State and local planners on the lessons learned and best practices for maximizing the use of the highway network in emergency evacuations. A fundamental step recommended by the FHWA primer is to involve transportation subject matter experts and those with appropriate authorities in the evacuation planning process. In addition to lessons learned, the FHWA primer discusses transportation resources including ITS tools, traffic operations and incident management that can support emergency evacuations.[233]

Findings

As of July 2011, there were seventy-one evaluation summaries of Emergency Management applications in the Knowledge Resource databases, as shown in Figure 10-1. The Emergency Management category with the largest number of summaries is Response and Recovery, with 62 summaries, followed by Emergency Medical Services (seven summaries), and Hazardous Materials Management (five summaries), as shown in Figure 10-2.

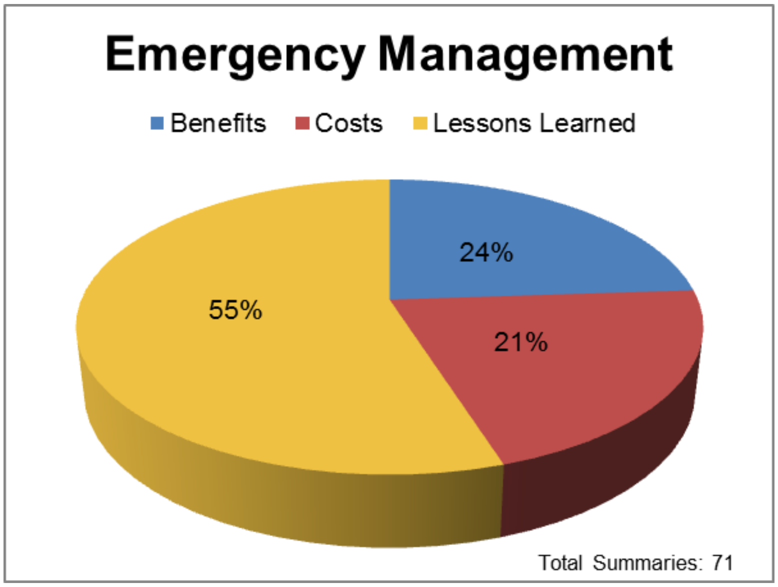


Figure 10-1. Emergency Management Summaries in the Knowledge Resources

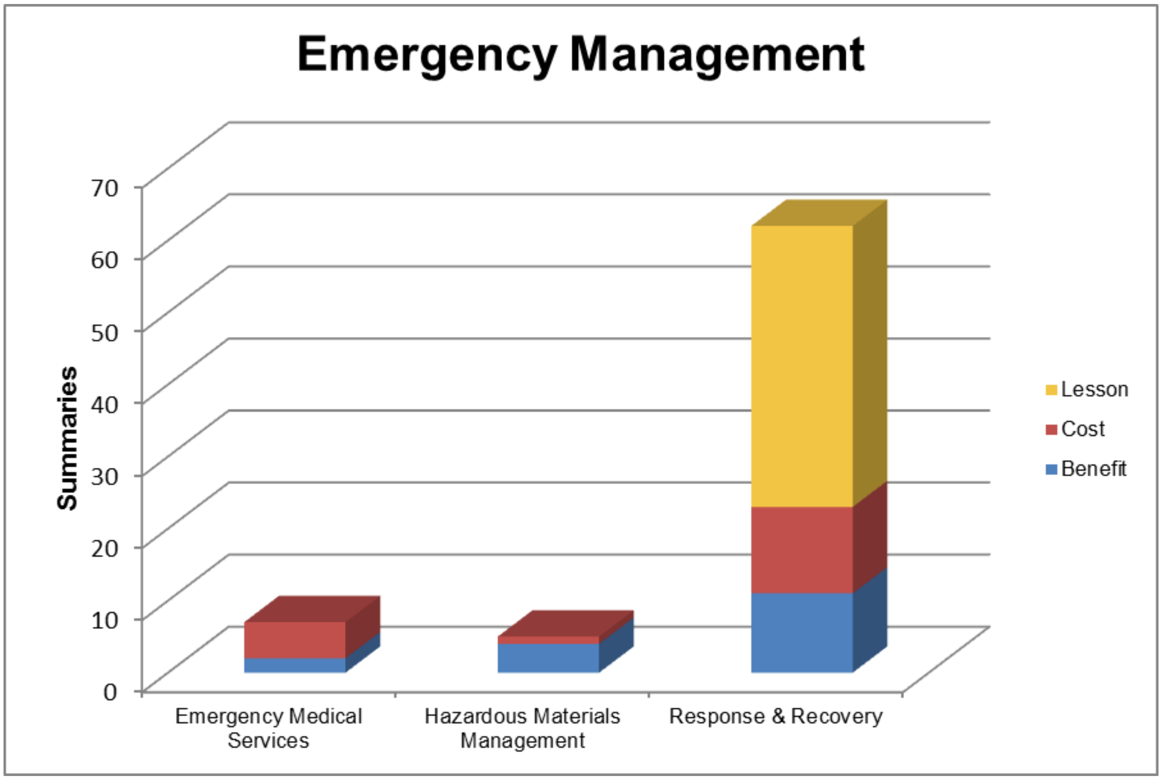


Figure 10-2. Summaries in the Knowledge Resources by Emergency Management Category

Benefits

Contraflow freeway operations in South Carolina enabled a 76 percent increase in traffic volumes.

ITS applications for emergency management can increase the efficiency of transportation capacity during emergencies, increase productivity for HAZMAT shipping operations, and improve overall traveler safety and security (see Table 10-1). Evaluation data collected from a number of studies suggest that customer satisfaction with emergency management is largely positive. Stakeholders perceive positive impacts and indicate that these technologies are widely accepted.

The HAZMAT Safety and Security Technology Field Operational Test (FOT) tested a variety of technologies designed to improve the security of HAZMAT shipments. In this FOT, it was estimated that the technologies would reduce the risk and vulnerability of HAZMAT shipments and therefore reduce the potential consequences of a terrorist attack on HAZMAT shipments by 36 percent. Through improved operations for carriers, the technologies were found to have a payback period of 3 to 34 months across the range of technologies and shipment types studied.[234]

ITS technologies in Commercial Vehicle Operations (CVO) support efforts in emergency management to identify high-risk heavy trucks, including those that carry threats to homeland security. The State of Kentucky, in partnership with the U.S. DOT, installed an Integrated Safety and Security Enforcement System (ISSES) in 2005 at a weigh station on Interstate 75 near London, Kentucky. The ISSES automatically and wirelessly accesses safety information on heavy trucks that pass the scale house located in the station. The ISSES consisted of a U.S. DOT number reader, an automated license plate recognition system (ALPR), a laser-based system for classifying vehicles according to the number of axles, a detection system for bulk radiation and thermal imaging inspection system for identifying threats to homeland security. The ISSES at the I-75 station could lower the number of crashes caused by high-risk heavy trucks from between 63 to 629, personal injuries between 16 and163, and fatalities by 7 per year.[235]

Successful operations for emergency management require agencies to communicate and coordinate effectively with little or no notice at times when resources may be limited. To help optimize the effectiveness of available resources, agencies can use ITS technologies to prioritize, allocate, track, and coordinate the deployment of personnel, supplies, and equipment.[236] Different agencies, however, can have different core missions and are sometimes unaware of the capabilities and priorities of other agencies. Transportation agencies, for example, may focus on reducing the time to restore normal traffic conditions, while an emergency services agency may focus on improving safety for responders.[237] Although goals and objectives may differ significantly between agencies, most officials agree that ITS technology is useful in promoting interagency coordination and coordinating emergency management. This coordination can beget significant improvements in evacuation and re-entry management, such as the 76 percent increase in traffic volumes accomplished with freeway contraflow operations in South Carolina as residents returned following a hurricane evacuation.[238]

Table 10-1. Emergency Management Benefits Summary

Emergency Management Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Hazardous Materials Management	●			●		
Emergency Medical Services						⇅
Response and Recovery			●			◉

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

The HAZMAT Transportation Safety and Security FOT was conducted to assess commercially-available, off-the-shelf technology that could be deployed in the near term to enhance the safety and security of HAZMAT transportation operations. Part of the assessment included collecting cost data for the different technologies. The study found that the technologies that enhance the safety and security of HAZMAT transportation operations range in cost from $250 to $3,500 per vehicle. These estimates represent only the hardware installed on the trucks in commercial quantities. These estimates do not reflect the price of servers and dispatch systems amortized over the number of vehicles since this can vary widely depending on customer setup. While none of the technologies tested was described as prototypes, several had limited prior field usage outside of government applications.[239]

A study found that the technologies that enhance the safety and security of hazmat transportation operations range in cost from $250 to $3,500 per vehicle.

The FHWA initiated a study to explore the benefits and costs of fully deploying operational strategies and integrating ITS in the large, medium, and small metropolitan areas of Seattle, Cincinnati, and Tucson, respectively. Among the identified ITS strategies for these areas was emergency management systems, including the amount of deployment and coverage in each of the three metropolitan areas. Deployment data included the number of emergency vehicles and ambulances equipped with control service, AVL, and telemedicine. Percentages of emergency vehicles and ambulances defined the amount of coverage. The estimates for the annualized lifecycle costs of emergency management systems were $1.8 million for Seattle, $1.8 million for Cincinnati, and $2.1 million for Tucson.[240]

Deployment

Figure 10-3 shows deployment trends for two key ITS technologies used in emergency management from 2000 to 2010, based on a multi-year survey of the country's largest metropolitan areas. As of 2010, 80 percent of emergency management vehicles operate under computer-aided dispatch (CAD), an increase from 67 percent in 2000, and 44 percent of emergency management vehicles are equipped with in-vehicle navigation, up from almost no deployment in 2000. Also as of 2010, 66 percent of fire and rescue agencies (out of 226 surveyed) and 19 percent of law enforcement agencies (out of 335 surveyed) adopted traffic signal preemption.

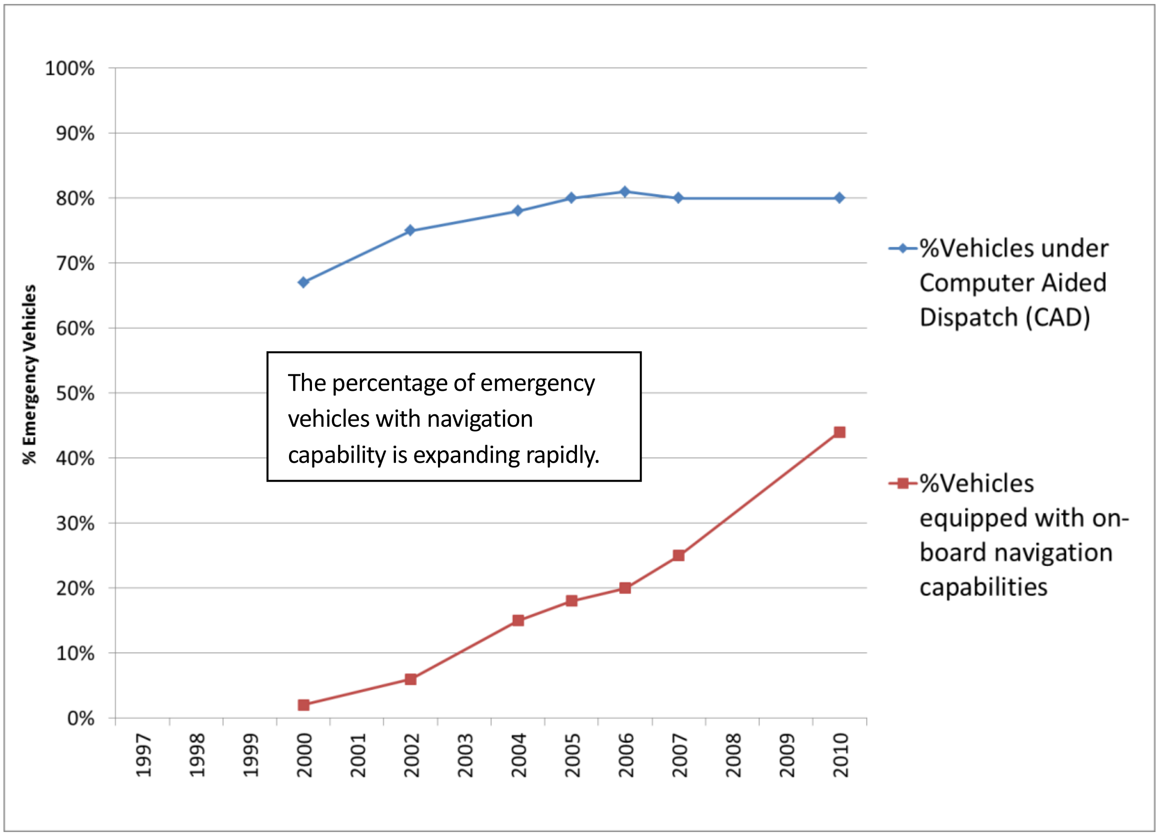


Figure 10-3. Deployment Trends for Emergency Management Systems

Selected Highlights from the ITS Knowledge Resources on Emergency Management

Hazardous Material Management

ITS applications associated with HAZMAT shipments can accomplish the following four major functions intended to provide safe and secure transport of hazardous materials by road:

- Vehicle-mounted hardware provides the capability to track HAZMAT shipments and support notification of management centers when a shipment deviates from its intended route.
- Roadside detectors can monitor the roadway environment for the presence of hazardous shipments in sensitive areas and, if electronic tag information is available on the detected vehicle, confirm that the shipment is on the expected route.
- Driver authentication technology can confirm that the individual operating a HAZMAT vehicle is authorized to do so and report operation by unexpected drivers to public safety entities.
- ITS can also provide assistance to commercial vehicle operations via electronic route planning services, ensuring compliance with HAZMAT shipment restrictions along planned travel routes, and with automatic detection of high-risk heavy trucks.

Emergency Medical Services

Advanced ACN and telemedicine address the detection of and response to incidents such as vehicle collisions or other incidents requiring emergency responders. In rural areas, response time for emergency medical services is greater than in metropolitan areas, resulting in more severe consequences for those in need of medical assistance.

Emergency Medical Services: Advanced Automated Collision Notification

Advanced ACN systems use vehicle-mounted sensors and wireless communication to notify emergency personnel and provide them with valuable information on the crash including location, crash characteristics, and possibly relevant medical information regarding the vehicle occupants.

Advanced Automated Collision Notification	
Benefits	
ITS Goals	**Selected Findings**
Safety	A study of the population of BMWs in service in Florida from 2006-2008 involved in crashes severe enough to trigger the ACN found that the ACN provided an initial crash notification and also transmitted data on the severity of the event. The ACN data correctly identified 75.9 percent of seriously injured occupants as seriously injured. Extrapolating the findings to population-based statistics indicates that implementing an enhanced ACN in all passenger vehicles in the United States would improve outcomes for 15,200 drivers involved in moderate to severe crashes each year. This population of occupants could benefit from an automatic call for help to a Public Services Answering Point (i.e., 911) that includes an estimate of the likelihood of serious injuries.[241,242]
Costs	
Unit Costs Data Examples	
Emergency Response Center subsystem: • Emergency Management Communications Software: $5K-$10K • Hardware, Software Upgrade for Enhanced 9-1-1 and Mayday: $104K-$179K • Emergency Response Labor: $79K-$261K (annually)	

Response and Recovery

In the event of a large-scale emergency, ITS applications can assist with response management through services such as the tracking of emergency vehicle fleets using AVL technology and two-way communications between emergency vehicles and dispatchers. Evacuation operations often require a coordinated emergency response involving multiple agencies, various emergency centers, and numerous response plans. Integration with traffic and transit management systems enables the sharing of emergency information among public and private agencies and the traveling public. This communication and cooperation also enables the use of ITS information dissemination capabilities to provide emergency traveler information.

Response and Recovery: Early Warning System

The variety of sensors deployed on the transportation infrastructure can help provide early warning systems for detecting large-scale emergencies such as natural disasters (hurricanes, earthquakes, floods, blizzards, tsunamis, etc.) and technological and man-made disasters (HAZMAT incidents, nuclear power plant accidents, and acts of terrorism including nuclear, chemical, biological, and radiological weapons attacks). Early warning systems monitor alerting and advisory systems, ITS sensors and surveillance systems, field reports, and emergency call-taking systems to identify emergencies and notify all responding agencies of detected emergencies.

Lessons Learned: Help reduce the number of false alarms generated by a bridge security monitoring system by ensuring to calibrate and validate system tests.

The iFlorida Model Deployment, which started in 2003, included a Bridge Security Monitoring System deployed at two bridges. The system monitored video images of the bridges and their vicinity, and activated an alarm if it detected suspicious activities near the bridge. After an alarm, operators could review real-time and archived video footage to identify the cause of the alarm and mobilize response activities, if required. An evaluation identified the following lessons learned.

- **Ensure that the number of false alarms is not excessive**. The high number of false alarms in the iFlorida Bridge Security Monitoring System resulted in alarms that were often ignored. It is important to adjust alarm systems so that they issue an acceptable number of alarms; otherwise, the effectiveness of the system may be compromised.
- **Perform adequate tests to calibrate and validate the capabilities of a bridge monitoring system**. The expertise required for security monitoring systems may not be available at state DOTs, so it may be necessary to hire specialists to conduct the testing required to detect threats and sound alarms.
- **Provide provisions for adjusting the alarm plan during special circumstances, such as construction activities or the presence of a disabled vehicle**. A number of common events on the bridges, such as construction activities or a disabled vehicle, would sometimes generate a large number of false alarms.
- **Locate the video processing and archiving equipment away from the bridge or the asset being protected, preferably in a climate-controlled environment**. With the video archiving hardware deployed in the field, a catastrophe at the bridge would likely destroy the archived video. Archiving the video at a location separate from the monitored asset would protect the archived video from damage, so that it could be used to support post-catastrophe analyses. The equipment in the field may have operated more reliably if deployed at the climate controlled environment of the Deland office.[243]

Response and Recovery: Response Management

Response management may include the tracking of emergency vehicle fleets using AVL technology and two-way communications between emergency vehicles and dispatchers. Integration with traffic and transit management systems enables emergency information to be shared between public and private agencies and the traveling public.

<table>
<tr><th colspan="2">Response and Recovery: Response Management</th></tr>
<tr><th colspan="2">Benefits</th></tr>
<tr><th>ITS Goals</th><th>Selected Findings</th></tr>
<tr><td>Customer Satisfaction</td><td>Survey responses collected from 166 key professionals at state and local agencies in five states (Kentucky, Georgia, Tennessee, North Carolina, and South Carolina) indicated the following ITS technologies have the highest potential to benefit emergency transportation operations: [244]
• Interoperable radio communications
• Dynamic message signs
• GPS and geographical information systems
• CCTV roadway surveillance
• Enhanced 9-1-1</td></tr>
<tr><th colspan="2">Costs</th></tr>
<tr><td colspan="2">Unit Costs Data Examples</td></tr>
<tr><td colspan="2">Emergency Response Center subsystem:
• Emergency Response Hardware: $6K-$8K
• Emergency Response Software: $70K-$149K
• Emergency Management Communications Software: $5K-$10K
• Emergency Response Labor: $79K-$261K (annually)
Emergency Vehicle On-Board subsystem:
• Communications Interface: $0.3K-$2K
• Signal Preemption Emitter: $0.4K-$1.8K
Transportation Management Center subsystem:
• Integration for Traffic Information Dissemination: $85K-$103K
• Labor for Regional Control: $233K-$285K (annually)</td></tr>
<tr><td colspan="2">Sample System Costs of ITS Deployments</td></tr>
<tr><td colspan="2">Michigan: The Flint Mass Transportation Authority developed a plan to deploy ITS technologies throughout the agency. Establishing a back-up emergency management center for coordinated emergency response between agencies was identified as one of the longer term priorities. Costs were estimated at $500,000 for capital and $50,000 per year for operations and maintenance.[245]</td></tr>
</table>

Response and Recovery: Evacuation and Re-Entry Management

Evacuation operations often require a coordinated emergency response involving multiple agencies, various emergency centers, and numerous response plans. Various communication technologies can support the management of evacuations, which may also include a variety of traffic and transit management activities.

Response and Recovery: Evacuation and Re-Entry Management	
Benefits	
ITS Goals	**Selected Findings**
Efficiency	An assessment of the hurricane evacuation plan in Hampton Roads, Virginia found that lane reversal is warranted for any hurricane predicted to make landfall as a Category 4 or 5 storm, and is strongly recommended for any Category 3 storm. In addition, the study found that with lane reversal, increasing ramp metering rates reduces ramp queuing and allows more efficient use of available mainline capacity.[246]
Costs	
Unit Costs Data Examples	
Emergency Response Center subsystem: • Emergency Response Hardware: $6K-$8K • Emergency Response Software: $70K-$149K • Emergency Management Communications Software: $5K-$10K • Emergency Response Labor: $79K-$261K (annually) Emergency Vehicle On-Board subsystem: • Communications Interface: $0.3K-$2K • Signal Preemption Emitter: $0.4K-$1.8K Transportation Management Center subsystem: • Integration for Traffic Information Dissemination: $85K-$103K • Labor for Regional Control: $233K-$285K (annually)	

Lessons Learned: Plan for the transport of special need populations, such as nursing home residents, during no-notice evacuations by advance identification of wheelchair accessible buses and shelters.

Jurisdictions are occasionally called upon in emergencies to implement an evacuation order with little or no advance notice. In one case in 2005, a fire in a hazardous waste storage and treatment facility in El Dorado, Arkansas led to a no-notice, emergency evacuations of nursing home residents in two nursing homes near the facility. The experience of this successful evacuation reinforces best practices and highlights lessons learned, including the following.

- **Request wheelchair-accessible buses as well as standard buses for the evacuation of a nursing home facility**. Most of the residents were transported in school buses, but it was necessary to use ambulances from the hospital to transport the numerous non-ambulatory residents who used wheelchairs or could not easily walk. The initial call for buses overlooked the need for wheelchair-accessible ones.
- **Keep up-to-date information on the location and contact data for specialized equipment such as wheelchair-accessible buses and small trucks**. Evacuation plans should have current contact information for specialized equipment. Not having access to wheelchair-accessible buses or trucks directly, the nursing home staff and emergency personnel relied on community volunteers and local schools for vehicles. A small truck was needed to transfer materials that could not easily be transported with buses, such as wheelchairs, linen and medicine carts.
- **Practice evacuation drills at least once a year**. One reason the evacuation in El Dorado of two nursing homes was successful was that nursing home staff conducted evacuation drills at least annually. The drills provided an opportunity for staff members to learn the procedures for

Lessons Learned: Plan for the transport of special need populations, such as nursing home residents, during no-notice evacuations by advance identification of wheelchair accessible buses and shelters.

evacuation and practice their assignments and roles.

- **Select a public shelter that is appropriate for the population**. The initial plan called for moving residents to a public shelter at a municipal auditorium. However, the director, after having sent staff to evaluate the shelter, learned that the shelter did not have bathrooms on the same level as the sleep facilities or cooking facilities. The director requested that residents be transported to a church, which had cooking facilities and accessible bathrooms. [247]

Response and Recovery: Emergency Traveler Information

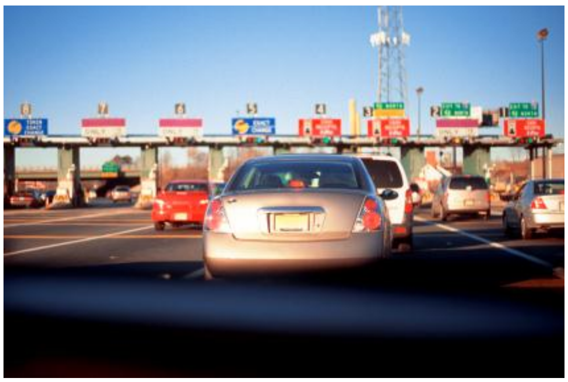
Integration with traffic and transit management systems enables emergency information to be shared between public and private agencies and the traveling public. This communication and cooperation also enables the use of the variety of ITS information dissemination capabilities to provide emergency traveler information.

Response and Recovery: Emergency Traveler Information
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Dynamic Message Sign: $28K-$136K • Dynamic Message Sign – Portable: $15.9K-$21K • Highway Advisory Radio: $15K-$36K • Highway Advisory Radio – Sign: $4K-$8K Emergency Response Center subsystem: • Emergency Response Hardware: $6K-$8K • Emergency Response Software: $70K-$149K • Emergency Management Communications Software: $5K-$10K • Emergency Response Labor: $79K-$261K (annually) Transportation Management Center subsystem: • Integration for Traffic Information Dissemination: $85K-$103K • Labor for Regional Control: $233K-$285K (annually)
Sample System Costs of ITS Deployments
Pennsylvania: The Pennsylvania Turnpike Commission expanded its statewide advanced traveler information system to better inform motorists of traffic, weather, and emergency conditions along the turnpike. The overall project cost was **$8.2 million**.[248]

Lessons Learned: Consult with traffic engineers early in the process of no-notice evacuations to secure the use of traffic management resources and to identify routes for evacuation and re-entry.
In March 2005, railroad workers in a rail yard in South Salt Lake City, Utah discovered a tanker car from which a large quantity of toxic chemicals had spilled onto the ground. The risk that a hazardous chemical fire might erupt and that toxic fumes would spread led the city to evacuate approximately 3,000 residents from the nearby neighborhood. The residents used their personal vehicles to evacuate. After residents had successfully evacuated, incident command revised their estimate of the duration of the evacuation as taking much longer, and utilized an authorized traffic management contractor to support transportation management. The contractor closed the interstate using barriers, deployed electronic signs, managed traffic flow and developed a plan for the rush hour commute for the following day.

- **Involve traffic engineers earlier in the incident**. In a review of the incident, the Utah Department of Transportation recommended that incident command involve traffic engineers as early as possible in the evacuation process to aid in traffic management including road closures, the control of traffic flow, the selection of interstate ramps for closure and the development of a plan to divert traffic from closures and hazardous areas to safe zones.
- **Increase the use of portable message signs**. The use of portable message signs enables incident command and traffic managers to provide accurate and timely information to the public about roadway conditions and road closures, and directions to safe zones and shelters.
- **Do not overlook the importance of using variable message signs on surface streets**. Deploying variable message signs on surface streets has proven highly useful in no-notice evacuations. The signs direct local residents who are fleeing the evacuation zone and guide travelers who were diverted to local surface streets from the closed sections of the interstate.
- **Use traffic engineers for the re-entry plan**. Traffic management is a critical part of a successful re-entry plan. It includes tasks such as evaluating whether closed roadways are safe and ready to be re-opened, educating the public about the re-opening of roads, determining when traffic can be restored, providing traffic control for the return of residents and directing traffic flow upon re-entry.[249]

Chapter 11 Electronic Payment and Pricing



Source: ©iStockphoto.com/Jitalia17

Electronic payment systems employ various communication and electronic technologies to facilitate commerce between travelers and transportation agencies.

Electronic toll collection (ETC) systems support the collection and processing of toll plaza transactions without requiring the driver to stop and pay manually, increasing operational efficiency and convenience for tollway travelers. ETC systems operate as either an integrated multi-state system such as the E-ZPass system, or single-state or single toll authority systems such as the Oklahoma Turnpike system. ETC can reduce fuel consumption and emissions at toll booths by minimizing delays, queuing, and idling time.

Transit fare payment systems can provide increased convenience to customers and generate significant cost savings to transportation agencies by increasing the efficiency of cash-handling processes and improving administrative controls. Public transportation users can select from a variety of fare products such as magnetic stripe cards (read-only or read-write), smart cards with varying levels of memory and computing power, or use credit cards to pay for transportation services.[250] Fare transaction machines can read and write to multiple types of media and fare products, and regional processing centers can consolidate financial information and streamline fare transaction management for multiple transit agencies. Billing systems supporting transit fare payment can

Categories

Toll Collection

Transit Fare Payment

Parking Fee Payment

Multi-use Payment

Pricing

be used in the coordination of human service transportation, linking the reservation system to a payment system that tracks billing to different mobility programs depending on client eligibility.

A single toll tag can now be used to pay tolls on facilities operated by multiple agencies.

Electronic parking fee payment systems can provide similar benefits to parking facility operators, simplifying payment for customers and reducing congestion at parking facilities.

Multi-use payment systems can make transit payment more convenient. Payment for bus, rail, and other public- or private-sector goods and services can be made simply by passing a smart-card-sized device over an automated transaction processor located at terminal gates, on-board bus fareboxes, or check-out counters of participating merchants. Fare transaction processors access information on smart cards and communicate account activity to a regional database. Centralized systems can track the location and activity of smart cards and limit unauthorized use of individual accounts. In addition, merchants who provide convenient access to smart card processors can be identified and receive special incentives for promoting use of transit services.

Congestion pricing, also known as road pricing or value pricing, refers to charging motorists a fee that varies with the level of congestion. Value pricing reflects the idea that road pricing directly benefits motorists through reduced congestion and improved roadways. To eliminate additional congestion, most pricing schemes are set up electronically to offer a more reliable trip time without creating additional delay. Pricing is different from tolling in that pricing strategies are used to manage congestion or demand for highway travel, while tolling is used to generate revenue to repay a bond or debt.

There are four main types of congestion pricing strategies:

- Variable priced lanes including express toll lanes and high-occupancy toll (HOT) lanes.
- Variable tolls on entire roadways or roadway segments (i.e., changing flat toll rates on existing toll roads to variable rates based on congestion levels).
- Cordon charge (i.e., charging a fee to enter or drive in a congested area).
- Area-wide charge including distance-based charging or mileage fees.[251]

The electronic payment and pricing applications profiled in this chapter, particularly variable tolling and congestion pricing are key elements of the U.S. DOT Tolling and Pricing Program. For more information please visit the Tolling and Pricing Program Web site: www.ops.fhwa.dot.gov/tolling_pricing/index.htm.

Findings

As of July 2011, there were 140 evaluation summaries of Electronic Payment and Pricing applications in the Knowledge Resource databases, as shown in Figure 11-1. The Electronic Payment and Pricing category with the largest number of summaries is Pricing, with 54 summaries, followed by Toll Collection (49 summaries), Transit Fare Payment (45 summaries), Parking Fee Payment (11 summaries), and Multi-Use Payment (seven summaries) as shown in Figure 11-2.

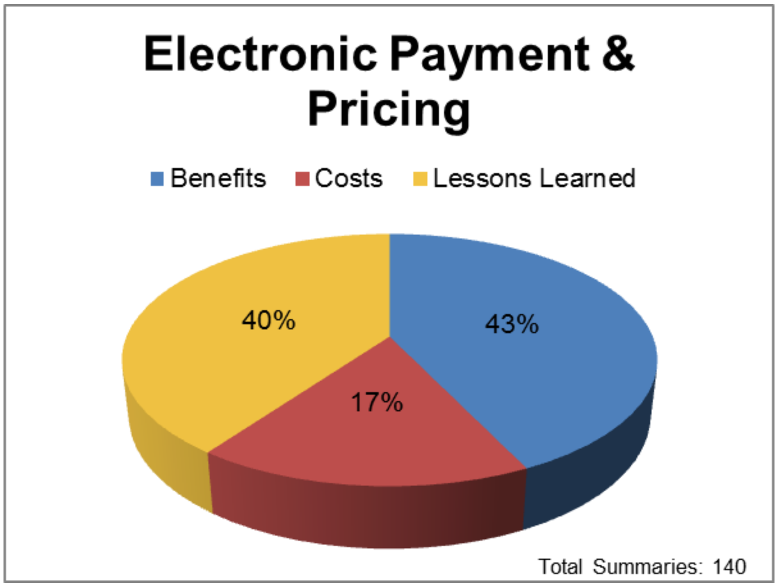


Figure 11-1. Electronic Payment and Pricing Summaries in the Knowledge Resources

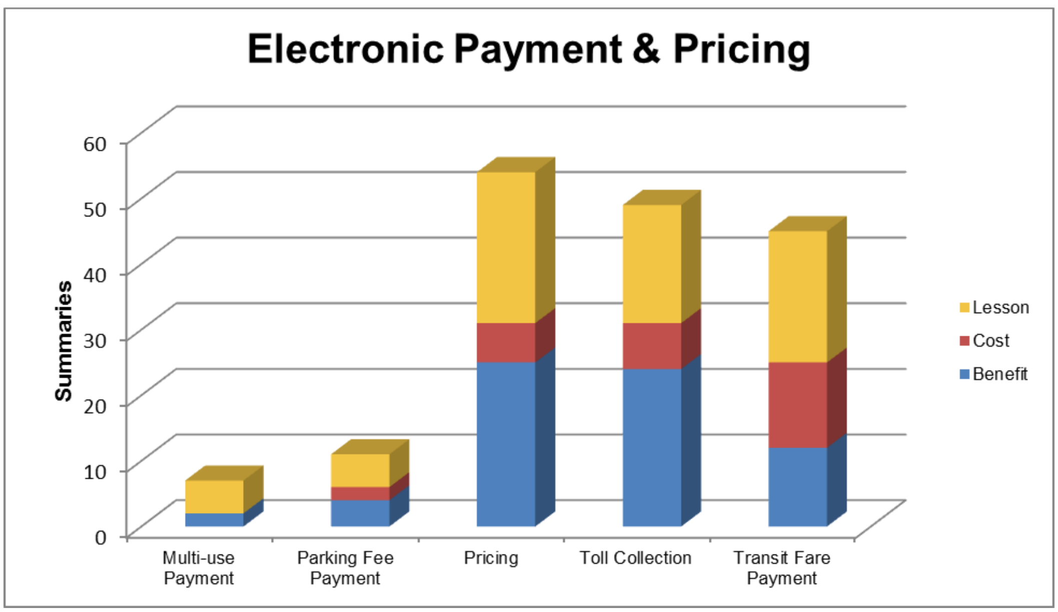


Figure 11-2. Summaries in the Knowledge Resources by Electronic Payment and Pricing Category

Benefits

ETC is one of the most successful ITS applications with numerous benefits related to delay reductions, improved throughput, and fuel economy. With advanced technologies such as open road tolling (ORT), toll transactions can be processed automatically at freeway speeds reducing the need for tollbooth barriers and improving performance. Concepts of ORT can be incorporated into new toll plaza designs or constructed at existing plazas that currently have speed-controlled, dedicated ETC lanes.

HOV to HOT conversion projects in San Diego saved I-15 Fastrak users up to 20 minutes compared to mainline travelers.

Variable pricing strategies can influence traveler behavior and improve utilization of highway capacity. In Puget Sound, for example, variable tolling on SR-167 made more efficient use of carpool lanes without delaying buses; average speeds in general purpose lanes increased by 21 percent while average speeds in HOT lanes increased by six percent.[252] Although initial public support for such tolls may be low, research indicates that road users value time savings and are willing to pay a price to avoid congestion and delay.[253] In California, for example, public support for variable tolling on State Route 91 was initially low, but after 18 months of operations, nearly 75 percent of the commuting public expressed approval of virtually all aspects of the Express Lanes program.[254] Similarly, surveys revealed broad support among motorist for a HOV to HOT lane conversion project with dynamic pricing. Approval was consistent across a wide range of income groups, with 71 percent higher-income, 61 percent middle-income, and 64 percent lower income having indicated "strong" or "somewhat" approval of tolling.[255]

Other pricing strategies such as cordon charging are also effective. In London, congestion charging remains politically sensitive, but evaluations have shown that the pricing program has been effective at reducing congestion and generating revenue for transit improvements.

Table 11-1 illustrates that electronic payment and pricing strategies have had significant impact under many of the ITS goal areas. Electronic toll collection is a proven technology that greatly reduced toll plaza delays, with corresponding improvements in capacity, agency cost savings, and fuel consumption reductions. Transit fare payment can provide similar mobility improvements for transit travelers by simplifying the boarding experience, improving customer satisfaction, and making it easier to take advantage of transit services. Parking and multi-use payment cards have been well received by travelers in several implementations. Congestion pricing strategies, as discussed above, have shown improvements in mobility, productivity, fuel consumption, and customer satisfaction.

Table 11-1. Electronic Payment and Pricing Benefits Summary

Electronic Payment and Pricing Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Toll Collection	⇂↾	●	●	●	●	
Transit Fare Payment		●	●			●
Parking Fee Payment				⦿		●
Multi-Use Payment						●
Pricing		●		●	●	⦿

● – substantial positive impacts	⦿ – positive impacts
○ – negligible impacts	⇂↾ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

Value pricing projects conducted in three metropolitan areas (Denver, Minneapolis, and Puget Sound) found the costs of converting HOV lanes to HOT lanes ranged from $9 million to $17.9 million.
In Denver, the Downtown Express HOT lanes project included a two-lane barrier-separated reversible facility in the median of a seven mile section of I-25 and US-36. Structures with communications equipment constructed above the roadway were used to interact with in-vehicle transponder tags installed on vehicle windshields. Back-end technology was then used to assess tolls on user accounts. The total implementation cost was estimated at $9,000,000. Planning, implementation, and construction occurred from 2001-2005.[256]

In Minneapolis, HOV lanes that extended from Highway 101 to I-94 were converted into dynamically priced HOT lanes. The project included two sections of highway, a three-mile east section that had two reversible lanes separated by a barrier from general purpose traffic, and an eight-mile west section that had one lane in each direction separated from general purpose traffic by a double-white stripe marker. The total implementation cost was estimated at $12,982,800. Planning, implementation, and construction occurred from 2002-2005.[257]

The HOV to HOT conversion project in Puget Sound was implemented on a nine mile section of SR-167 that extended from 15th Street in Auburn to I-405 in Renton. Expansion of the existing freeway was not required. HOV lanes were re-striped using double white striped buffers to define the new HOT lanes and access points. Transponder-equipped vehicles were allowed to enter the HOT lanes at certain access points. The total implementation cost was estimated at $17,000,000. Planning, implementation, and construction occurred from 2004-2008. Preliminary capital costs for the conversion were expected to be recovered by net annual toll revenue within 11 to 12 years.[258]

Deployment

Figure 11-3 shows deployment trends for two forms of electronic payment—toll collection and transit fare payment—based on a multi-year survey of the country's largest metropolitan areas from 1997 to 2010.

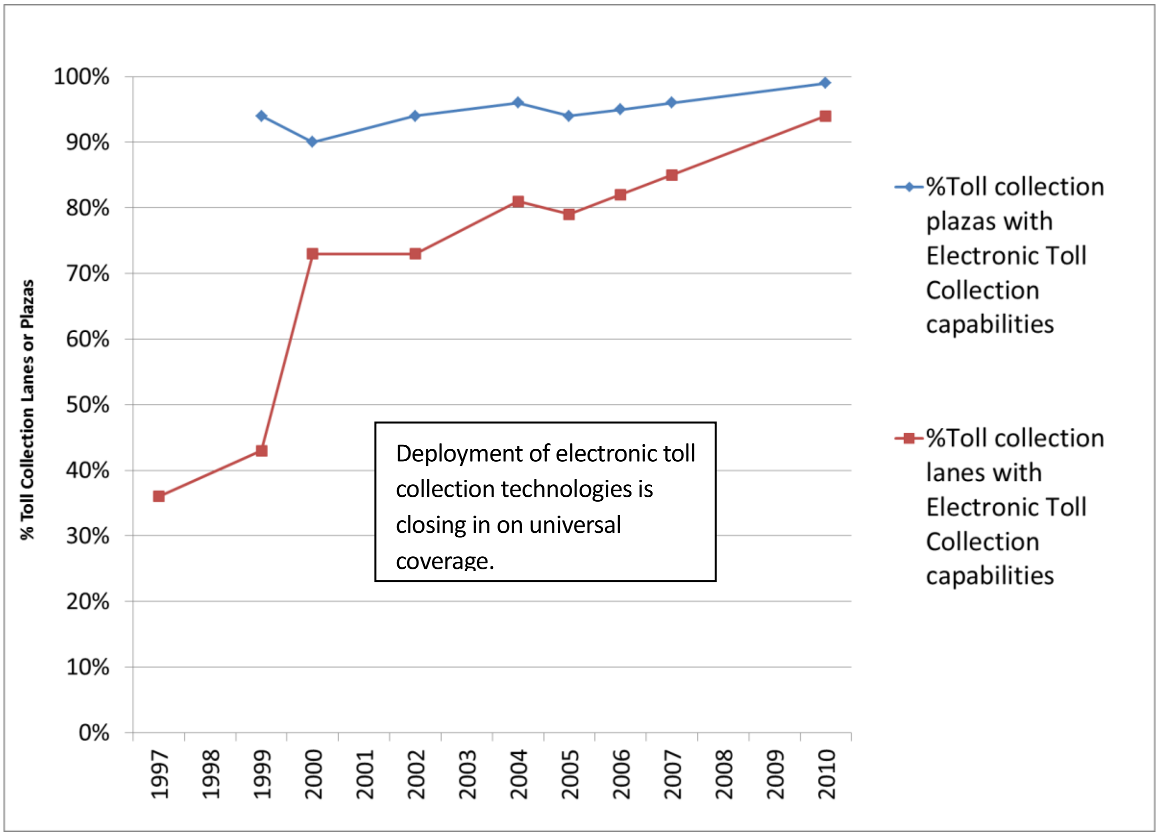


Figure 11-3. Electronic Toll Collection Indicators

Selected Highlights from the ITS Knowledge Resources on Electronic Payment and Pricing

Toll Collection

ETC supports the collection of payment at toll plazas using automated systems to increase the operational efficiency and convenience of toll collection. Systems typically consist of vehicle-mounted transponders identified by readers located in dedicated and/or mixed-use lanes at toll plazas.

Toll Collection

Deployment

Deployment of ETC is nearly universal. Approximately 98 percent of toll collection lanes offer ETC and a significant number of toll collection plazas offer ETC capabilities (83 percent).

Costs

Unit Costs Data Examples

Toll Plaza subsystem:

- Electronic Toll Reader: $2K-$4K (per lane)
- High-Speed Camera: $6K-$8K

Toll Administration subsystem:

- Toll Administration Hardware: $4.8K-$6.4K
- Toll Administration Software: $40K-$80K

Roadside Telecommunication subsystem:

- Conduit Design and Installation – Corridor: $52K-$77K (per mile)
- Fiber Optic Cable Installation: $21K-$54K (per mile)

Transit Fare Payment

Electronic transit fare payment systems, often enabled by smart card or magnetic stripe technologies, can provide increased convenience to customers and generate significant cost savings to transportation agencies by increasing the efficiency of money handling processes and improving administrative controls.

Transit Fare Payment

Deployment

Survey data collected in 2000 and 2010 indicate that the number of agencies deploying magnetic strip readers increased from 5 percent to 40 percent. The adoption of “smart card” readers also increased during this period from 3 percent to 24 percent.

Costs

Unit Costs Data Examples

Transit Management subsystem:

- Upgrade for Automated Scheduling, Run Cutting, or Fare Payment: $20K-$40K
- Integration for Automated Scheduling, Run Cutting, or Fare Payment: $224K-$498K
- Further Software Upgrade for E-Fare Payment: $40K-$60K

Transit Vehicle On-Board subsystem:

- Electronic Farebox: $0.5K-$1.0K

Parking Fee Payment

Electronic parking fee payment systems can provide benefits to parking facility operators, simplify payment for customers, and reduce congestion at parking facility entrances and exits. These payment systems can be enabled by any of a variety of technologies including magnetic stripe cards, smart cards, in-vehicle transponders, or vehicle-mounted bar codes.

Parking Fee Payment
Deployment
Survey data collected in 2000 and 2010 indicate that the adoption of parking management systems increased from 5 to 8 percent.
Costs
Unit Costs Data Examples
Transit Management subsystem: • Integration for Auto. Scheduling, Run Cutting, or Fare Payment: $224K-$498K Parking Management subsystem: • Entrance/Exit Ramp Meters: $1K-$3K • Tag Readers: $1K-$3K • Database and Software for Billing & Pricing: $10K-$15K • Parking Monitoring System: $16K-$35K

Multi-Use Payment

Multi-use payment systems can make transit payment more convenient. Payment for bus, rail, and other public- or private-sector goods and services can be made using transit fare cards at terminal gates, or at check-out counters of participating merchants located near transit stations. Multi-use systems may also incorporate the ability to pay highway tolls with the same card.

Multi-Use Payment
Costs
Unit Costs Data Examples
Transit Management subsystem: • Upgrade for Automated Scheduling, Run Cutting, or Fare Payment: $20K-$40K • Integration for Automated Scheduling, Run Cutting, or Fare Payment: $224K-$498K • Further Software Upgrade for E-Fare Payment: $40K-$60K Transit Vehicle On-Board subsystem: • Electronic Farebox: $0.5K-$1.0K

Pricing

Congestion pricing, also known as road pricing or value pricing, employs the use of technologies to vary the cost to use a transportation facility or network based on demand or the time of day. Pricing strategies include: variable priced lanes, variable tolls on entire roadways or roadway segments, cordon charging, area-wide charging, and fast and intertwined regular lanes.

Pricing	
Deployment	
Survey data collected from metropolitan areas between 2007 and 2010 indicate that eight agencies use High Occupancy Toll (HOT) lanes and six agencies use congestion pricing.	
Benefits	
ITS Goals	**Selected Findings**
Mobility	In Puget Sound, variable tolling on SR-167 improved traffic in carpool lanes without delaying buses. Average speeds in the general purpose lanes increased by 21 percent while average speeds in HOT lanes increased by 6 percent.[259]
Efficiency	In Minneapolis, converting HOV to HOT lanes with dynamic pricing increased peak period throughput by 9 to 33 percent.[260]
Productivity	Integrated Corridor Management (ICM) strategies that promote integration among freeways, arterials, and transit can help balance traffic flow and enhance corridor performance. Simulation models indicated that HOT lanes were one of the most effective ICM investments. Converting an existing HOV lane to a HOT lane produced a benefit-cost ratio ranging from of 14 to 39.[261]
Energy and Environment	In Stockholm, Sweden, a permanent charging program (cordon charging) improved the environment by reducing Carbon dioxide emissions by 10 to 14 percent, reducing oxides of Nitrogen by 7 percent, and decreasing particulates by 9 percent.[262]
Customer Satisfaction	In Minneapolis, key findings from a November 2006 attitudinal survey revealed broad support for a HOV to HOT lane conversion projects that included dynamic pricing. Approval was consistent across all income groups. Seventy-one (71) percent of higher-income respondents, 61 percent middle-income respondents, and 64 percent lower income respondents indicated "strong" or "somewhat" approval of tolling.[263]
Costs	
Unit Costs Data Examples	
Roadside Detection subsystem: • Inductive Loop Surveillance on Corridor: $2K-$6K Roadside Control subsystem: • Fixed Lane Signal: $4K-$5K Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Transportation Management Center subsystem: • Hardware, Software for Traffic Surveillance: $134K-$164K • Integration for Traffic Surveillance: $224K-$273K	

Pricing

- Software for Traffic Information Dissemination: $18K-$20K
- Integration for Traffic Information Dissemination: $85K-$103K

Toll Plaza subsystem:

- Electronic Toll Reader: $2K-$4K (per lane)
- High-Speed Camera: $6K-$8K

Toll Administration subsystem:

- Toll Administration Hardware: $4.3K-$6.4K
- Toll Administration Software: $40K-$80K

Roadside Telecommunications subsystem:

- Conduit Design and Installation – Corridor: $52K-$77K
- Fiber Optic Cable Installation: $21K-$54K

Sample System Costs of ITS Deployments

Value pricing projects conducted in three metropolitan areas indicated the costs to convert HOV lanes to HOT lanes ranged from $9 million to $17.9 million.

Denver, Colorado: The Downtown Express HOT lanes project included a two-lane barrier-separated reversible facility in the median of a seven mile section of I-25 and US-36. Structures with communications equipment constructed above the roadway were used to interact with in-vehicle transponder tags installed on vehicle windshields. Back-end technology was then used to assess tolls on user accounts. Planning, implementation, and construction occurred from 2001-2005. The total implementation cost was estimated at $9,000,000.[264]

Minneapolis, Minnesota: HOV lanes that extended from Highway 101 to I-94 were converted to dynamically priced HOT lanes. The project included two sections of highway, a three-mile east section that had two reversible lanes separated by a barrier from general purpose traffic, and an eight-mile west section that had one lane in each direction separated from general purpose traffic by double-white stripes. Planning, implementation, and construction occurred from 2002-2005. The total implementation cost was estimated at $12,982,800.[265]

Seattle, Washington: In Puget Sound, a HOV to HOT conversion project was implemented on a nine mile section of SR-167 that extended from 15th Street in Auburn to I-405 in Renton. Expansion of the existing freeway was not required. HOV lanes were re-striped using double white striped buffers to define the new HOT lanes and define access points. Transponder-equipped vehicles were allowed to enter the HOT lanes at certain access points. Planning, implementation, and construction occurred from 2004-2008. The total implementation cost was estimated at $17,000,000. Preliminary capital costs of the conversion were expected to be recovered by net annual toll revenue within 11 to 12 years.[266]

The cost estimates and project dates of several international examples of congestion pricing programs are shown below.

- **Bergen, England** (1986): Implementation: $8 million. Annual O&M: $4.59 million.
- **Oslo, Norway** (1990): Implementation: $40 million. Annual O&M: $23.26 million
- **Trondheim, Norway** (1991): Implementation: $7.50 million. Annual O&M: $3.75 million.
- **Singapore City, Singapore** (1998): Implementation: $130 million. Annual O&M: $10 million.
- **Rome, Italy** (2001): Implementation: $72 million. Annual O&M: $4 million
- **London, England** (2003): Implementation: $170 million. Annual O&M: $161 million.
- **Stockholm, Sweden** (2006): Implementation: $500 million. Annual O&M: $35 million.[267]

Chapter 12 Traveler Information

Source: ©iStockphoto.com/Hillary Fox

Public and private agencies that collect, process, and broadcast traveler information can help travelers make more informed decisions regarding departure times, route choice, and mode of travel. With timely traveler information, travelers can defer or delay trips, select alternate routes, or use transit services to help reduce congestion. Travelers may also decide to drive a different vehicle or use snow tires or chains based on weather-related traveler information. In recent years, traveler information seekers have come to expect reliable access to timely and detailed information about traffic conditions, weather conditions, transit schedules, work zones, and special events.

ITS applications providing traveler information can provide assistance to travelers prior to their trip or while en route. Pre-trip information includes traffic, road weather, transit, and work zone information most commonly posted on Internet Web sites, made available on 511 or other telephone systems, or broadcast on local media such as radio and TV. En-route information can be made available via roadside or in-terminal message signs or via various devices in the vehicle. These applications include technologies that collect real-time data from one or more agencies or sources, process the data into meaningful information useful to travelers, and then provide information to travelers.

Categories

Pre-Trip Information

- Internet/Wireless
- 511
- Other Telephone
- TV/Radio
- Kiosks

En Route Information

- Wireless
- 511
- Other Telephone
- Radio
- In-Vehicle Systems

Tourism and Events

- Travel Services
- Advanced Parking

> *The most successful traveler information systems have been those deployed with significant public support.*

ITS can support tourism and special events by providing information to travelers in unfamiliar areas as well as travelers and patrons that need guidance during major events such as sporting events or concerts. These types of information services typically focus on traveler convenience and improving access to local businesses. Information provided can include features that support applications for electronic yellow pages, parking management, and electronic payment.

This chapter focuses on traveler information systems that typically draw information from multiple sources across a metropolitan area or region. The chapters on arterial, freeway, transit, traffic incident, and road weather management discuss experiences of agencies collecting information on the system for which they are responsible and providing it to travelers.

Findings

As of July 2011, there were 174 evaluation summaries of Traveler Information applications in the Knowledge Resource databases, as shown in Figure 12-1. The Traveler Information category with the largest number of summaries is Pre-Trip Information, with 141 summaries, followed by En-Route Information (111 summaries), and Tourism and Events (30 summaries), as shown in Figure 12-2.

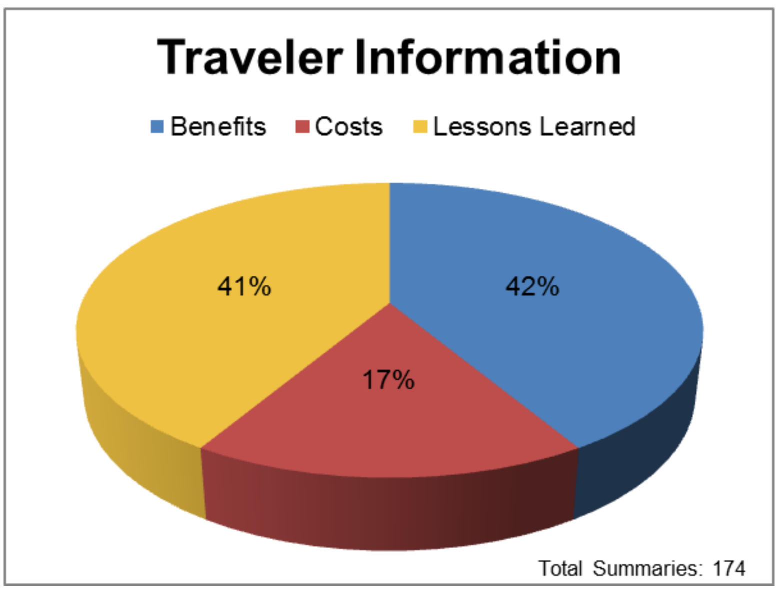


Figure 12-1. Traveler Information Summaries in the Knowledge Resources

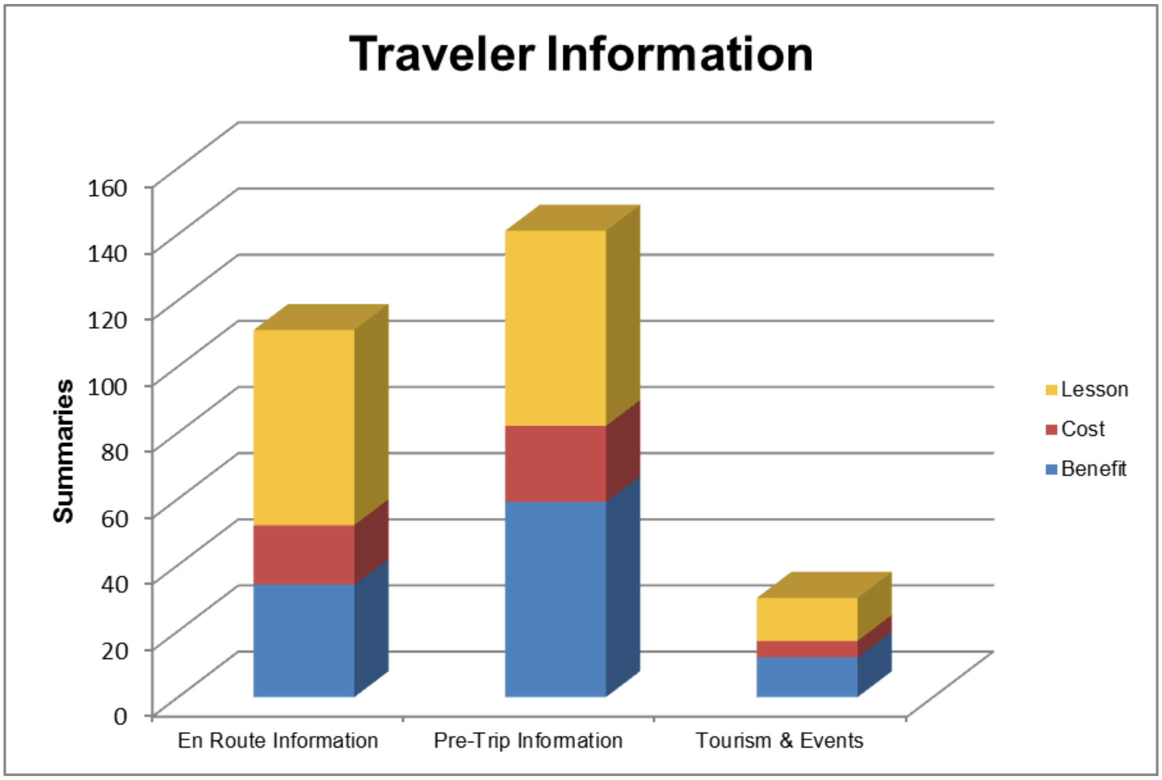


Figure 12-2. Summaries in the Knowledge Resources by Traveler Information Category

Benefits

Evaluation of traveler information services show that these systems are well received by those that use them. Benefits are found in the form of improved on-time reliability, better trip planning, and reduced early and late arrivals. The overall number of people who use traveler information on a daily basis represents a relatively small portion of travelers in a region; however, demand can be extremely high during periods of severe weather, emergencies, or special events. Traveler information systems during these periods have recorded extremely high usage. Recent studies indicate that traveler information can be very effective during periods of non-recurring congestion caused by unexpected events such as incidents. Benefit-cost ratios range from 16:1 to 25:1.[268] Although the estimated impacts are lower for transit traveler information compared to highway traveler information, simulation models indicate that up to up to four percent of travelers will shift to transit when adequate information is available. Data reliability, however, is critical. In order to gain and maintain public trust, traveler information must be accurate. The U.S. DOT FHWA has recommended that traveler information such as travel time data be at least 80 to 90 percent accurate.[269]

> *Traveler information can have large benefits during unexpected events such as incidents, prompting up to 4 percent of travelers to shift to transit.*

Commuters who choose environmentally friendly routes and modes can reduce their carbon footprint by 20 percent.

With increased awareness of environmental issues and advancements in personal communications, travelers can now monitor and improve travel choices in real-time using GPS-equipped cell phones and multi-modal route guidance tools, and Web sites that help commuters improve the performance of individualized travel plans (route, mode and timing selections). For example, a pilot program in Japan found that participants who were able to monitor, evaluate, and adjust their travel behavior reduced their Carbon footprint by 20 percent.[270]

Historically, the most successful traveler information systems have been those deployed with significant public support.[271] 511 deployments, for example, have been very successful. With increased information available on traffic and road conditions, work zones, weather, traffic incidents, and travel times, 511 system now serve more than 181 million Americans or 66 percent of the population in 36 states.[272] Going forward, there will be significant opportunities for increased public and private partnerships as the U.S. DOT continues to pursue strategies to develop a nationwide real-time traffic information system. With exponential increases in the number of GPS-equipped mobile phone users in the United States, the private marketplace has begun to validate the concept of using mobile phones as probes. In the next few years, additional evaluation data should become available as the U.S. DOT facilitates public and private sector competencies and fosters advancement of innovative solutions needed to collect and disseminate real-time traffic information.

As shown by Table 12-1, traveler information systems have demonstrated the ability to improve mobility for travelers using them. The systems can also enhance network traffic distribution, modestly improving effective capacity and reducing fuel consumption and related emissions. As discussed above, several evaluations have documented positive customer satisfaction ratings for the systems.

Table 12-1. Traveler Information Benefits Summary

Traveler Information Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Pre-Trip Information		◉	◉		◉	●
En-Route Information		◉		◉	◉	●
Tourism and Events						●

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	↓↑ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

Historically, interactive voice response (IVR) features of 511 systems have been a major cost driver. Data indicate the average costs to design, implement, and operate a 511 system for the first year can range from $1.8 million for a metropolitan system to $2.5 million for a statewide system. The costs to disseminate traveler information using an Internet Web site can be much less. Web site development costs can vary widely depending on the level of software development and integration required. Rural transit traveler information Web sites, for example, can be implemented for under $12,000, whereas Web sites that integrate TMC data and include multi-modal data for a regional or metropolitan area can cost over $250,000 to implement and operate over the first year.[273, 274]

Deployment

Between 2007 to 2010 the percentage of agencies targeting traveler information to mobile devices expanded substantially.

The Internet has become a major travel information medium, supporting both pre-trip planning and en route decision making as shown in Figure 12-3, Figure 12-4, and Figure 12-5. Survey data collected from large metropolitan areas having a population of one million or more between 2007 and 2010 have indicated for the first time that traveler information based on infrastructure systems such as radio and DMS are migrating to in-vehicle messaging through mobile devices and social media such as Twitter. The low cost and wide reach of these sources are attractive to agencies.[275]

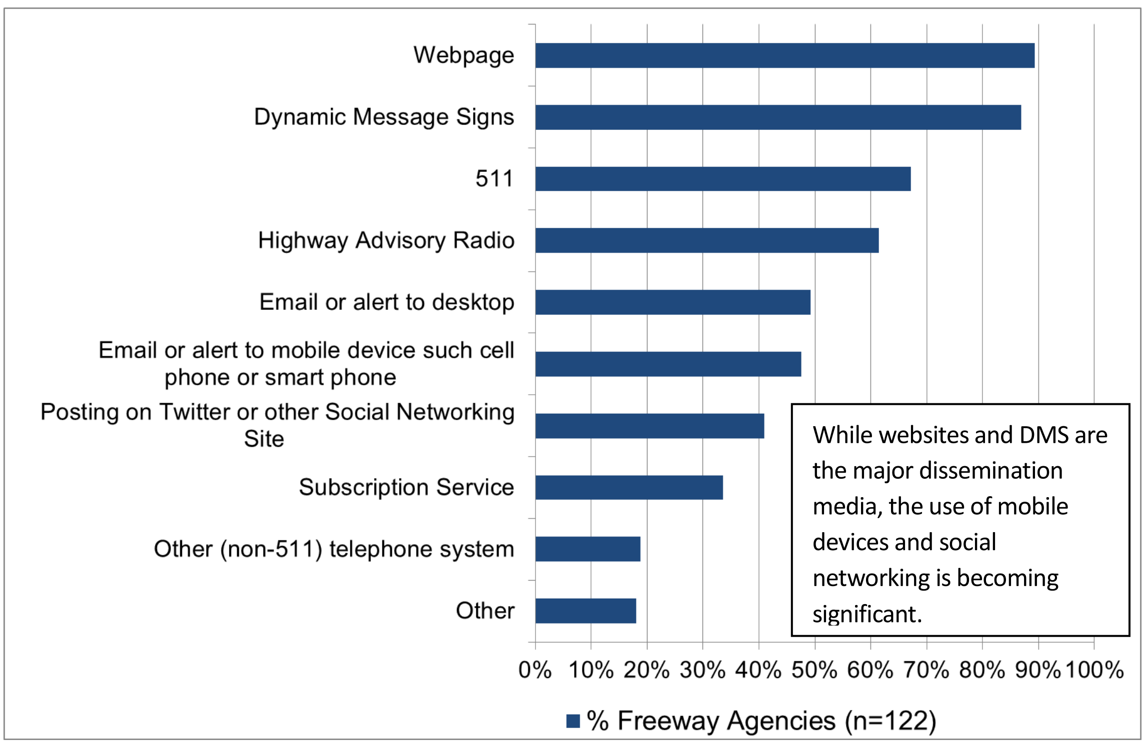


Figure 12-3. Methods to Distribute Traveler Information Adopted by Freeway Management Agencies

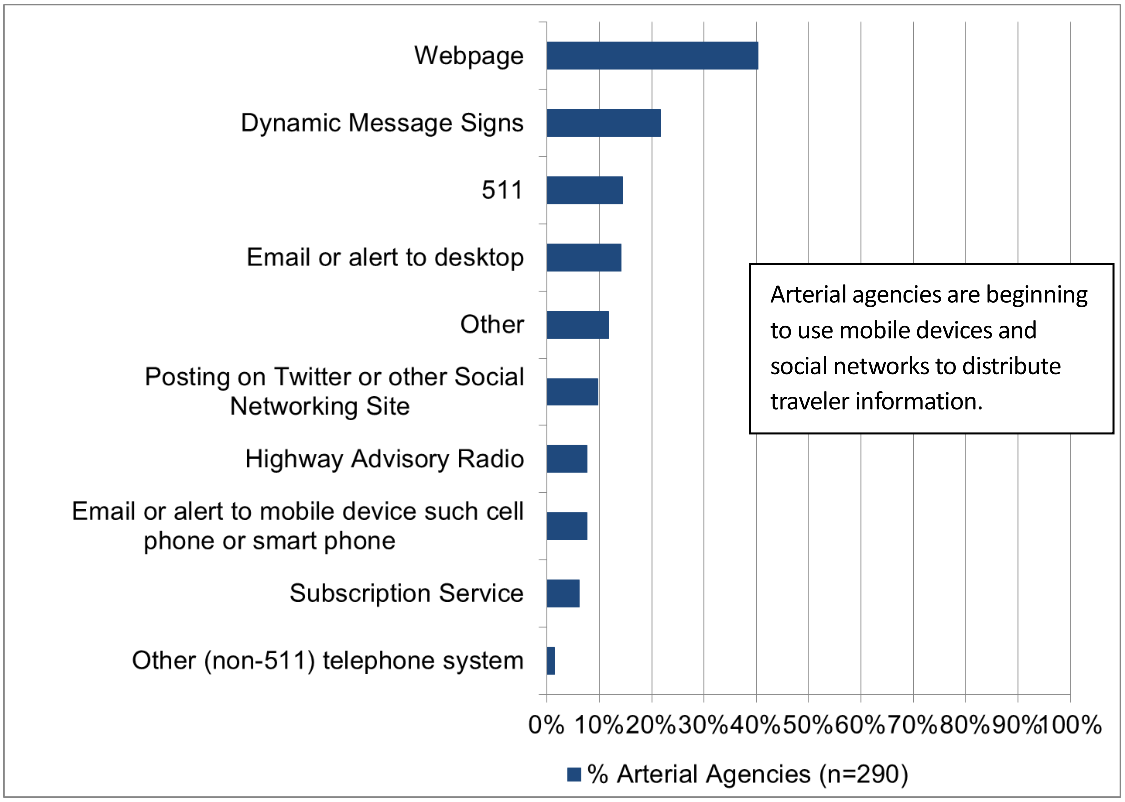


Figure 12-4. Methods Used to Distribute Traveler Information by Arterial Management Agencies.

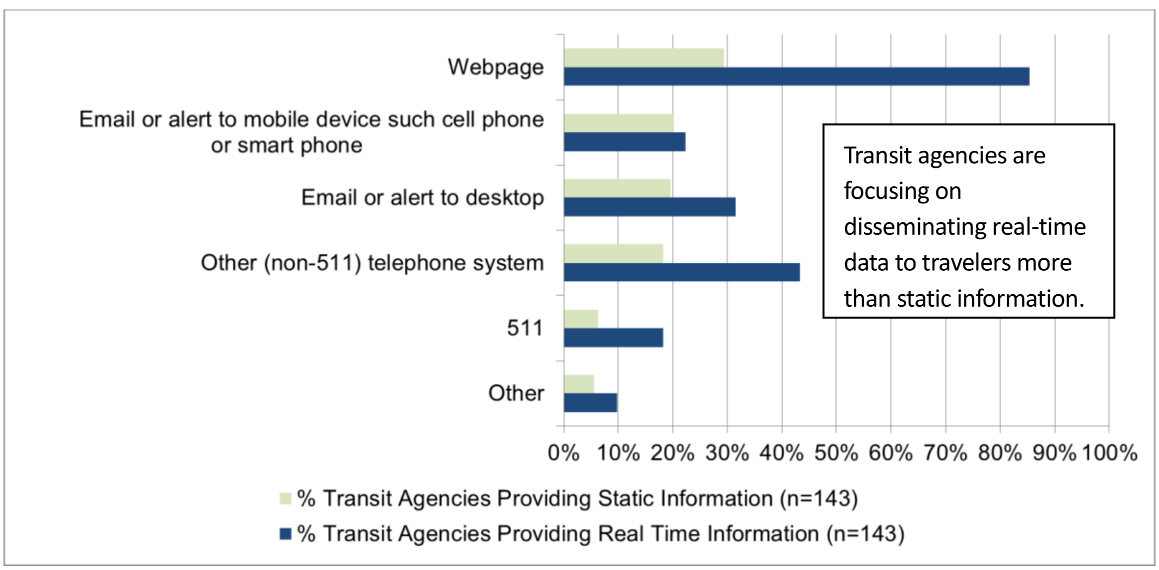


Figure 12-5. Methods Used to Distribute Traveler Information by Transit Management Agencies.

Selected Highlights from the ITS Knowledge Resources on Traveler Information

Traveler Information

Traveler information applications use a variety of technologies, including Internet Web sites, telephone hotlines, as well as television and radio, to allow users to make more informed decisions regarding trip departures, routes, and mode of travel.

Traveler Information
Deployment
2010 Deployment Tracking Survey data indicate that the Internet is the most common medium for traveler information dissemination and is used by nearly 89 percent of freeway management agencies, 40 percent of arterial agencies, and 85 percent of transit agencies. In addition to using Web pages, email has become an important method of distributing both pre-trip information (alerts to desktop, subscription services) and en route information (alerts to mobile devices). The next most widely adopted traveler information technology includes 511 systems and highway advisory radio which are used by approximately 60 percent of agencies. Interestingly, slightly over 40 percent of agencies reported using social networking sites to distribute traveler information.[276]

Pre-Trip Information

Pre-trip traveler information provided via Internet Web sites, other wireless devices, 511 telephone numbers, other telephone services, television, radio, or kiosks allows users to make more informed decisions for trip departure, route choice, and mode of travel.

Pre-Trip Information	
Benefits	
ITS Goals	**Selected Findings**
Productivity	In the San Francisco area, simulation models found that traveler information can have large benefits on major corridors during unexpected events, such as incidents. Benefit-cost ratios ranged from 16 to 25. Although the majority of benefits were derived from highway traveler information, transit traveler information was also effective in prompting up to four percent of travelers to shift to transit.[277]
Energy and Environment	In Japan, a personalized travel planning system provided commuters with GPS equipped cell phones and Internet access to help them analyze their daily travel behavior and choose more environmentally friendly routes and modes. Survey data indicated the system influenced travel behavior (primarily mode selection) enabling volunteers to reduce carbon dioxide emissions by 20 percent during their daily commutes.[278]

Pre-Trip Information
Costs
Unit Costs Data Examples
Information Service Provider subsystem: • Information Service Provider Hardware: $18K-$27K • Information Service Provider Software: $273K-$547K • Information Service Provider Labor: $277K-$396K (annually) Remote Location subsystem: • Informational Kiosk: $9K-$20K Transportation Management subsystem: • Hardware for Traffic Information Dissemination: $2K - $3K • Software for Traffic Information Dissemination: $18K-$22K • Integration for Traffic Information Dissemination: $85K-$103K • Labor for Traffic Information Dissemination: $116K-$142K (annually)
Sample System Costs of ITS Deployments
Washington State: A traveler information system deployed on State Route 14 was implemented in two phases. Phase 1 (the Columbia Gorge Traveler Information System Pilot Program) cost $300,000, and included two DMS units, a highway advisory radio (HAR) station, and one RWIS station equipped with a CCTV camera. Phase 2 (SR 14 Traveler Information System Enhancements) cost $211,300, and included one HAR station and one DMS. The system was designed to communicate with the Southwest Region TMC and aid WSDOT personnel with roadway management activities. RWIS data also were made available on the WSDOT public Web site.[279]

En-Route Information

En-route traveler information provided via wireless devices, 511 telephone numbers, other telephone services, radio, and in-vehicle signing allows users to make informed decisions regarding alternate routes and expected arrival times.

En-Route Information	
Benefits	
ITS Goals	**Selected Findings**
Mobility	In San Francisco, DMS units displayed highway and transit trip times including departure times for trains. Evaluation data indicated that 1.6 percent of motorists switched to transit when the time savings were less than 15 minutes, and 7.9 percent of motorists switched to transit when the time savings were greater than 20 minutes.[280]
Productivity	Vehicle probes used to monitor traffic in North Carolina and South Carolina delivered travel times and traffic speeds to travelers on freeways and arterials at a quarter of the cost of microwave or radar detector alternatives.[281]

En-Route Information	
Customer Satisfaction	***Summary Finding**:* Customer satisfaction with regional 511 deployments range from 68 to 92 percent. In 2004, 92.3 percent of users surveyed in the San Francisco Bay Area were satisfied with 511 and, in Montana, 90.3 percent were satisfied. On the I-81 corridor in Virginia, 99 percent of users surveyed said they would call again. In 2005, the 511 model deployment evaluation project in Arizona found that 71 percent of users were satisfied. In Washington, satisfaction levels were at 68 percent and 87 percent of the callers said they would call again.[282]
Costs	
Unit Costs Data Examples	
Roadside Information subsystem: examples include • Dynamic Message Sign: $41K-$101K Information Service Provider subsystem: • Information Service Provider Hardware: $18K-$27K • Information Service Provider Software: $273K-$547K • Information Service Provider Labor: $277K-$396K (annually) Remote Location subsystem: • Informational Kiosk: $9K-$20K Transportation Management subsystem: • Hardware for Traffic Information Dissemination: $2K - $3K • Software for Traffic Information Dissemination: $18K-$22K • Integration for Traffic Information Dissemination: $85K-$103K • Labor for Traffic Information Dissemination: $116K-$142K (annually)	

Tourism and Events

Tourism and event-related travel information systems focus on the needs of travelers in areas unfamiliar to them or when traveling to major events such as sporting events or concerts. These services address issues of mobility and traveler convenience. Information provided can include electronic yellow pages as well as transit and parking availability.

Tourism and Events	
Benefits	
ITS Goals	**Selected Findings**
Productivity	A traveler information system in the Grand Canyon National Park provided visitors with information on the availability of a shuttle used for car-free access to the Canyon View Visitor Information Plaza. The system added 368 shuttle riders per day and increased the transit mode share by 45.7 percent.[283]

Tourism and Events
Costs
Unit Costs Data Examples
Roadside Information subsystem: • Dynamic Message Sign: $41K-$101K Information Service Provider subsystem: • Information Service Provider Labor: $277K-$396K (annually) Remote Location subsystem: • Informational Kiosk: $9K-$20K Transportation Management subsystem: • Software for Traffic Information Dissemination: $18K-$22K • Integration for Traffic Information Dissemination: $85K-$103K
Sample System Costs of ITS Deployments
Arizona: A traveler information system installed in the Grand Canyon National Park was operated over a three month period. The total system cost was estimated at $24,000 and included the following: • Rental fee for two solar powered portable HAR units (with communications license) at $1600 per month for three month • Rental fee for one portable DMS at $50 per day for 90 days • Delivery/pick-up for one portable DMS at $300 • Two static signs with flashing beacons at $5000 each.[284]

Lessons Learned: Smart parking programs should be user-friendly and help travelers find and reserve available parking spaces.

During the BART Smart Parking Field Test in San Francisco participants had the option to reserve parking spaces through an online reservation system or a telephone Interactive Voice Response (IVR) system. Overall, users expressed greater satisfaction with the online system versus the IVR system. In regards to the online reservation system, users noted that:

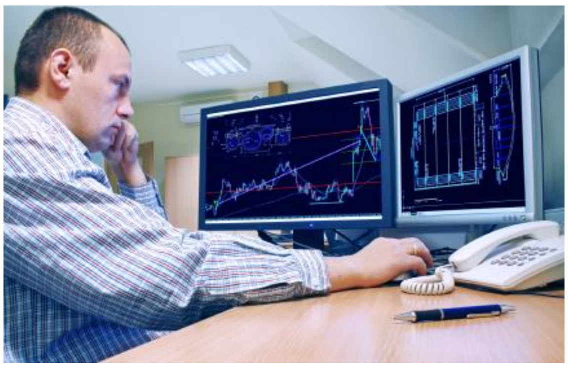
- **The process for creating an account should be simple.**
- **A parking reservation reminder sent to a mobile phone or personal digital assistant (PDA) would be helpful.**

In regards to the IVR system, users noted that a successful IVR system should:

- **Repeat and confirm information; understand verbal commands in noisy environments.**
- **Include multiple language options; provide a touchtone option for users having difficulty with the voice recognition.**

A courtesy phone or kiosk should be provided near the parking lot for those travelers without a mobile phone.[285]

Chapter 13 Information Management



Source: ©iStockphoto.com/kryczka

Intelligent transportation systems collect large amounts of data on the operational status of the transportation system. Archiving and analyzing this data can provide significant benefits to transportation agencies.

Archived data management systems (ADMS) collect data from ITS applications and assist in transportation administration, policy evaluation, safety, planning, program assessment, operations research, and other applications. Small-scale data archiving systems can support a single agency or operations center, while larger systems support multiple agencies and can act as a regional warehouse for ITS data. Transportation management centers (TMCs) provide an opportunity for centralized collection of data collected by ITS. However, TMC performance requirements are necessary during ADMS development for the successful development of such a system.

Example uses of archived ITS data include the following:

- Incident management programs may review incident locations to schedule staging and patrol routes, and frequencies for service patrol vehicles.
- Historical traffic information can be used to develop predictive travel times.

Categories

Data Archiving

- Transit agencies may review schedule performance data archived from automatic vehicle location, computer-aided dispatch systems and/or automatic passenger counting systems to design more effective schedules and route designs, or to manage operations more efficiently.

The most common uses for archived data by arterial management agencies were traffic analysis, operations planning and analysis, traffic management, and capital planning.

As information management and data archiving systems evolve they are moving from archiving information from a single source or system to more complex implementations. In order to provide support for regional operations across jurisdictional and agency boundaries data fusion from multiple sources and/or agencies, integration of both real time and archived information, and data visualization are being incorporated. They are also providing applications for exploring transportation problems covering issues from the impacts of incidents, to recurring bottlenecks, to bus bunching, to transit schedule adherence and the capture of new performance measures for reliability and sustainability.[286] More and more archived data is being used to analyze the effectiveness of other ITS applications such as incident management or traveler information systems, and to develop the inputs for travel forecasting and traffic or transit simulation models. [287]

Information management and data archiving from both infrastructure and mobile sources in data environments are also the foundation of the Real -Time Data Capture and Management track of the ITS Research Program.

The collection and storage of data on transportation system performance often occurs at TMCs. The transportation management centers chapter discusses TMCs in detail. In addition, the transit management chapter discusses the archiving and use of transit performance data.

Findings

As of July 2011, there were 30 evaluation summaries of Information Management applications in the Knowledge Resource databases, as shown in Figure 13-1, all of which fall under the Data Archiving category under Information Management.

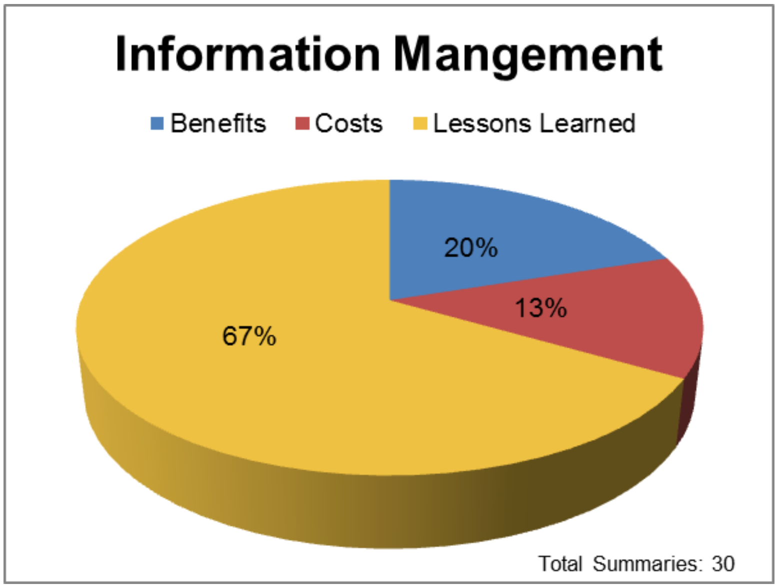


Figure 13-1. Information Management Summaries in the Knowledge Resources

Benefits

Data archiving enhances ITS integration and allows for coordinated regional decision making. Traffic surveillance system data, as well as data collected from commercial vehicle operations, transit systems, electronic payment systems, and road weather information systems have been the primary sources of archived data available to researchers and planners. Often the benefits of the archived data systems are indirect. The archived data provides information not previously available, and enables analyses of problems and solutions not possible with traditional data. As more advanced data analysis techniques develop and the efficiency of data reporting systems are improved, additional examples of the effectiveness of information management systems will become available.

As shown in Table 13-1, results of studies to date have demonstrated the cost savings that can be achieved by agencies making use of archived ITS data. A study reviewing over 60 data archiving programs documented substantial returns on the investments made in the programs. Stakeholders making use of archived data also had positive experiences to report.

Table 13-1. Information Management Benefits Summary

Information Management Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Data Archiving			◉	●		◉

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

The costs to develop ADMS vary based on the size of the system and features provided. Based on limited data available from a study of six transportation agencies that have established ADMS, costs for one system was $85,000 and $8 million for another. Four of the six systems were developed jointly with a university. Typically, the state DOT pays for the development with the university hosting the system. Operations and maintenance (O&M) costs were in a closer range, $150,000 to $350,000; these costs were usually on an annual basis.[288] In the Northeast, the University of Maryland hosts the Regional Integrated Transportation Information System (RITIS) which collects, archives, and provides data fusion and visualization for agencies in the Washington DC region and beyond. The system costs about $400,000 a year to maintain and operate (in 2011). Costs for an agency to integrate their data within RITIS have varied depending on the system and effort required for integration from a low of $15,000 to a high of $300,000.[289]

In 2011, it cost approximately $400,000 per year to maintain and operate the Regional Integrated Transportation Information System for the Washington DC region.

Foundation system development must also be carried out as part of creating an archived data system. Montana developed a public road information system that included a digitized road inventory using mobile global positioning technologies for $823,000. The system is used to support data collection, storage, and retrieval of public road information and for 911 emergency response.[290]

Deployment

The archiving of ITS data is becoming standard practice across the country. The most recent ITS deployment survey (2010) shows the top three types of information archived by Freeway Management Agencies in large Metropolitan Areas were traffic volumes (70 percent), speed data (68 percent), and save lane occupancy information (50 percent) (Other data archived include vehicle classifications, travel times, road conditions, weather conditions, and video surveillance). For Arterial Management Agencies the top three (3) types of archived data included traffic volumes (38 percent), speed data (23 percent), and phasing/cycle lengths (21 percent). The top three (3) types of data archived by Transit Agencies included vehicle time and location (45 percent), passenger counts (36 percent), and incident data (22 percent).

Table 13-2 shows the percentage of arterial, freeway, and transit management agencies that reported using archived data for various functions from a survey of the country's large metropolitan areas in 2010. Responses were received from 290 arterial management agencies, 122 freeway management agencies, and 143 transit agencies. The most common uses for archived data by arterial management agencies were traffic analysis, operations planning and analysis, traffic management, and capital planning/analysis. Most common uses for archived data reported by freeway agencies were traffic analysis, operations planning and analysis, capital planning/analysis, construction impact determination, safety analysis and monitor system performance. Transit agencies most frequently reported using archived data for operations planning/analysis, performance measurement, capital planning/analysis, safety analysis, and dissemination to the public. In general the information archived and its use increased dramatically from the previous ITS deployment surveys.

Table 13-2. Uses for Archived Data by Agencies in Large Metropolitan Areas in 2010

	Arterial Management (n=290)	Freeway Management (n=122)	Transit Management (n=143)
Accident prediction models	2%	5%	3%
Capital Planning / Analysis	19%	48%	24%
Construction Impact Determination	19%	47%	6%
Dissemination to the Public	1%	28%	12%
Incident Detection Algorithm Development	3%	16%	2%
Monitor/Measure System Performance	13%	40%	34%
Operations Planning / Analysis	29%	60%	48%
Planned Special Events	11%	NA	NA
Roadway impact analysis	8%	25%	NA
Safety Analysis	12%	40%	20%
Traffic Analysis	39%	69%	NA
Traffic Control / Management	28%	31%	3%
Traffic Simulation Modeling	18%	29%	NA
Travel Time Prediction	45%	31%	NA

Source: Deployment of ITS: A Summary of 2010 National Survey Results, August 2011.

Selected Highlights from the ITS Knowledge Resources on Information Management

Data Archiving

Data archiving is the collection, storage, and distribution of ITS data for transportation planning, administration, policy, operation, safety analyses, and research. Data archiving systems make use of a variety of software, database, and electronic data storage technologies.

Data Archiving	
Deployment	
Data collection and archiving were reported by arterial management agencies in 77 metropolitan areas, by freeway management agencies in 49 metropolitan areas, and by transit agencies in 38 metropolitan areas.	
Benefits	
ITS Goals	**Selected Findings**
Efficiency	In Portland, Oregon, the Tri-Met transit agency used archived AVL data to construct running time distributions (by route and time period) and provide enhanced information to operators and dispatchers. Evaluation data indicated that the reduced variation in run times and improved schedule efficiency maximized the effective use of resources.[291]
Productivity	In Chattanooga Tennessee the transit agency, CARTA, found that by using a data archiving warehouse, they saved $72,000 by being able to produce reports in-house that they formerly needed to hire contractors to produce. Every month this tool saves the CARTA purchaser two days' labor because of improved access to necessary information. CARTA estimates that the system paid for itself in 1.39 years.[292]
Productivity	In Portland Oregon, a bus stop spacing model was developed that accounts for both operations and potential ridership. A case study was conducted using one bus route using one year's stop-level archived Bus Dispatch System (BDS) data provided by TriMet Transit. The stop optimization and consolidation resulted in time savings of 5.4 minutes per inbound AM trip, or 5.9 hours of service time per day providing approximately $100,000 of potential operating cost savings per year. The time reduction also leads to reduced bus cycle times and therefore could also be used to provide up to 12 additional trips (using the same fleet), reducing the average headway from 18 to 15 minutes.[293]
Productivity	In the San Francisco, California region a case study on using archived data as a tool for operations planning looked at how archived data was used for the Metropolitan Transportation Commission's Freeway Performance Initiative. The case study found that archived data provided several advantages over traditional corridor study data collection: It proved to be cost effective since individual data collection for each corridor study would have been cost prohibitive due to their 30 to 60 mile extent or not possible at all. Since the archived data were readily available significant time savings in conducting the studies were also achieved.[294]
Customer Satisfaction	In Virginia, a Web-based ADMS was deployed to provide decision makers and other transportation professionals with traffic, incident, and weather data needed for planning and traffic analysis. An assessment of Web site activity (from 2003 to 2005) indicated that 80 percent of the Web site usage was devoted to downloading data files needed to create simple maps and graphics. Overall, users were pleased with the ability to obtain a variety of data; but they wanted more data on traffic counts, turning movements, and work zones, as well as broader coverage.[295]

Data Archiving
Costs
Sample System Costs of ITS Deployments
Maryland: The Regional Integrated Transportation Information System (RITIS) is an automated data sharing, dissemination, and archiving system. RITIS improves transportation efficiency, safety, and security through the integration of existing transit and transportation management data in Virginia, Maryland, and Washington D.C. across jurisdictional and agency boundaries. The two main RITIS functions include—the real-time fusion and exchange of regional transportation data; and data archiving. In 2011 it cost approximately $400,000 per year to maintain and operate RITIS with its current participants, data, and applications. Costs for an agency to integrate their data within RITIS have varied depending on the system and effort required for integration from a low of $15,000 to a high of $300,000.[296]   **Illinois:** In Northeast Illinois Estimated costs for a consolidated regional data archive system vary depending on how it is implemented. If the systems is hosted by a partnering agency the implementation/startup costs are estimated to be from $746,000 to $1,046,000 with annual O&M Costs at $423,000 (in 2008$). If a University hosts, the implementation costs are the same but the O&M Costs are less at $312,000 per year. Contracting with a National Lab reduces the initial costs to $700,000 to $1,000,000 and has annual $O&M costs of $419,000.[297] A single data warehouse is expected to provide better decision making based on a single repository encompassing the entire region. The ready availability of extensive data may help operators in real time make more informed and thus better control and traveler guidance decisions. With aggregated data from several agencies, correlations among events stored in several existing systems can be studied and used to improve operations.   **Washington, California, and Arizona:** A study was conducted of six successful ADMS and included cost data from three of the agencies. The annual software upgrades for the California DOT Freeway Performance Measuring System ranged from **$150,000 to $250,000 per year** and required approximately 1.5 full-time equivalent positions. Biannual budgets, which included software improvements, ranged from **$250,000 to $350,000** for the Washington State Transportation Center ADMS. The annual maintenance cost for the Maricopa County Arizona Regional Archive Data Server is estimated at **$150,000**, but does not include hardware or software upgrades.[298]

Lessons Learned: Provide data visualization and analysis applications to build support for data archiving and transportation ITS and Operations overall.

Michael Pack, Director of the Center for Advanced Transportation Technology at the University of Maryland which manages the multi jurisdiction and system RITIS archive for the Washington DC region explains the success of the RITIS system despite common complaints of other such as "we can't afford to collect the data we need", "nobody cares about or understands ITS and operations", and "we can't get data this is of acceptable quality." This is often the result of not properly communicating the importance of the data, not showing all the benefits and value of the data, only using each type of data for the specific use it was collected for, and not maximizing the use of the data. Data tends to be stove piped. He argues, as demonstrated by the RITIS System, that an alternative approach is to focus on visualization and easy accessibility of the information:

- **Give everyone a real reason to want to collect data and support your programs.**
- **Provide data fusion of information from different sources and systems so users have more and a more complete picture of the transportation system than they would have using just their own resources or archives of individual systems.**
- **Provide easy, free access to all of the data (or as much as you can legally can) to everyone.**
- **Develop interesting, fun, useful applications for the data that make people aware of what you are doing.**

This results in others seeing the benefits of the transportation data services and gaining a better understanding of how ITS and operations benefits the transportation system and responds to real time events and changing conditions.[299]

Lessons Learned: Archived Data helps resolve conflicts between traditional data sources, but also requires knowledge and resources to properly mine the information and use in a credible way.

A case study on using archived data as a tool for operations planning in San Francisco, California found that the detail and additional information (e.g. 24/7, or additional network coverage) provided by the archived data helped resolve conflicting findings between different data sources. The archived information helped provide quality assurance on more traditional data collection. However, the study also found that the successful application of archived data depended on both the consulting team's ability to fully mine the data and the credible use of the data. If data were not analyzed, assessed for reasonableness, and compared against other sources, or if the data had been misinterpreted, the conclusions from the analysis could be unreliable.[300]

Lessons Learned: Training is important for Archived Data User Service (ADUS) acceptance and increased use.

In California, CALTRANs found that training was needed for their PeMS archive system to increase awareness of the system and correct common fallacies about ADUS tools. Outreach is needed to make users aware of the archived data and its services.

The PeMS systems started in 1998, but by 2006 dissemination inside of Caltrans was still via word of mouth. To expand awareness, over 34 training sessions were provided. A few advanced traffic engineers had picked it up on their own, and over 75 percent of those trained had never used the system. Many were not aware of its full capabilities.

The data and the tools used by ADUS are complex enough to require training. During the training, users asked how to get the input information for traditional manual analysis methods rather than how to do computations using the more complete 24/7 archived data. An example concerns calculating delay for lane closures. Users were surprised that there were different ways to do the calculations and automate the process. Users were also concerned with data quality. Assurance was needed that the archived ITS detector based calculations were high quality. The training described the data and the calculations used by the archived data and tools. At the end of training, ninety–three percent of the participants stated that it was a good class.[301]

Chapter 14 Commercial Vehicle Operations

Source: ©iStockphoto.com/WendellandCarolyn

With trucks responsible for much of the overall freight movement and carrying approximately two-thirds of the value of goods in the United States, traffic conditions and operational factors that result in unreliable delivery times and missed deliveries can have major business implications. For example, In 2005, increased traffic congestion, unpredictable travel times, and higher fuel expenditures contributed to a 17 percent increase in inventory-carrying costs and a $74 billion increase in trucking costs.[302] The recent rapid increases in trucking fuel costs and the focus on greenhouse gases and emission have also increased the interest in the trucking industry for improvements in efficient and "green" operations.

ITS applications for commercial vehicle operations (CVO) are designed to enhance communication between motor carriers and regulatory agencies, particularly during interstate freight movement. ITS can aid both carriers and agencies in reducing operating expenses through increased efficiency and assist in ensuring the safety of motor carriers operating on the Nation's roadways. The American Transportation Research Institute's (ATRI) annual survey of critical issues in the trucking industry reflects this potential with issues that are related to CVO technologies and systems continually appearing in the top 10 list of concerns including: onboard truck technology (requirements for electronic onboard

Categories

Credentials Administration

- Electronic Funds
- Electronic Registration/Permitting

Safety Assurance

- Safety Information Exchange
- Automatic Inspection

Electronic Screening

- Safety Screening
- Border Clearance
- Weight Screening
- Credential Checking

Carrier Operation and Fleet Management

- Automatic Vehicle Location/Computer Aided Dispatch
- On-Board Monitoring
- Traveler Information

Security Operations

- Asset Tracking
- Remote Disabling Systems

recorders, etc.), environmental impacts, truck size and weight, fuel costs and Congestion/Highway Infrastructure.[303]

The Federal Motor Carrier Safety Administration (FMCSA) created the CVISN program with the goal of improving the safety and efficiency of CVO. The CVISN Program provides a framework or "architecture" that enables CVISN stakeholders – government agencies, the motor carrier industry, and other parties engaged in commercial vehicle safety assurance, regulation, and operations – to share and use information and technology to improve safety and security and to conduct business transactions electronically. The CVISN program includes a collection of information systems and communications networks that support CVO. These systems and networks include information systems owned and operated by governments, motor carriers, and other stakeholders. Nationwide CVISN deployment will be accomplished by developing and deploying information systems that will support new capabilities in three areas: safety information exchange (SIE) to standardize the exchange of vehicle and driver safety information; credentials administration which provides electronic registration and permitting at state agencies allowing carriers to register online, decreasing the turn-around time associated with permit approval; and electronic screening to focus inspections on likely violators and reduce the time and cost of inspections (both by inspectors and carriers) . CVISN deployment in a state is measured by the achievement of a core capability within each of the three major capability areas.[304]

As of June 2011, 23 states had completed core deployment of CVISN and were working on expanding the core capability.

A state achieving a core CVISN capability is required to have established the following:

- An organizational framework for cooperative system development among State agencies and motor carriers.
- A State CVISN System Design that conforms to the CVISN Architecture and can evolve to include new technology and capabilities.
- All the elements of three capability areas using applicable architectural guidelines, operational concepts, and standards.

Specific requirements for each of the three major capability areas are shown in Table 14-1.

Table 14-1. CVISN Core Capability Requirements

Capability Area	State CVISN Core Capabilities
Safety Information Exchange	• ASPEN (or equivalent) at all major inspection sites. • Connection to the Safety and Fitness Electronic Records (SAFER) system to provide exchange of interstate carrier and vehicle snapshots among states. • Implementation of the Commercial Vehicle Information Exchange Window (or equivalent) system for exchange of intrastate and interstate snapshots and connection to SAFER for exchange of interstate snapshots.

Capability Area	State CVISN Core Capabilities
Credentials Administration	• Automated processing (i.e., carrier application, state application processing, credential issuance, and tax filing) of at least International Registration Plan (IRP) and International Fuel Tax Agreement (IFTA) credentials: ready to extend to other credentials (intrastate, titling, oversize/overweight, carrier registration, and hazardous materials (HAZMAT)). Note: processing does not necessarily include e-payment. • Connection to IRP and IFTA clearinghouses. • At least 10 percent of the transaction volume handled electronically, with the state ready to bring on more carriers as carriers sign up and ready to extend to branch offices where applicable.
Electronic Screening	• Implemented at a minimum of one fixed or mobile inspection site. • Ready to replicate at other sites.

As the CVISN Program advanced, a set of expanded CVISN capabilities were identified that would continue to improve commercial motor vehicle safety and security and extend the services provided through CVISN. These capabilities are designed to:

- Enhance the safety, security, and productivity of commercial vehicle operations, and
- Improve the access to and quality of information about commercial drivers, carriers, vehicles, chassis, cargo, inspections, crashes, compliance reviews; and citations for authorized public and private sector users.

FMCSA, in conjunction with public and private stakeholders, identified 40 capabilities that could be integrated into the CVISN program (and be funded through CVISN grants). These capabilities were segmented into the following four expanded CVISN program areas:

- Driver Information Sharing
- Enhanced Safety Information Sharing
- Smart Roadside
- Expanded Electronic Credentialing

Electronic screening promotes safety and efficiency for commercial vehicle operators. Trucks equipped with low-cost, in-vehicle transponders can communicate with check stations. Communication equipment at the roadside can automatically query regulatory data as trucks approach these stations and issue a red or green light on in-vehicle transponders, so drivers know whether to continue on the mainline (bypass) or report to the station for possible inspection.

In the United States, there are currently two major national electronic screening programs, the North American Pre-clearance and Safety System (NORPASS) and the PrePass™ program.[305] As of March 2011, the NORPASS program was available in 10 states and Canadian provinces operating at 48 sites (with 3 more under construction) and had an enrollment of approximately 114,000 trucks. The PrePass™ program was available in 30 states operating at 292 sites and had an enrollment of approximately 416,555 trucks.[306] The Oregon Green Light program has also reported significant growth. Since the first Green Light station was opened in 1997, 22 stations are operational and the program serves 37,348 trucks equipped with transponders.[307]

Day-to-day CVO are supported by many other ITS technologies. Automated vehicle location (AVL) and computer-aided dispatch (CAD) technologies assist with scheduling and tracking of vehicle loads. On-board monitoring of cargo alerts drivers and carriers of potentially unsafe load conditions. Real-time traffic information dissemination helps carriers choose alternate routes and departure times and avoid traffic congestion and inclement weather. Asset tracking technologies enable motor carriers to monitor the safety and security of fleet assets and cargo.

Related to CVO technologies are technologies that facilitate efficient freight transport—especially across modal connections, such as truck-air, truck-rail and rail-sea. These technologies are discussed in the intermodal freight chapter.

The Electronic Freight Management (EFM) initiative, a major ITS initiative being conducted by the U.S. DOT, also has the potential to enhance CVO and freight management. Through the EFM, the U.S. DOT seeks to develop service-oriented, Web-based technologies that will improve information exchange between multiple entities (both government and commercial) and increase the efficiency of cargo transfer. The new Web-based services are intended to improve the visibility of shipments in the supply chain, reduce redundant data entry, improve diagnostic tracking, simplify interfaces with government authorities, and enhance security.[308] Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/efm.

CVO technologies and services are also increasingly being integrated into Federal safety and other regulations. These regulations include: the mandated use of Electronic On Board Recorders (EOBRs) to help monitor Hours of Service (HOS) for carriers with poor safety records, and a notice of proposed rulemaking released in 2011 to extend the use of EOBRs to all vehicles; and, the installation of speed limiters/governors for speed management and onboard safety systems (e.g. roll stability control and Department of Defense trailer tracking rules for transporting the military's high-security and sensitive commodities (arms, ammunition, and explosives). FMCSA also recently announced a pilot to use GPS to track Mexican based trucks and carriers while they are in the United States as part of its implementation of the North American Free Trade Agreement (NAFTA) cross-border long-haul trucking provisions, Additional information on these and other regulations is available at the FMCSA website: www.fmcsa.dot.gov.

The Department is looking towards the future through the Smart Roadside short term intermodal research. Smart Roadside is the development of roadside infrastructure for commercial vehicle operations that employs technologies for information sharing. The vision for Smart Roadside research is to demonstrate, evaluate, and deploy interoperable technology and improved data sharing to improve safety, security, operational efficiency, and mobility on the Nation's freight transportation system. As shown in Figure 14-1, Smart Roadside will provide the foundation and interoperability between a number of ongoing activities and applications. Initially, four applications that are in various stages of deployment/development are targeted by Smart Roadside: E-screening, Truck size and weight, Wireless Roadside Safety Inspection, and Truck Parking Research.[309]

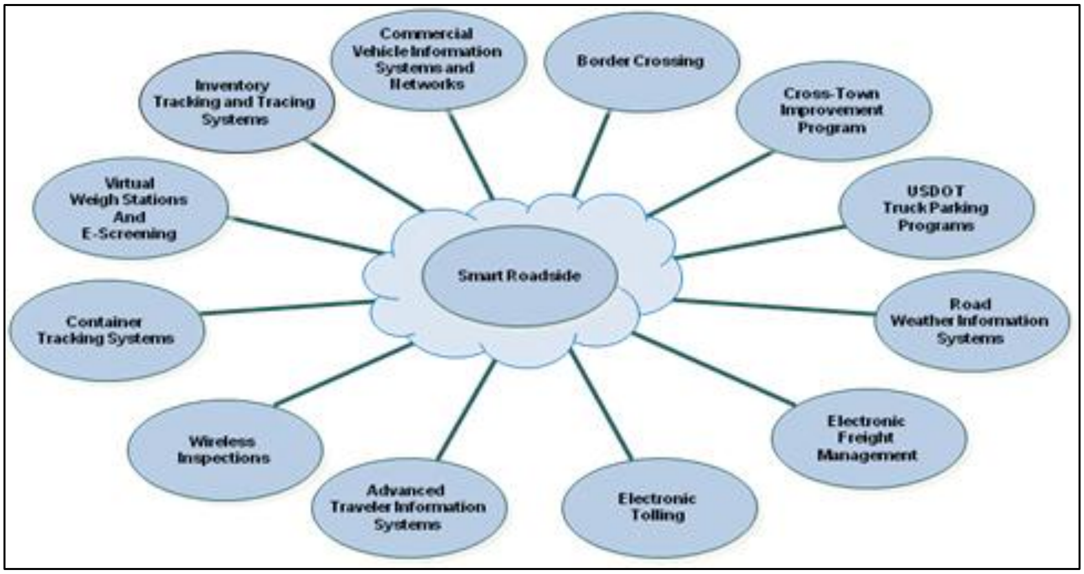


Figure 14-1. Roadside Programs/Projects for Integration or Interoperability with Smart Roadside

Findings

As of July 2011, there were 77 evaluation summaries of Commercial Vehicle Operations applications in the Knowledge Resource databases, as shown in Figure 14-2. The Commercial Vehicle Operations category with the largest number of summaries is Electronic Screening, (43 summaries), followed by Safety Assurance (23 summaries), Credentials Administration (21 summaries), Carrier Operations and Fleet Management (19 summaries), and Security Operations (five summaries), as shown in Figure 14-3.

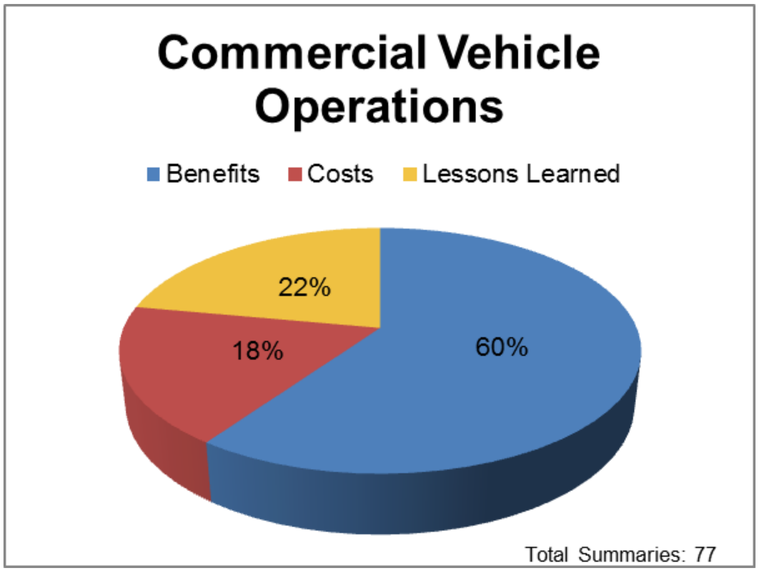


Figure 14-2. Commercial Vehicle Operations Summaries in the Knowledge Resources

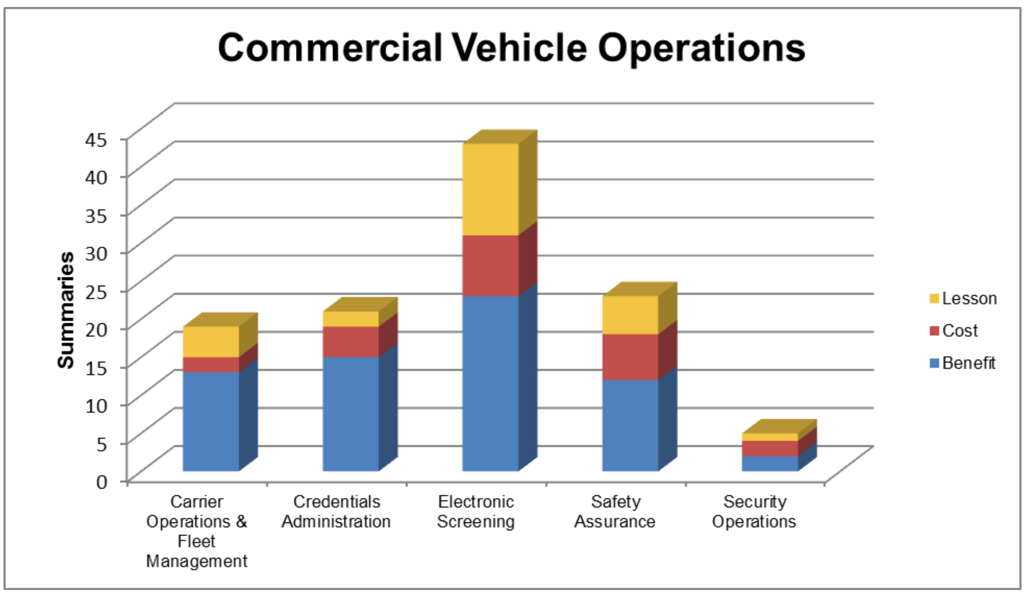


Figure 14-3. Summaries in the Knowledge Resources by Commercial Vehicle Operations Category

Benefits

Table 14-2 documents experience with the ITS applications for CVO. The various strategies that have been evaluated have shown substantial improvements under the safety, mobility and productivity goal areas. Electronic credentialing reduced paperwork and saved carriers both time and money. It allows trucks to be placed in service an average of 3.5 days sooner than paper-based systems, and results in a labor savings of $4.13 (reduction of 10-12 minutes per transaction), and a $1 savings in materials and postage (providing a payback of costs in less than a month and a return on investment ratio of 2,971:1).[310] Electronic screening has been shown to moderately reduce emissions through reduced congestion at inspection stations and trucks given a “bypass” by the screening system avoid delays and save fuel. Drivers and operating companies are generally satisfied with the various programs, though particular applications have been troubling to truck drivers in some instances. Carriers have favorable opinions of commercial vehicle electronic clearance overall though participation and awareness vary by carrier size. In the nationwide survey conducted for the National CVISN Evaluation carriers with 100 or more power units, 71.3 percent were aware of and 45.5 percent used e-credentialing; carriers with 10 to 99 power units 47.4 percent were aware and 14.7 percent used e-credentialing; and for carriers with less than 10 power units 32.1 percent were aware and only 12.2 percent used e credentialing.[311]

Table 14-2. Commercial Vehicle Operations Benefits Summary

Commercial Vehicle Operations Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Credentials Administration				●		●
Safety Assurance	●					⇅
Electronic Screening		●	●	●	◉	●
Carrier Operations and Fleet Management		●		●		●
Security Operations						
● – substantial positive impacts	◉ – positive impacts					
○ – negligible impacts	⇅ – mixed results					
✖ – negative impacts	(blank) – not enough data					

Costs

To help states track their own progress in deploying CVISN technologies, a self-evaluation requirement was included in the partnership agreements between the U.S. DOT and individual states. Self-evaluation reports are expected to foster the widespread deployment of CVISN through the sharing of timely, accurate, usable information among states. A process for reporting CVISN costs data was established, and the results of the costs data collection and analysis were published and the costs data imported to the ITS Costs Database.[312] Examples of the CVISN costs data are presented in the "Selected Highlights from the ITS Knowledge Resources on Commercial Vehicle Operations" section below. The reader is encouraged to access the ITS Costs Database for complete details on CVISN unit costs.

The Evaluation of the National CVISN deployment program based its update of CVISN costs on two major sources: self-evaluations and site visits to four states (Montana, New Jersey, New York, and South Dakota). It found that costs did vary widely from state to state based upon the state's size, and the level and type of systems it chose to deploy. For electronic credentialing the average start up cost per state was about $1.35 million (with a range of $28,037 to $8.5 million) and the annual operating and maintenance cost was about $250,000 per year ($22,645 to $1,091,968). For safety information exchange systems the costs was roughly $680,000 ($31,000 to $2.7 million), with about $74,000 per year in operating costs. Electronic screening systems startup costs varied from $1 million to $2.8 million.

ITS strategies were identified for "full" deployment scenarios to determine the potential benefits from a coordinated and complementary system in three metropolitan areas: Seattle, Tucson, and Cincinnati. The ITS strategies for CVO included weigh-in-motion (WIM), SIE, and a combination of screening and clearance for credentials and safety. For Seattle and Cincinnati, the average lifecycle costs of the resources necessary to implement, operate, and maintain CVO estimated for 2003 conditions were $23 million and $23.1 million, respectively. For Tucson, the average lifecycle costs of the resources necessary to implement, operate, and maintain CVO estimated for 2025 conditions was $20.2 million. It is important to note for CVO, a portion of these costs are to the private sector for the equipment needed on commercial trucks to enable automated screening and clearance deployments at check stations. The number of trucks in the scenarios ranged from 53,000 to 60,000.[313]

The National Evaluation found that benefit-cost ratios for roadside enforcement range from 1.9:1 to 7.5:1.

Benefit-Cost Studies

CVISN technologies are cost-effective, increasing safety; simplifying credential checking and tax administration; and lowering the costs of freight handling, fleet management, and vehicle operations.

A comprehensive evaluation of the CVISN program was completed in 2009. It found that the benefits and costs of the CVISN program to each state depend on the system configuration and cost, level of deployment, and the benefits of crash avoidance gained through increased compliance. The National Evaluation found that benefit/cost ratios for roadside enforcement range from 1.9:1 to 7.5:1 depending on the scenario deployed. Electronic credentialing provides a benefit/cost ratio of 2.6:1. "Taken together, these results indicate that all aspects of the National CVISN Deployment Program examined in this BCA are expected to produce significant net benefits to society and are economically justified."[314]

Deployment

As shown in Figure 14-4, as of June 2011, 23 states had completed core deployment of CVISN and were working on expanding the core capability. Twenty-three (23) states and the District of Columbia are in the process of deploying the core capability. Four states are the process of planning and design of their core CVISN capability.[315]

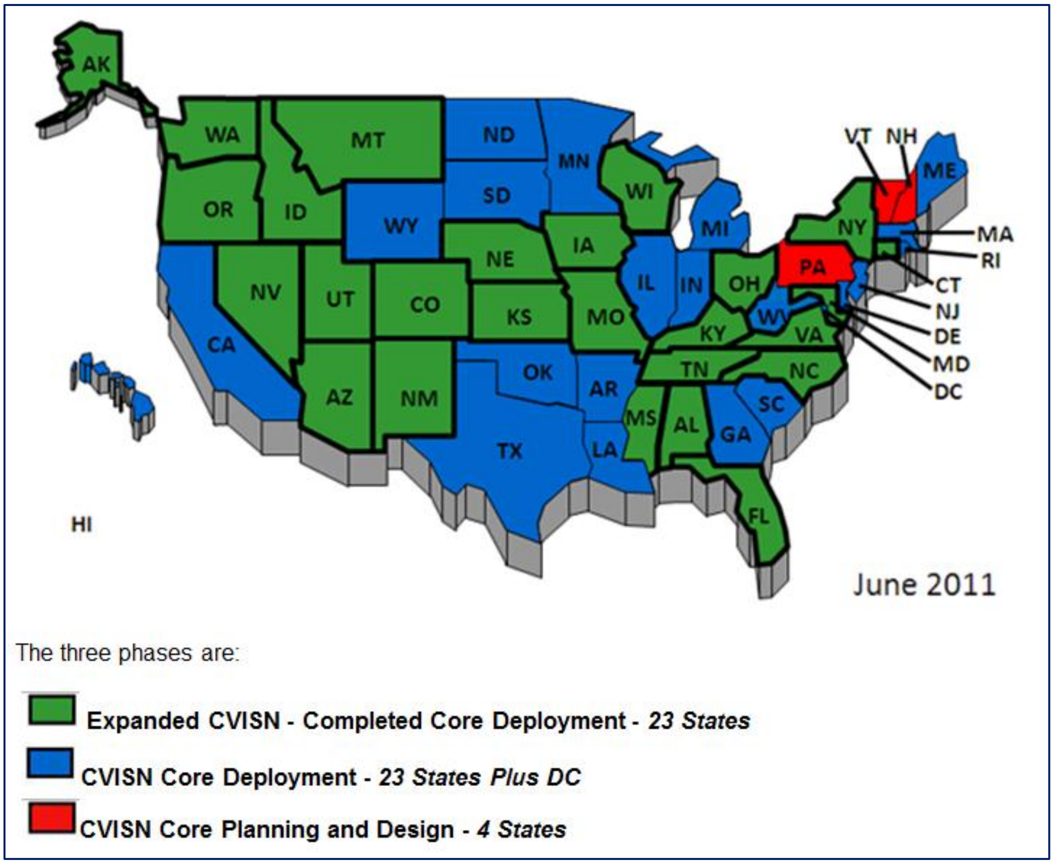


Figure 14-4. Status of CVISN Deployment

Selected Highlights from the ITS Knowledge Resources on Commercial Vehicle Operations

Credentials Administration

Electronic registration and permitting at State agencies allow carriers to register online, decreasing the turn-around time associated with permit approval.

Credentials Administration	
Benefits	
ITS Goals	**Selected Findings**
Customer Satisfaction	In a Nationwide motor carrier survey of over 800 firms, for those that participated in e-credentialing the three most important factors considered when deciding to participate were convenience of obtaining credentials, potential staff time savings, and getting trucks into service more quickly. Approximately 94 percent of the participating carriers found e-credentialing more convenient, over 80 percent realized savings in staff time worked, and 58 percent achieved cost savings.[316]

Credentials Administration	
Customer Satisfaction	Approximately 50 percent of CVISN managers surveyed indicated that CVISN electronic credentialing systems can save staff time and labor, allowing additional support to be assigned to more critical agency functions. Comments from several state agencies show that CVISN electronic credentialing and safety inspection software can improve data quality, reduce clerical errors, and make it easier and less time consuming for carriers to apply for and renew credentials.[317]
Productivity	A survey of 38 interstate motor carriers found that electronic credentialing expedited the credentialing process for new trucks and increased overall efficiency. It is faster and more accurate than paper based systems, enables one-stop licensing and permitting (IRP, IFTA, and Oversize-Weight). This allows trucks to be placed in serves an average of 3.5 days sooner than paper-based systems, and results in a labor savings of $4.13 (reduction of 10-12 minutes per transaction), and a $1 savings in materials and postage. Payback of costs was less than a month and the return on investment ratio was 2,971:1. The annual average net benefit per firm was estimated at $360,500.[318]
Costs	
Unit Costs Data Examples	
Commercial Vehicle Electronic Credentialing/Administration subsystem: • State Employee Labor International Registration Plan (IRP) Credentialing (Legacy): $50K-$178K (per 1,000 accounts, annually) • Contractor Labor for IRP Credentialing: $6.9K-$18.5K (per 1,000 accounts, annually) • State Employee Labor International Fuel Tax Agreement (IFTA) Credentialing: $15K-$121.5K (per 1,000 accounts, annually) • Vendor Labor for IFTA Credentialing: $1K-$20.8K (per 1,000 accounts, annually)	
Sample System Costs of ITS Deployments	
Nationwide: The Evaluation of the National CVISN Deployment Program reports that the average per-state start-up cost for electronic credentialing is about $1.35 million (ranges widely between a high of nearly $8.5 million to a low of $28,037). In terms of total annual cost to operate and maintain EC systems for IRP and IFTA credentials, states reported an average cost per state of about $250,000 per year, with the range extending from a low of $22,645 to a high of $1,091,968 per year.[319]	

Lessons Learned: Use the National ITS Architecture as the basis for CVISN design, supplement the architecture with standards from the CVISN program if needed.

In an evaluation of CVISN deployments across the United States, CVISN managers from 23 states provided the following recommendations on deploying electronic screening, safety information exchange, and electronic credentialing.

Understand the status of existing standards at the time of development, use the National ITS Architecture for the basis of the CVISN design, supplemented with standards from the CVISN program. Without standards, the development effort is vulnerable to changes, which will likely cause delays.

- **Maintain continuity among personnel, vendors, and consultants throughout the deployment process.**
- **Be certain that the state has a clear understanding of federal goals and objectives.**
- **Ensure that you request adequate funding.** The CVISN managers frequently cited insufficient funding as a challenge to projects, making it more difficult to retain sufficient, dedicated, and trained staff, especially in the information technology area.

Lessons Learned: Use the National ITS Architecture as the basis for CVISN design, supplement the architecture with standards from the CVISN program if needed.

The managers also provided recommendations for encouraging the expansion of CVISN:

- **Create a federal rule to standardize the placement and format of apportioned plates for efficient delivery of information to enforcement officers.** The managers identified a discrepancy between the need for national standards and the need to accommodate different formats among the states.
- **Provide a federal subsidy for operating funds to enhance enforcement functions.** The larger, lower-risk, safer carriers are in a stronger position to take early advantage of CVISN productivity and efficiency benefits; in contrast, the larger numbers of smaller, higher-risk carriers with limited economies-of-scale may face greater burden in engaging in CVISN. Providing this group with incentives may be necessary to improve participation and compliance.
- **Provide federal investment or incentives to improve mobile communications, reduce associated costs, and increase coverage.** Mobile communications are currently a key limiting factor in information exchange/ information access. [320]

Safety Assurance: Safety Information Exchange

Safety information exchange programs assist the safe operation of commercial vehicles, providing inspectors with electronic access to carrier and vehicle safety information from previous inspections.

Safety Assurance: Safety Information Exchange	
Benefits	
ITS Goals	**Selected Findings**
Safety	The Evaluation of the National CVISN Deployment Program estimated the benefits of fully utilizing the information provided by national and statewide safety databases. When compared to existing screening practices, it found that using the Carrier ISS scores to target unsafe vehicles would lead to a reduction of 1,004 crashes, 260 injuries, and 12 fatalities per year across the nation. When higher ISS scores are targeted (top 5 percent) and also established at the vehicle and driver level the reduction would be 2,460 crashes, 637 injuries, and 29 fatalities. Combining targeted screening based upon the highest past OOS rates and infrared brake inspection led to the highest reduction of 17,907 crashes, 4,638 injuries, and 215 fatalities per year. [321]
Safety	The results of field testing in Connecticut indicated that inspection selection systems supplemented with electronic sharing of safety inspection data increased out-of-service order rates by two percent. Modeling efforts estimated that the systems could prevent 84 commercial vehicle crashes per year nationwide. Further analysis indicated that if the system deployment was accompanied by a 10 percent increase in motor carrier safety compliance, then the number of crashes avoided would jump to 4,332 each year. [322]

Safety Assurance: Safety Information Exchange
Costs
Unit Costs Data Examples
Commercial Vehicle Safety Information Exchange (SIE) subsystem: • SIE Software Purchased Off the Shelf: \$6.2K-\$20.7K (per state) • State Employee Labor for New SIE Software Development: \$21K-\$132K (per state) • State Employee Labor for SIE: \$22K-\$72.91K (per state, annually) • Contractor Labor for SIE: \$16.2K-\$46.3K (per state, annually)
Sample System Costs of ITS Deployments
Nationwide: The Evaluation of the National CVISN Deployment Program reports that on average, the states paid roughly \$680,000 in safety information exchange start-up costs (ranging from a high of almost \$2.7 million to a low of about \$31,000). On average, the SIE system costs each state roughly \$74,000 annually to operate.[323]
Nationwide: A survey of 38 interstate motor carriers found that the average startup system costs for the carriers enrolled in credentialing systems were \$275 with annual recurring costs of \$125. [324] In addition, recurrent costs incur from monthly subscriptions of bypass fees and transponder maintenance and ranged from \$7 to \$14 per transponder.[325]

Safety Assurance: Automated Inspection

Automated inspection equipment can be implemented to remotely test commercial trucks for faulty equipment, such as non-functioning brakes.

Safety Assurance: Automated Inspection	
Benefits	
ITS Goals	**Selected Findings**
Safety	An evaluation of the Smart InfraRed Inspection System (SIRIS) associated with the Kentucky I-71 ISSES inspection station found that roughly 9.4 percent of the vehicles screened by SIRIS were flagged by the system as having one or more thermal issues, with brakes issues making up 91.67 percent of those. Of the vehicles flagged as having thermal issues, 86.11 percent were found to have a violation, and 83.33 percent of those vehicles were placed out-of-service (OOS). Overall, the enforcement staff was pleased with the potential of the system but found that cold or wet weather impacted its performance. [326]
Productivity	Washington State deployed a mobile inspection "thermal eye" van in 2006 that uses heat sensors to detect hot spots on commercial vehicles and RVs. The sensors rate of correctly identifying vehicles that need to be taken off the road was 44 percent which compares to a much lower out of compliance rate using random inspections alone. It also cut down on unnecessary physical screenings which on average took 30 minutes to complete.[327] In Alberta Canada a similar system had an almost 90 percent success rate in identify vehicles that needed to be taken out of service.[328]

Electronic Screening: Safety Screening

In-vehicle transponders can communicate with inspection stations to pre-screen trucks for safety records.

Electronic Screening: Safety Screening	
Benefits	
ITS Goals	**Selected Findings**
Safety	On the Interstate 71 weigh station in Kentucky, an Integrated Safety and Security Enforcement System (ISSES) was estimated to provide significant safety benefits per year. The ISSES identified high-risk heavy trucks and screened them for inspection based upon safety criteria. It incorporated both observation of truck characteristics such as brake conditions, radiation, size and weight, and automatic vehicle identification (license plate and US DOT number readers), and connection to safety databases. It was estimated to contribute to reductions in crashes between 63 and 629, personal injuries between 16 and163, and 7 fatalities per year.[329]
Mobility	A survey of 38 interstate motor carriers reported that trucks participating in electronic screening programs receiving a bypass of an inspection station had travel time savings of 10 to 12 minutes per bypass.[330]
Customer Satisfaction	For those participating in e-screening, a Nationwide motor carrier survey of over 800 firms found that the factors in their decisions to participate were the potential for reduced delays or turnaround time for shipments, the convenience or efficiency provided by e-screening, and the ability of e-screening in states where they operate. Over 99 percent of the carriers participating in e-screening experienced more convenience and efficiency, 97.6 percent experienced a reduction in shipping or turnaround time delays, and 79.4 percent observed improved working conditions for drivers and a decrease in labor costs. Carriers also mentioned increased safety of their drivers and savings on fuel costs as additional benefits.[331]
Productivity	A survey of 38 interstate motor carriers found that participating in electronic screening programs realized significant cost savings in time and labor. Carriers saved $8.68 per bypass. The Return on Investment (ROI) ranged from 6.1:1 to 15.9:1, and payback periods were less than a year. The annual net benefit per transponder equipped truck was estimated at $1,169. Total net benefits per company ranged from $3.2 to $219.4 million over the 10-year business case study horizon.[332]
Costs	
Unit Costs Data Examples	
Commercial Vehicle Electronic Screening (Pre-Clearance) subsystem: • Mainline (High Speed) Weigh-in-Motion Scale: $50.9K-$212.3K • Automated Vehicle Identification Equipment/System: $42K-$84K • Contractor Labor for Electronic Screening Software Development: $214.1K-$217.5K (per state) • Costs for Marketing, Outreach, Publicity: $0.6K-$6.4K (per state, annually)	

Electronic Screening: Safety Screening
Sample System Costs of ITS Deployments
Nationwide: The Evaluation of the National CVISN Deployment Program reports that, the states invested between $1 million and $2.8 million in electronic screening as one-time start-up costs (in 2006 dollars). However, this varies based on the business model or the ES program or partnership chosen by a given state. The average state spent almost $160,000 annually to operate and maintain an ES system (ranging from a high of $902,258 annually to a low of $11,071).[333]
Kentucky: An Integrated Safety and Security Enforcement System (ISSES) was installed on I-75 near London, Kentucky that consisted of a radiation monitor, thermal inspection device, laser scanner and vehicle detector, license plate recognition system and a USDOT number reader. The first ISSES installment cost $350,000. Two subsequent ISSES installments in Kentucky cost $500,000 each. Follow-up maintenance, monitoring and trouble-shooting costs were $109,000 per year per installation.[334]
Benefit-Cost Studies
United States: A comprehensive evaluation of the CVISN program was completed in 2009. It found that the benefits and costs of the CVISN program to each state depend on the system configuration and cost, level of deployment, and the benefits of crash avoidance gained through increased compliance. The National Evaluation found that benefit/cost ratios for roadside enforcement (e-screening) range from 1.9:1 to 7.5:1 depending on the scenario deployed (i.e. the e-screening criteria applied).[335]

Lessons Learned: Ensure that new technology deployed in a weigh station to detect high-risk heavy trucks is in alignment with state organizational goals and inspection priorities.

An evaluation of an Integrated Safety and Security Enforcement System (ISSES) installed in 2005 to detect high-risk heavy trucks in a weigh station found that the subsystems functioned according to performance specifications. The goal of the deployment was to support Kentucky Vehicle Enforcement (KVE) by automatically accessing safety information from heavy trucks as they passed the scale house in the inspection station. The system included a U.S. DOT number reader, an automated license plate recognition system (ALPR) and a laser-based system for classifying vehicles (e.g., based on the number of axles). The evaluation revealed several key lessons learned in design and deployment that may be useful in the planning and installing of similar inspection decision-aid systems in the field, as follows.

- **Deploy an inspection decision-aid system that has a purpose and function in alignment with the state's enforcement goals, measures, and inspection priorities.** The Kentucky state inspection process emphasized the quantity of inspections completed, whereas the function of the ISSES was to increase the rate of Out of Service (OOS) orders issued. Each of these goals is valid but involves different procedures and priorities. Because the purpose of the ISSES was to help inspectors focus on the trucks with the worst safety records, it did not directly support the organizational goals of the inspectors and was not perceived in general by the inspectors as helping them achieve their goals in terms of quantity of inspection performed.
- **Ensure that the weigh/inspection station has adequate staffing levels for inspectors to have the time and resources to use an inspection decision-aid system.** The staffing levels at the weigh/inspection station may have been a barrier to inspectors using the ISSES. The inspectors in general focused on the standard screening activities as opposed to the ISSES tasks. Rather than using the ISSES, inspectors relied on their visual judgment and knowledge of the carriers to select trucks for inspection. Inspector feedback suggests that they considered watching the ISSES screen for information was not a productive use of time.
- **Upon deployment, integrate the automated functions with inspection, registration, licensing and safety databases so that it provides immediate value to the weigh/inspection station.** At the Interstate 75 weigh/inspection station, the ISSES was not integrated with state or federal safety information systems. As a result, information on the truck passing through ISSES equipment was not integrated with Kentucky or federal safety data sources. Therefore, inspectors in general did not use ISSES information in their inspection selection decision.

Lessons Learned: Ensure that new technology deployed in a weigh station to detect high-risk heavy trucks is in alignment with state organizational goals and inspection priorities.

- **Systems must be designed for actual operating conditions and speeds and performance expectations, not "legal" speed limits.** The evaluation team noted that the OCR system used to read DOT numbers on the ISSES was designed for trucks traveling 15 MPH past the equipment. However, trucks routinely travel up to 20 or 30 MPH, which is over the speed limit. Automated systems require a certain amount of time to capture data from moving trucks. Likewise, inspectors need sufficient time to make an inspection decision, but are also interested in preventing a backlog of trucks.
- **Ask inspectors to provide input when selecting the location of the detectors and station equipment.** The ISSES equipment may have been too close to the scale house to allow time for the inspectors to interpret information displayed on the ISSES display screen and decide whether to pull a truck over for inspection. The site should be further enough from the scale house to allow the time to process data and display information to the inspectors. [336]

Electronic Screening: Border Clearance

In-vehicle transponders can communicate with customs check points to pre-screen trucks for safety records, border clearance, and proper credentials.

Electronic Screening: Border Clearance	
Benefits	
ITS Goals	**Selected Findings**
Productivity	An evaluation of the integration of CVISN at the Nogales Port of Entry in Arizona demonstrated that cost efficiencies of the port's inspection booths could potentially be improved by 30 percent by implementing CVISN. Specifically, shippers save an estimated $228,120 per year and the port operates with a 32.2 percent improvement in inspection efficiency. CVISN provided automated clearance for 3,802 vehicles per year that otherwise would have been subject to traditional inspections. In addition the port saved roughly 1.9 FTE in inspection staff time.[337]
Productivity	The Customs ACE Truck e-Manifest allows motor carriers to submit electronic versions of mandated paperwork in advance of the truck physically crossing the border. The evaluation included both a survey of participating carriers and a scenario based cost-benefit analysis. The survey results were mixed primarily due to early adoption learning curves, training and other initial set up costs. In all but one of the scenarios the annual savings varied between $2,632.50 to $7,897.50 per driver, $2,275 to $2825 per clerk, and $2,762 to $5,525 per Customs analyst. When a routine cargo is red flagged and pulled in for inspection when it otherwise would not have been the carrier experiences costs of $60.75 and $81.00 per trip.[338]
Productivity	The Santa Teresa radio frequency identification device (RFID) E-Screening Demonstration Project used RFID transponders to electronically screen commercial vehicles through New Mexico's state border-crossing facility at Santa Teresa, New Mexico. The test found that using RFID tags for identification is feasible (99 percent plus reads). Full electronic verification and screening took place in less than one second compared to 15 minutes when done manually, The number of vehicles screened for full compliance was also increased by 300 percent. The system positively identified compliant/noncompliant vehicles more than 99 percent of the time, enabling officers to focus their efforts on vehicles with "fail" reads and on those which were not transponder-equipped.[339]

Electronic Screening: Credential Checking

In-vehicle transponders can communicate with weigh stations and customs check points to pre-screen trucks for proper credentials.

Electronic Screening: Credential Checking Benefits	
Benefits	
ITS Goals	**Selected Findings**
Mobility	In Colorado, an automated pre-screening system installed at three port-of-entry check stations allowed PrePass™ subscribers to bypass inspection stations if their credentials were in order. Evaluation data indicated that the automated system saved approximately 8,000 vehicle-hours of delay per month.[340]
Energy and Environment	In Colorado, an automated pre-screening system installed at three port-of-entry check stations allowed PrePass™ subscribers to bypass inspection stations if their credentials were in order. Evaluation data indicated that the automated system saved 48,200 gallons of fuel per month.[341]
Productivity	A survey of 38 interstate motor carriers found that participating in electronic screening programs realized significant cost savings in time and labor. Carriers saved $8.68 per bypass. The Return on Investment (ROI) ranged from 6.1:1 to 15.9:1, and payback periods were less than a year. The annual net benefit per transponder equipped truck was estimated at $1,169. Total net benefits per company ranged from $3.2 to $219.4 Million over the 10-year business case study horizon.[342]
Productivity	Pre-clearance systems that use interagency coordination to deploy interoperable electronic toll collection (ETC) and electronic screening systems improve the efficiency of motor carrier operations by saving them time and money. Interoperable applications incorporated into a single transponder can save carriers between $0.63 to $2.15 per event at weigh stations. The greater the number of interoperable applications incorporated into a single transponder, the greater the benefit. The estimated benefits realized by industry through participation in ETC and electronic screening, when combined through interoperability, double in value.[343]
Productivity	A survey of 38 interstate motor carriers found that participating in electronic screening programs realized significant cost savings in time and labor. Carriers saved $8.68 per bypass. The Return on Investment (ROI) ranged from 6.1:1 to 15.9:1, and payback periods were less than a year. The annual net benefit per transponder equipped truck was estimated at $1,169. Total net benefits per company ranged from $3.2 to $219.4 Million over the 10-year business case study horizon.[344]

Carrier Operations and Fleet Management: Automatic Vehicle Location/Computer-Aided Dispatch and Onboard Monitoring Systems

AVL and CAD can assist carriers with scheduling and tracking of vehicles and freight. Onboard monitoring is becoming an integral part of the recently deployed AVL/CAD systems (with various monitoring options).

Carrier Operations and Fleet Management: AVL/CAD and Onboard Monitoring	
Benefits	
ITS Goals	**Selected Findings**
Mobility	In Europe, several projects investigated management systems designed to improve the operating efficiency of carriers. Centralized route planning systems reduced vehicle travel distances by 18 percent and decreased travel time by 14 percent.[345]
Energy and Environment	Tire Pressure Monitoring and Maintenance Systems can provide significant cost savings and save fuel. Preliminary results from a field operational test showed a 1.4 percent improvement in overall fuel economy, longer tire life and reduced road calls. [346]
Costs	
Unit Costs Data Examples	
Commercial Vehicle subsystem: • Global Positioning System (GPS)/Differential GPS (DGPS): $0.4K-$1.5K • Cargo Monitoring Sensors and Gauges: $0.11K-$0.23K Fleet Management subsystem: • Vehicle Location Interface: $10K-$15K • Software for Tracking and Scheduling (COTS): $10K-$34K	
Sample System Costs of ITS Deployments	
United States: The HAZMAT Transportation Safety and Security Field Operational Test (FOT) was conducted to assess commercially-available, off-the-shelf technology that could be deployed in the near term to enhance the safety and security of HAZMAT transportation operations. Part of the assessment included collecting cost data of the different technologies. On-board monitoring technologies included software products to monitor engine diagnostics and vehicle maintenance that ranged in costs from **$10,000 to $33,000**.[347]	

Lessons Learned: Account for accuracy and privacy issues in using truck transponder data for developing real-time traveler information applications.

A field study reported by the Oregon Department of Transportation (ODOT) and Oregon Transportation Research and Education Consortium (OTREC) examined the feasibility of producing freight corridor performance measures and real-time travel time estimates from truck transponder data collected at weigh-in-motion (WIM) stations in Oregon. Obtaining performance measurement data can help agencies assess the corridor performance in terms of mobility, reliability, safety, and reducing costs and environmental impacts. Results showed that truck transponder matching algorithms support long-term monitoring of freight corridor performance, but that applications for real-time traveler information are limited when data quality is poor (e.g., incorrect time stamps). When data quality is good, the research indicates that it is possible to detect corridor delays, especially those that are weather-based, by calculating average speeds and standard deviations.

Results highlight the following lessons learned.

- **Consider truck transponder data as a data source for monitoring freight corridor performance measures**: For freight corridors, performance measures that can be evaluated using the transponder-linked WIM data include: average travel time on key corridors; ton-miles on each corridor by various temporal considerations; overweight vehicles on corridors by temporal variation; empty vehicles; seasonal variability in loading, routes, and volumes; percent trucks with tags on each corridor; potentially estimating an origin-destination matrix; and average weight for various configurations.

Lessons Learned: Account for accuracy and privacy issues in using truck transponder data for developing real-time traveler information applications.

- **Account for unique characteristics of truck transponder data in order to provide reliable real time traveler information.** Transponder tag matching at successive weigh stations is useful in estimating long-term freight corridor performance. However, for reliable results when developing applications for real-time traveler information systems the design should account for:
  - The market penetration of transponder tags in freight vehicles on different types of road segments. There were enough trucks with tags (both numbers and frequency) on primary roads to establish travel times between stations but not on secondary routes.
  - The distance between weigh stations (reader locations) was relatively long. The report suggested that sensor spacing of 100 miles or less is reasonable.
  - Trucks may stop for fuel, rest, or deliveries. It will be necessary to use sophisticated algorithms to filter out trucks that made stops between stations.
  - Comparisons to passenger cars may be difficult since truck travel speeds are different.
  - Recent advances in alternative traffic monitoring technologies such as cell phone, navigation devices, vehicle-to-vehicle, vehicle–to-infrastructure, and Media Access Control (MAC) address matching may be more suitable for providing real-time traveler information.
- **Address privacy issues in any public release of truck transponder data.** Typically, state policy protects the identity of any individual truck or carrier associated with a transponder. Sanitize database archives by linking data to fictitious names and numbers.[348]

Security Operations

ITS applications can be used to ensure the security and safety of motor carriers. Asset tracking technologies can monitor the location and condition of fleet assets (e.g., trailers, cabs, and trucks), and remote disabling systems can prevent the unauthorized use of fleet vehicles and assist in asset recovery.

Security Operations	
Benefits	
ITS Goals	**Selected Findings**
Safety & Security	The HAZMAT Safety and Security Technology field operational test was conducted in working towards the goals of improving homeland security protection of truck-based hazardous materials shipments. The test deployed different technology combinations from wireless mobile communications with GPS vehicle tracking and two-way communications between the operator and dispatch, to digital phone tracking without GPS. In vehicle technologies included on-board computers, panic buttons and electronic cargo seals. Personal identification including biometrics was also explored. The technologies were estimated to reduce risk and vulnerability and therefore potential terrorist consequences by approximately 36 percent.[349]
Costs	
Unit Costs Data Examples	
Commercial Vehicle subsystem: • Driver and Vehicle Safety Sensors, Software: $0.7K-$1.5K • Cargo Monitoring Sensors and Gauges: $0.11K-$0.23K	

Security Operations
Sample System Costs of ITS Deployments
United States: The HAZMAT Transportation Safety and Security FOT was conducted to assess commercially-available, off-the-shelf technology that could be deployed in the near term to enhance the safety and security of HAZMAT transportation operations. A digital cellular phone with pickup and delivery software with phone/on-board directions/mapping costs approximately **$250 per vehicle**. This technology would also include on-site vehicle disabling with the wireless panic remote. Basic asset tracking units using satellite, terrestrial triangulation, and global positioning system-based locators cost $**139 to $500 per unit**; mid-range units cost **$375 to $450 per unit**.[350]

Chapter 15 Intermodal Freight

Source: ©iStockphoto.com/choicegraphx

The dramatic growth in freight movement over the last several years has severely strained the transportation network. Landside access to U.S. ports, congestion on highways around major gateways, delays at border crossings, and congestion at major east-west rail interchanges have created major freight bottlenecks.

With increasing threats to productivity (i.e., shortage of drivers, high insurance rates, highway congestion, and increasing fuel and labor costs), ITS technologies support efficient and reliable freight transportation along the supply chain and can help the freight industry achieve just-in-time, lean-inventory business models. [351]

Freight tracking applications can monitor, detect, and communicate freight status information to ensure containers remain sealed while en route. In addition, asset tracking technologies can monitor the location and identity of containers in real time. ITS freight terminal processes can improve operations at freight transfer stations, using information technology to expedite procedures often carried out using paper records. These technologies combined can provide an electronic freight manifest, reduce shipment processing time and increase the productivity of freight carriers and the freight transportation system. Security can be augmented by tracking devices that confirm the location and

Categories

Freight Tracking

Asset Tracking

Freight Terminal Processes

Drayage Operations

Freight-Highway Connector System

International Border Crossing Processes

condition of freight as it is sealed for transfer. ITS support for drayage operations can promote the efficient transfer of cargo by truck around major port facilities using information technology applications to provide dispatchers and truck drivers with information on vessel traffic, container/cargo availability, on- and off-port traffic conditions, and delay times at terminal entrances. At international border crossings, automation of revenue transactions and faster, more efficient confirmation of cargo manifest information can reduce delays associated with customs and tax collection processing. In addition, ITS applications that optimize traffic control and coordinate transfers near intermodal ports of entry can help reduce the strain of increased freight movement on the Nation's freight-highway connector system.

Regional intermodal freight information sharing systems that eliminate empty back-haul movements between transfer facilities can potentially reduce annual truck VMT by more than three million.

To support the U.S. DOT Congestion Initiative and reduce congestion at ports and terminals, the U.S. DOT developed the *Framework for a National Freight Policy* and implemented the Electronic Freight Management (EFM) initiative. The EFM seeks to develop service-oriented Web-based solutions that have the potential to improve information exchange between multiple entities (both government and commercial) and increase the efficiency of cargo transfer.

The *Framework for a National Freight Policy* lays out a vision and objectives and details strategies and tactics that the U.S. DOT and its partners in the public and private sectors can pursue to achieve these objectives. A draft framework was developed in 2006 and revised in 2008. Since that time, the U.S. DOT has been soliciting feedback on the policy, in order to building support among stakeholders. For more information, please visit the ITS JPO and *Framework for a National Freight Policy* Web sites: www.its.dot.gov and http://www.freight.dot.gov/freight_framework/index.cfm.

Findings

As of July 2011, there were 29 evaluation summaries of Intermodal Freight applications in the Knowledge Resource databases, as shown in Figure 15-1. The Intermodal Freight category with the largest number of summaries is Freight Tracking (18 summaries), followed by Asset Tracking and Freight Terminal Processes (with six summaries each), Drayage Operations (five summaries), and Freight-Highway Connector System and International Border Crossing Processes (one summary each), as shown in Figure 15-2.

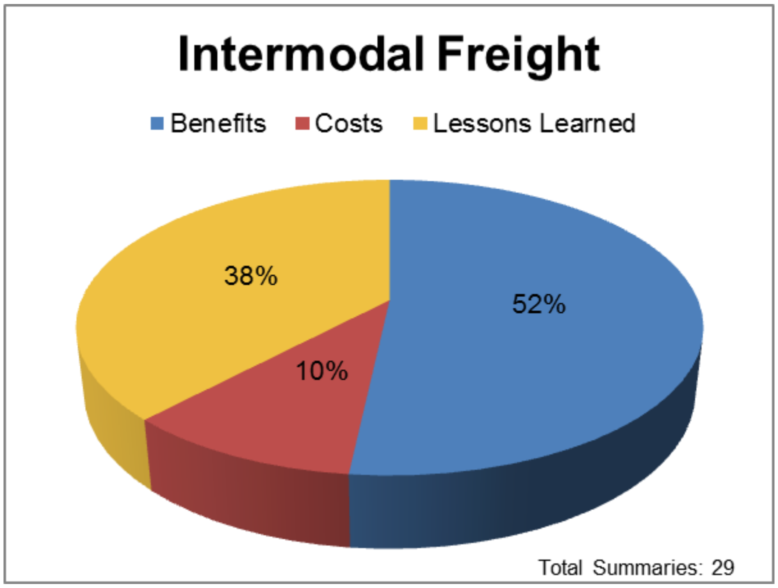


Figure 15-1. Intermodal Freight Summaries in the Knowledge Resources

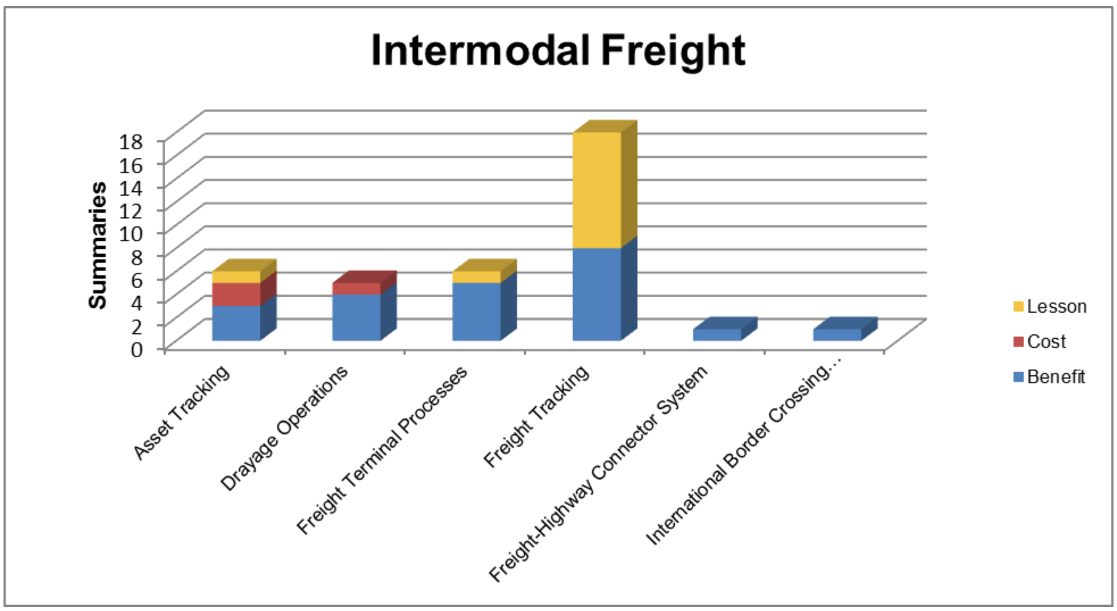


Figure 15-2. Summaries in the Knowledge Resources by Intermodal Freight Category

Benefits

EFM systems increase the ability of supply chain partners to collaborate and exchange information on the status of cargo and assets within the supply chain. Evaluation data indicate that shippers, freight forwarders, container freight stations, and customs brokers, among others, experience a wide variety of specific productivity, service quality, and data quality and availability improvements. Survey data show industry-wide benefits as well, including: reduced transportation costs, reduced administrative costs, more efficient use of inventory and shipping assets, and better service quality and shipment integrity.[352] Limited scope field testing of a prototype web-based EFM platform used by a Kansas City based importer on an international supply chain indicated that the system reduced inventory backorders, increased shipping container utilization, and facilitated customs paperwork.[353]

Table 15-1 provides an overview of evaluation findings for a variety of ITS strategies for intermodal freight. Most results indicate improvements in the mobility and corresponding productivity benefits for freight transportation companies.

Table 15-1. Intermodal Freight Benefits Summary

Intermodal Freight Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Freight Tracking				◘		●
Asset Tracking				◘		
Freight Terminal Processes				◘		
Drayage Operations		●		●	◘	
Freight-Highway Connector System						
International Border Crossing Processes		●		●		

● – substantial positive impacts	◘ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Benefit-Cost Studies

An Electronic Freight Management (EFM) system reduced inventory backorders, increased shipping container utilization, and facilitated customs paperwork, resulting in a positive economic payback over a five year period with a discount rate of 12 percent and lifespan of 5 years.[354] Compared to an outsourced IT operations scenario, an in-house IT operations scenario resulted in stronger financial impacts with lower operating costs and a higher overall benefit-cost ratio, as shown in Table 15-2.

Table 15-2. Out-sourced vs. In-house Financial IT Operations

Out-sourced vs. In-house IT Operations		
	Out-sourced IT Operations	**In-house IT Operations**
Internal Rate of Return	70.94 %	97.64 %
Payback in Years	1.31	0.99
Discounted Payback in Years	1.51	1.12
Benefit-cost Ratio	2.75	3.64

Selected Highlights from the ITS Knowledge Resources on Intermodal Freight

Freight Tracking

Freight tracking applications can monitor, detect, and communicate freight status information such as the condition and location of goods while ensuring that containerized cargo remains sealed within shipping containers while en route.

Freight Tracking	
Benefits	
ITS Goals	**Selected Findings**
Productivity	An EFM system used to reduce inventory backorders, increase shipping container utilization, and facilitate customs paperwork had a benefit-cost ratio ranging from 2.75 to 3.64. [355]
Productivity	Survey responses from 101 companies indicated that twice as many large firms realized significant benefits (greater than $500,000) from using supply chain visibility software compared to those that reported no payoff or a loss from using the technology. With respect to smaller firms, 46 percent reported benefits of greater than $100,000.[356]
Productivity	The Columbus Electronic Freight Management (CEFM) system reduced total transit time of an air-freight supply chain from 96 hours to 82 hours (14 percent) and saved $5.94 per shipment in labor costs across the entire supply chain by reducing paper work.[357]
Productivity	In Taiwan, an evaluation study found that 70 percent of the paperwork required for international air cargo shipments included redundant data entry that could have been handled by automated Electronic Supply Chain Manifest (ESCM) systems. An analysis of a typical export case indicated that an ESCM system would save freight forwarders approximately 546 New Taiwan (NT) Dollars per transaction while a partnering airline would save 66 NT Dollars. In addition, the cargo terminal would save 6.26 NT Dollars and the customs function would save 3.94 NT Dollars for each transaction.[358]

Freight Tracking
Costs
Unit Costs Data Examples
Commercial Vehicle On-Board subsystem: • Electronic Cargo Seal Disposable: \$0.008K-\$0.021K • Electronic Cargo Seal Reusable: \$0.029K-\$0.36K Fleet Management Center subsystem: • Electronic Cargo Seal Reader: \$0.2K-\$1.2K • Software for Tracking and Scheduling: \$10K-\$34K

Lessons Learned: Develop electronic communications infrastructure to enhance supply chain visibility and monitoring, mitigate disruptions and unanticipated events, and improve productivity.

Companies of varying size and technical sophistication have potential to improve productivity through implementation of EFM technologies that can improve visibility within the supply chain and help mitigate disruptions and unanticipated events.

- Collect and distribute high quality operational data. An EFM prototype test conducted by an independent evaluator to examine supply chain visibility and data sharing found that data quality is the foundation for supply chain performance improvements.

With access to accurate, timely, and complete information about anticipated product arrival times, businesses can reduce safety stocks and inventories and decrease associated administrative costs by automating manual data processing activities along the supply chain. With accurate data available that show real-time progression of individual shipments along the supply chain, companies can make minor adjustments in delivery schedules to save money, improve delivery time reliability, and increase customer satisfaction.[359]

Asset Tracking

Asset tracking technologies can monitor the location, identity, and status of mobile or stored freight containers, chassis, or other transportation assets in real time.

Asset Tracking	
Benefits	
ITS Goals	**Selected Findings**
Productivity	An importer expected to increase its shipping container space utilization by nearly four percent through the use of EFM.[360]
Costs	
Unit Costs Data Examples	
Commercial Vehicle On-Board subsystem: • Autonomous Tracking Unit: \$0.29K-\$0.7K • Autonomous Tracking Unit: \$0.12K-\$0.3K (annual service charge) • Global Positioning System (GPS)/Differential GPS (DGPS): \$0.4K-\$1.5K Freight Management subsystem: • Software for Tracking and Scheduling: \$10K-\$34K	

Freight Terminal Processes

ITS freight terminal processes can improve the efficiency of freight transfers or freight storage by activating transponder tags to track cargo containers within the terminal as they are processed and sealed for transfer or storage.

Freight Terminal Processes	
Benefits	
ITS Goals	**Selected Findings**
Productivity	An importer estimated that they would be able to reduce 10+2 filing fees by 50 percent with data elements provided by EFM.[361]
Costs	
Unit Costs Data Examples	
Commercial Vehicle On-Board subsystem: • Electronic Cargo Seal Disposable: $0.008K-$0.021K • Electronic Cargo Seal Reusable: $0.029K-$0.36K Fleet Management Center subsystem: • Electronic Cargo Seal Reader: $0.2K-$1.2K • Software for Tracking and Scheduling: $10K-$34K	

Freight-Highway Connector System

Freight-highway connector systems optimize traffic control and coordinate transfers near intermodal ports of entry to help reduce the strain of increased freight movement on the nation's highways.

Freight-Highway Connector System	
Benefits	
ITS Goals	**Selected Findings**
Mobility	C-TIP technologies that eliminate empty back-haul movements at regional intermodal freight transfer facilities have potential to generate benefits equivalent to eliminating 245,000 personal vehicle trips annually.[362]
Costs	
Unit Costs Data Examples	
Freight Management subsystem: • Software for Tracking and Scheduling: $10K-$34K	

Chapter 16 Collision Avoidance

Source: U.S. DOT Research and Innovative Technology Administration (RITA) IVBSS Web page: http://www.its.dot.gov/ivbss/

Collision avoidance systems use sensors and telecommunication networks to communicate with other vehicles as well as with the roadway infrastructure. In-vehicle warning systems can alert drivers when their vehicles are about to collide with another vehicle or with the roadside infrastructure. To improve the ability of drivers to take countermeasures, collision avoidance systems continue to be tested and deployed.

- Intersection collision warning systems (CWS) are designed to detect and warn drivers of approaching traffic and potential right-of-way violations at intersections.
- Obstacle detection systems, including side object detection systems use vehicle-mounted sensors to detect obstructions—such as other vehicles, road debris, or animals—in a vehicle's path or projected path and alert the driver.
- Lane change warning systems have been deployed to alert bus and truck drivers of vehicles, or other obstructions, in adjacent lanes when the driver prepares to change lanes.

Categories

Intersection Collision Warning

Obstacle Detection

Lane Change Assistance

Lane Departure Warning

Rollover Warning

Road Departure Warning

Forward Collision Warning

Rear Impact Warning

Forward Collision Warning systems have potential to prevent 24 percent of crashes involving large trucks.

- Lane departure warning (LDW) systems warn drivers that their vehicle is unintentionally drifting out of the lane.
- Rollover warning systems notify drivers when they are traveling too fast for an approaching curve, given their vehicles operating characteristics.
- Road departure warning systems warn drivers that their vehicle is about to leave the roadway, whether they are approaching a curve too fast, or about to drift off the road on a straight roadway segment.
- Forward collision warning (FCW) systems, also known as rear-end collision avoidance systems, warn drivers that they are in a conflict situation with a lead vehicle. These conflicts can arise when the lead vehicle is stopped, slowing, or traveling at a constant speed.
- Rear-impact warning systems warn the lead vehicle driver that they are in conflict with a following vehicle. The warning can be presented by the lead vehicle or transmitted from the following vehicle to an in-vehicle warning system in the leading vehicle.

The U.S. DOT continues to explore crash-warning system concepts and establish partnerships with industry to improve vehicle safety. In the private sector, commercial packages have become available to help drivers avoid the most common types of fatal crashes: rear-end, lane-change, and roadway departure collisions. The U.S DOT supports a variety of current research focused on advancing collision avoidance technology.

The Connected Vehicle Research Program uses wireless communication networks to enhance data exchange between vehicles and the roadside infrastructure. Vehicle to vehicle (V2V) applications provide significant opportunities to improve safety and driver situational awareness through exchange of wireless data among vehicles in the same vicinity. Vehicle to infrastructure (V2I) applications connect vehicles to a "smart infrastructure" and perform complex calculations using advanced algorithms to evaluate risk and activate countermeasures to warn drivers to mitigate crash potential. For additional information, please visit the Connected Vehicle Research Program Web site: www.its.dot.gov/connected_vehicle/connected_vehicle.htm.

The Integrated Vehicle-Based Safety System (IVBSS) initiative is focused on improving safety for light vehicles and heavy trucks. As part of this initiative, several prototype systems have been developed and tested. An independent analysis is currently underway to evaluate impacts. For additional information, please visit the IVBSS Web site: www.its.dot.gov/ivbss.

The Federal Motor Carrier Safety Administration (FMCSA) provides additional information on collision avoidance technology. Please see "On-board Safety Systems" under "Technology Product Guides" on the FMCSA Web site: www.fmcsa.dot.gov/facts-research/art-productguides.aspx.

Findings

As of July 2011, there were 47 evaluation summaries of Collision Avoidance applications in the Knowledge Resource databases, as shown in Figure 16-1. The Collision Avoidance category with the largest number of summaries is Forward Collision Warning (22 summaries), followed by Lane Departure Warning (15 summaries), and Lane Change Assistance and Obstacle Detection (nine summaries each), Road Departure Warning (five summaries), Rear Impact Warning (two summaries), and Intersection Collision Warning (one summary), as shown in Figure 16-2.

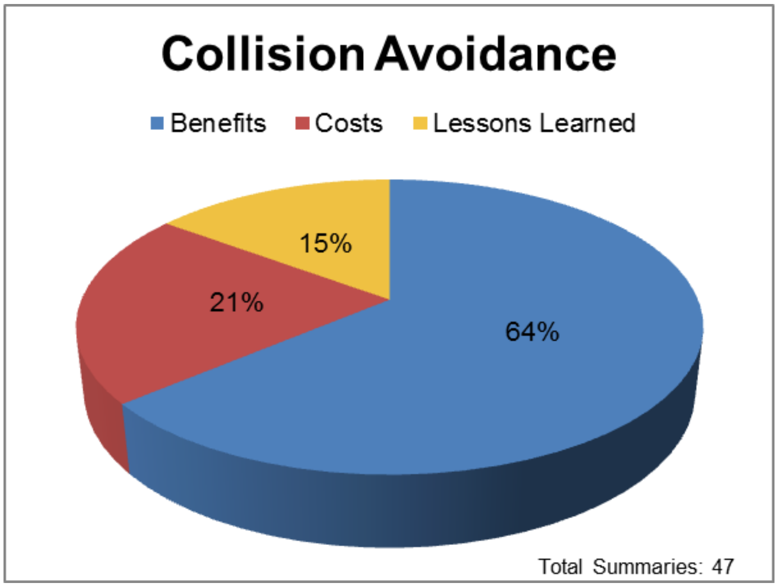


Figure 16-1. Collision Avoidance Summaries in the Knowledge Resources

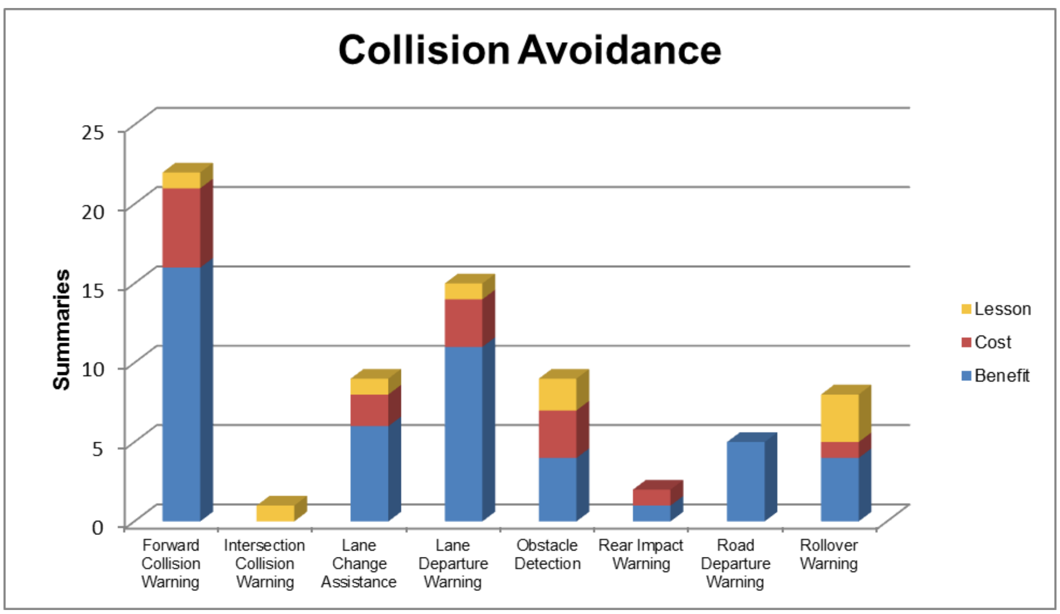


Figure 16-2. Summaries in the Knowledge Resources by Collision Avoidance Category

Benefits

Table 16-1 summarizes the research to date on collision avoidance systems and documents the potential safety benefits for each type of warning system evaluated. Several of the studies project positive impacts based on the prevalence of the particular crash types addressed, and the likelihood that the deployed systems could address these crashes. Others evaluated the performance of the systems in field deployments on test vehicles.

Forward collision warning systems can reduce crashes and improve safety for commercial vehicles;[363] however, these technologies can have high initial costs making it difficult to deploy cost-effective solutions for fleets that experience few crashes.[364] For passenger vehicles, CWS can have much broader impacts. Working with industry, the U.S. DOT estimates that widespread deployment of integrated countermeasure systems could prevent over 48 percent of rear-end, run-off-road, and lane change crashes.[365] This would represent 1.8 million target crashes.

Table 16-1. Collision Avoidance Benefits Summary

Collision Avoidance Benefits Summary	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Intersection Collision Warning						
Obstacle Detection	◘			⇅		
Lane Change Assistance	◘					
Lane Departure Warning	●			⇅		◘
Rollover Warning	●			◘		
Road Departure Warning	●					◘
Forward Collision Warning	●					
Rear Impact Warning						

● – substantial positive impacts	◘ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

Collision avoidance systems are available as factory-installed options, as standard items included in the base cost of a vehicle, or as a component of an upgrade package. Forward collision warning systems and lane departure warning systems, for example, are typically bundled and cost less than $2,000 when sold as a factory upgrade to heavy trucks and transit vehicles. [366]

Selected Highlights from the ITS Knowledge Resources on Collision Avoidance

Obstacle Detection

Obstacle detection systems use vehicle-mounted sensors to detect obstructions in a vehicles path or projected path and warn the driver.

Obstacle Detection	
Safety	The deployment of side object detection systems on 257 transit buses in two different transit agencies reduced the side collision rate per 100,000 Vehicle Miles Traveled by 0.186.[367]
Productivity	A U.S. DOT business case assessment of collision warning systems found that side object detection system (SODS) were cost-effective with a baseline benefit-cost ratio of 1.43. The cost-effectiveness of SODS was attributable to the fact that sideswipe collisions occur relatively frequently, and a high proportion of them are avoidable, rendering the potential for savings relatively high. In contrast, forward, rear, and angled collisions were less frequent, and not as avoidable, thus these types of warning systems were found not to be cost-effective. Pedestrian detection systems were cost-effective only for operators with above-average collision rates or high collision costs.[368]
Costs	
Sample System Costs of ITS Deployments	
United States: The costs of deploying SODS for transit buses include acquisition, training and maintenance costs. A recent evaluation of a SODS deployment across three different transit agencies calculated the Return on Investment and reported the following: • The acquisition and installation costs on a per unit basis were **$2,000**. (The acquisition of SODS was part of a new bus procurement that included installation; note that retrofits may have higher costs due to installation.) • Initial training costs for the first year were **$14.13** (0.5 hrs) per operator and **$15.04** (0.5 hrs) per mechanic. The ongoing costs associated with maintaining SODS were estimated to be **$69.86 per bus** per year for repairs, and **$7.52 per bus per year** for SODS testing.[369] **United States:** The U.S. DOT evaluated the technical, financial, and qualitative investment merits of collision warning systems. The acquisition costs for forward and side detection systems were estimated at **$2,350 and $2,550**, respectively. Typically, these technologies are bundled in an integrated system. An example of a commercially available package that addresses obstacle detection: **Forward Object and Side Object Detection: $3,065 -** System costs included capital acquisition and installation (shown here as a combined "unit cost" per installation). Annual operating and maintenance costs were based on an **hourly labor rate of $23.50**, and 30 minutes of service each month for a year. (Acquisition = $2,750; Installation = $94; Training = $120; Annual O&M = $141)[370]	

Lessons Learned: Deploy side object detection systems for transit buses that have proven effectiveness in transit operating environments and been accepted by transit operators.

- **Design side object detection systems that will detect objects in the operator's blind spot** (e.g., on the far rear sides) and in locations that are frequent points of collisions (e.g., the side mirrors).
- **Design visual alerts that are comprehensible and not visually distracting.**
- **Issue audible alerts only when necessary.**
- **Deploy technologically mature collision avoidance systems.**
- **Engage transit operators in the deployment process.**
- **Provide training on the installation and use of the system that is consistent across sites.**

Overall, the results of an independent evaluation pointed to the importance of the design and testing process to develop effective visual and auditory displays, select and place sensors that cover the areas most needed, and conduct field evaluations to ensure reliability and effectiveness in the operating environment. This results in others becoming hooked on the transportation data services and a better understanding of how ITS and operations benefit the transportation system and respond to real-time events and changing conditions.[371]

Lane Change Assistance

Lane-change warning systems have been deployed to alert drivers of vehicles or other obstructions in adjacent lanes when the driver prepares to change lanes.

Lane Change Assistance	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Michigan, 8 of 108 volunteers who drove light vehicles equipped with an integrated crash warning system for a period of six weeks indicated the system prevented them from having a crash.[372]
Customer Satisfaction	In Michigan, driver behavior and acceptance data were collected from 108 volunteers who drove 16 vehicles equipped with crash warning systems (forward crash, lateral drift, lane change/merge crash and curve speed warnings) for a period of six weeks each. Post-drive survey results indicated the blind-spot detection component of the lane-change/merge crash warning system was the most useful and satisfying aspect of the integrated system. Overall, 72 percent of drivers said they would like to have the integrated system in their personal vehicles.[373]
Costs	
Sample System Costs of ITS Deployments	
United States: Blind spot monitoring provides warnings to drivers that another vehicle is in one of the "blind" spots to the side and rear of the car. One such system available on the U.S. market utilizes digital camera-based sensors mounted on the exterior side mirrors and provides a visual warning when another vehicle is in the blind spot. This system is available as an option and is priced at approximately **$500 per vehicle**. Other mirror-mounted blind spot detection systems continue to be developed, but will utilize 24 GHz radar. Production costs for these systems, installed on both side mirrors, are estimated at **$400 to $500 per vehicle**.[374]	

Lane Departure Warning

Lane departure warning systems warn drivers that their vehicle is unintentionally drifting out of the lane.

Lane Departure Warning	
Benefits	
ITS Goals	**Selected Findings**
Productivity	The operating conditions of transit buses, characterized by low-speeds, frequent stops, and pulling in and out of traffic in a frequently dense urban environment may not be amenable to LDW systems. Results from a U.S. DOT study indicated benefit-cost estimates for these systems ranged from 0.04 to 0.20.[375]
Productivity	An analysis of benefits and costs of LDW systems in the trucking industry found benefits per dollar spent values of $1.37 to $6.55 with varying estimates of efficiency and annual VMT.[376]
Costs	
Sample System Costs of ITS Deployments	
United States: LDW systems can use vehicle-mounted cameras and image processing software to recognize lane markings, and process this information along with vehicle trajectory data (speed, steering angle). In 2006, a U.S. DOT study found that one automobile manufacturer offered LDW features, but buyers were required to purchase an **"options package" for $2,750 and a "technology package" for $4,200**.[377] **United States:** In 2007, a U.S. DOT study estimated that the acquisition cost of an LDW system was about $900. This technology, however, was only available when bundled with other systems such as Forward Collision Warning (FCW) systems. • **LDW/FCW commercial package = $1,946.** System costs included acquisition ($1,800), installation ($0), training ($10), and annual O&M ($141). Annual O&M was based on an hourly labor rate of $23.50 and 30 minutes of service each month for a year. [378] **United States:** In 2009, an industry analysis found that the cost of a LDW system for a large truck can range from **$765 to $866**. These costs included the purchase price of the technology, maintenance costs, and the costs of driver training.[379]	

Rollover Warning

Rollover warning systems notify drivers when they are traveling too fast for an approaching curve, given their vehicle's operating characteristics. This has been primarily a focus of heavy trucks.

Rollover Warning	
Benefits	
ITS Goals	**Selected Findings**
Productivity	A benefit-cost analysis of roll stability control (RSC) systems for the trucking industry found benefits per dollar spent values of $1.66 to $5.34 with varying estimates of efficiency and annual vehicle miles traveled.[380]

Rollover Warning
Costs
Sample System Costs of ITS Deployments
United States: RSC systems have an original equipment manufacturer (OEM) option book price of approximately $500, and with traction control, the system cost is approximately **$1000 per vehicle**. Large trucks typically use OEM installed units. An industry analysis found the costs for large trucks ranged from **$439.99 and $1,101.39**. These costs included the purchase price of the technology, maintenance costs, and the costs of driver training.[381]

Forward Collision Warning

In the application area of forward collision warning systems, microwave radar and machine vision technology help detect and avert vehicle collisions. These systems typically use in-vehicle displays or audible alerts to warn drivers of unsafe following distances. If a driver does not apply brakes properly in a critical situation, some systems automatically assume control and apply the brakes in an attempt to avoid a collision.

<table>
<tr><th colspan="2">Forward Collision Warning</th></tr>
<tr><th colspan="2">Benefits</th></tr>
<tr><td>ITS Goals</td><td>Selected Findings</td></tr>
<tr><td>Productivity</td><td>A benefit-cost analysis of forward collision warning (FCW) systems for the trucking industry found benefits per dollar spent values of $1.33 to $7.22 with varying estimates of efficiency and annual VMT.[382]</td></tr>
<tr><th colspan="2">Costs</th></tr>
<tr><td colspan="2">Sample System Costs of ITS Deployments</td></tr>
<tr><td colspan="2">United States: In 2007, a U.S. DOT study estimated the costs of integrated vehicle-based safety systems (IVBSS) for transit buses. The acquisition costs for an FCW system were estimated at $1,500. This technology, however, was only available when bundled with other systems such as LDW systems.
• FCW/LDW commercially package = $1,946. System costs included acquisition ($1,800), installation ($0), training ($10), and annual O&M ($141). Annual O&M was based on an hourly labor rate of $23.50 and 30 minutes of service each month for a year.[383]
United States: In 2009, an industry analysis found that the cost of a FCW system for a large truck can range from $1,415 to $1,843. These costs included the purchase price of the technology, maintenance costs, and the costs of driver training.[384]</td></tr>
<tr><th colspan="2">Benefit-Cost Studies</th></tr>
<tr><td colspan="2">United States: The cost-effectiveness of CWS was evaluated for large trucks and tractor-trailers. The results indicated that there was little or no economic justification for deploying these systems on all large trucks. With respect to tractor-trailers, however, future deployments were economically justified if relative deployment costs were lower.[385]</td></tr>
</table>

Chapter 17 Driver Assistance

Source: ©iStockphoto.com/mathieukor

Driver assistance refers to a collection of capabilities and associated technologies to help augment key driving tasks, such as navigation, speed control, and parking. These technologies continue to gain interest in the marketplace.

- In-vehicle navigation and route guidance systems with global positioning system (GPS) technology may reduce driver error, increase safety, and save time by improving driver decisions in unfamiliar areas.
- Integrated communication systems that enable drivers and dispatchers to coordinate re-routing decisions on-the-fly can also save time and money, and improve productivity.
- In-vehicle vision enhancement improves visibility for driving conditions involving reduced sight distance due to night driving, inadequate lighting, fog, drifting snow, or other inclement weather conditions.
- Object detection systems, such as parking aids for passenger vehicles, warn the driver of an object (front, side, or back) that is in the path of or adjacent to the path of the vehicle.
- Adaptive cruise control (ACC), intelligent speed control, and lane-keeping assistance support drivers with safe vehicle operation.

Categories

Navigation/Route Guidance

Driver Communication

- With Other Drivers
- With Carrier/Dispatch

Vision Enhancement

Object Detection

Adaptive Cruise Control

Intelligent Speed Control

Lane Keeping Assistance

Roll Stability Control

Drowsy Driver Warning Systems

Precision Docking

Coupling/Decoupling

On-Board Monitoring

- Cargo Condition
- Safety and Security
- Vehicle Diagnostics
- Event Data Recorders

- Roll stability control systems take corrective action, such as throttle control or braking, when sensors detect that a vehicle is in a potential rollover situation.
- Drowsy driver warning systems alert the driver that he or she is fatigued which may lead to lane departure or road departure.
- Precision docking systems automate precise positioning of vehicles at loading/unloading areas.
- Coupling/decoupling systems help vehicle operators link multiple vehicles, such as buses or trucks, into platoons.
- On-board monitoring systems track and report cargo condition, safety and security status, and the mechanical condition of vehicles equipped with in-vehicle diagnostics. This information can be presented to the driver immediately, transmitted off-board, or stored. In the event of a crash or near-crash, in-vehicle event data recorders can record vehicle performance data and other input from video cameras or radar sensors to improve the post-processing of crash data.

Many of these driver assistance systems have begun to emerge in production automobiles.

Several other chapters in this report discuss ITS applications related to driver assistance technologies. Many of the technologies that enable the warning systems discussed in the Collision Avoidance chapter also support the driver assistance capabilities discussed in this chapter. Traveler information programs can provide important data to in-vehicle navigation systems, improving the performance of these devices. Data recorded by in-vehicle devices can be archived and monitored over time to improve vehicle performance and facilitate vehicle safety studies for future enhancements to vehicle technology.

The ITS JPO's connected vehicle research program, which seeks to enhance communication between vehicles and the roadside infrastructure, will have an impact on the deployment of ITS applications for driver assistance in the coming years. The availability of enhanced information on traffic conditions has the potential to improve the performance of in-vehicle navigation systems. For example, information transmitted from the roadside also has the potential to enhance lane keeping assistance. Connected vehicle research has the potential to impact many other aspects of ITS deployment discussed throughout this report. Additional information on the connected vehicle initiative is available at the ITS JPO's Web site:
www.its.dot.gov/connected_vehicle/connected_vehicle.htm.

Findings

As of July 2011, there were 94 evaluation summaries of Driver Assistance applications in the Knowledge Resource databases, as shown in Figure 17-1. The Driver Assistance categories with the largest number of summaries is Driver Communication (with 25 summaries), Adaptive Cruise Control (22 summaries), Navigation/Route Guidance (19 summaries), On-Board Monitoring (16 summaries) and Intelligent Speed Control (13 summaries). The remaining Driver Assistance categories have less than ten summaries each, with Roll Stability Control (seven summaries), Lane Keeping Assistance (six summaries), Object Detection (four summaries), Precision Docking and Drowsy Driver Warning Systems (three summaries), Vision Enhancement (two summaries), and Coupling/Decoupling (one summary), as shown in Figure 17-2.

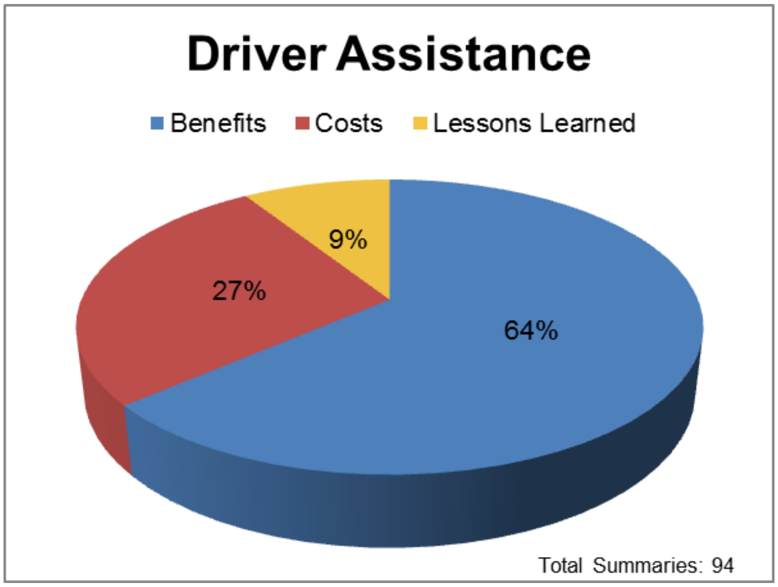


Figure 17-1. Driver Assistance Summaries in the Knowledge Resources

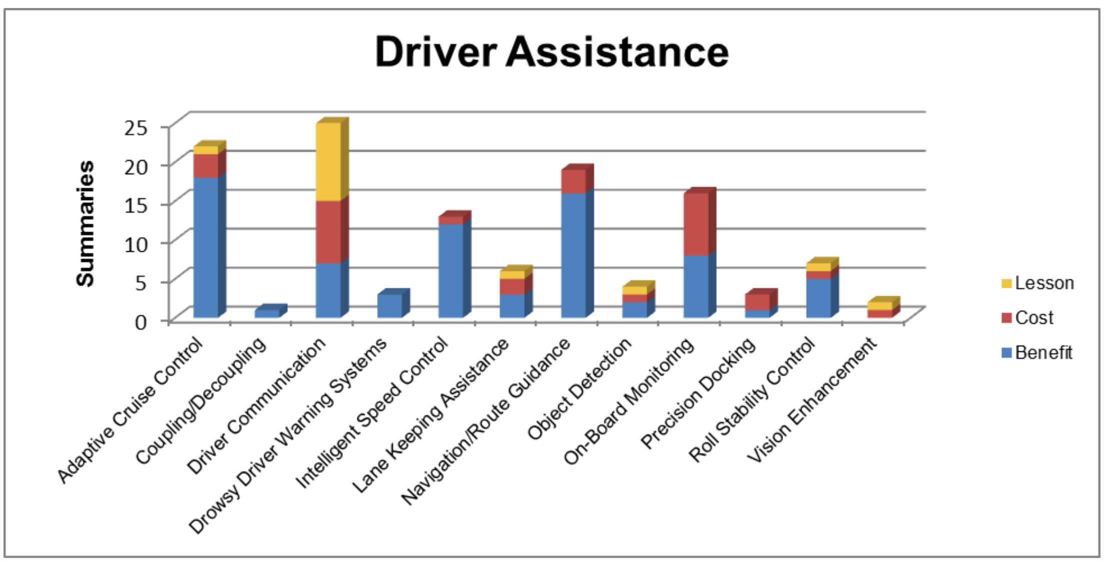


Figure 17-2. Summaries in the Knowledge Resources by Driver Assistance Category

Benefits

As shown in Table 17-1, evaluations have documented the performance of in-vehicle navigation systems, driver communication systems, ACC, and roll stability control. In-vehicle navigation and route guidance systems have gained mainstream acceptance and are widely available in private vehicles. Studies of the systems from the mid-to-late 1990s identified the ability of the devices to provide mobility benefits and improve safety by routing travelers to limited-access freeways and major arterials. When linked to sources of current traffic congestion information to provide dynamic routing, studies have found that the devices could reduce traffic congestion and thereby provide additional network capacity. These studies also found travelers had favorable impressions of the devices.

Source: ©thinkstockphotos.com/Comstock

Recent studies have assessed the use of navigation systems in providing alternative route guidance during heavy traffic or incidents, thereby conserving fuel and lowering carbon dioxide emissions. According to recent surveys, consumers are very interested in rear-vision camera systems and blind spot detection and these technologies are becoming more widely available.[386]

Several studies have been completed assessing the potential of ACC, which is now available in some private vehicles. The studies have found that the systems are most effective at improving safety when bundled with collision warning systems and other safety features. ACC has the ability to reduce vehicle emissions and increase the capacity of roadways, and there are some indications that the price of the equipment is beginning to drop. However, a recent study found that driver misunderstanding of ACC's capabilities is a potential obstacle to widespread deployment.[387]

While both cars and sport utility vehicles (SUVs) benefit from electronic stability control systems, the reduction in the risk of single-vehicle crashes was significantly greater for SUVs (49 to 67 percent) than for cars (33 to 44 percent).[388] With respect to fatal single-vehicle crashes, however, the impacts were similar (59 percent reduction for SUVs and 53 percent reduction for cars).[389] It is estimated that as many as 10,000 of the 34,000 fatal passenger vehicle crashes that occur each year could be prevented with the use of these devices.[390]

Table 17-1. Driver Assistance Benefits Summary

Driver Assistance Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Navigation/Route Guidance	○	●	●			●
Driver Communication				●		
Vision Enhancement	●					●
Object Detection	●					●
Adaptive Cruise Control	●		○		○	●
Intelligent Speed Control						
Lane Keeping Assistance						

Driver Assistance Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Roll Stability Control	●					
Drowsy Driver Warning Systems						
Precision Docking						
Coupling/Decoupling						
On-Board Monitoring						
● – substantial positive impacts	◘ – positive impacts					
○ – negligible impacts	⇃↾ – mixed results					
✖ – negative impacts	(blank) – not enough data					

Costs

Automakers and their technology partners are pursuing low cost reliable products that allow customers to legally and safely make calls, get directions, and connect with other devices. Features such as hands-free wireless communication, speech commands, and touch input dashboard systems will provide easy access to maps, navigation, and connectivity with other devices. Ability to integrate other electronic devices/equipment into an automobile's electronic system is an important technology innovation under development. It is likely that popular on-board safety technologies such as rear-vision cameras and blind spot detection will be integrated in these new electronic systems.[391]

There are some indications that as technology matures, the cost of certain on-board safety systems are coming down. A U.S. auto manufacturer, for example, has introduced a radar-based adaptive cruise control (ACC) with Collision Warning and Brake Support marketed in 2010 for $1,195.[392]

The widespread adoption of smart phones has impacted Driver Assistance applications as many of these devices offer free navigation functions. As these devices replace the Personal Navigation Device (PND), manufacturers are moving into the in-vehicle navigation segment with low-cost PND-based systems, which in turn places pressure on suppliers of in-vehicle navigation systems to lower prices.

In the area of concierge services, competitors to on-board assistance systems such as OnStar® have emerged in recent years, which should drive down the price of such services. Other auto manufacturers have entered the market, with one offering a subscription rate of $79 per year for the basic service level of its system, which bundles automatic collision notification and assistance, SOS emergency assistance, enhanced roadside assistance and a monthly report of the vehicle systems' status.[393]

Selected Highlights from the ITS Knowledge Resources on Driver Assistance

Navigation/Route Guidance

In-vehicle navigation systems with GPS technology may reduce driver error, increase safety, and save time by improving driver decisions in unfamiliar areas. The systems may be linked to traveler information services to provide updated routing instructions that account for current traffic conditions.

Over the past decade, on-board and portable navigation systems have frequently been purchased and used by drivers to assist with driving directions and routing around congestion. Combining navigation systems and traveler information can create powerful tools to assist drivers in reducing fuel consumption and vehicle emissions. It should be noted that eco-driving navigation systems do not passively reduce emissions; drivers must actively engage and follow the provided directions in order to reduce vehicle emissions.[394]

Navigation/Route Guidance	
Benefits	
ITS Goals	**Selected Findings**
Energy and Environment	Navigation systems can provide substantial benefits for fuel economy and environmental impacts. Drivers using in-vehicle and portable navigation systems in unfamiliar locations can reduce vehicle miles traveled (VMT) by 16 percent, and drivers can save up to 30 percent in mileage searching for a parking space, if the appropriate information is provided by the system. Fuel consumption and time savings are also realized through the use of real-time traffic information that helps drivers avoid traffic jams. These reductions all add up to emissions saving, particularly when supported by intermodal information.[395]

Vision Enhancement

In-vehicle vision enhancement improves visibility during night driving, inadequate lighting, fog, drifting snow, or other inclement weather conditions. These systems may also monitor vehicle blind spots to assist the driver in making safe lane changes.

Source: ©thinkstockphotos.com/istockphoto

The National Highway Traffic Safety Administration (NHTSA) has proposed a rule that would expand the required field of view for all passenger cars, pickup trucks, minivans, buses and low-speed vehicles with a gross vehicle weight rating of up to 10,000 pounds so that drivers can see directly behind the vehicle when the vehicle's transmission is in reverse. NHTSA believes automobile manufacturers will install rear mounted video cameras and in-vehicle displays to meet the proposed standards. To meet the requirements of the proposed rule, ten percent of new vehicles must comply by Sept. 2012, 40 percent by Sept. 2013 and 100 percent by Sept. 2014.[396]

Vision Enhancement	
Benefits	
Safety	NHTSA estimates that, on average, 292 fatalities and 18,000 injuries occur each year as a result of back-over crashes involving all vehicles. Of these, 228 fatalities involve light vehicles weighing 10,000 pounds or less. Children and the elderly are affected most, with approximately 44 percent of light vehicle fatalities being children under five. In addition, 33 percent of fatalities involving light vehicles are elderly people 70 years of age or older. With the requirement in place, NHSTA estimates that annual fatalities in back-over crashes would be reduced by 95 to 112 fatalities, and annual injuries by 7,072 to 8,374 injuries.[397]
Costs	
Sample System Costs of ITS Deployments	
United States: NHSTA estimates that rear view camera systems will add **$159 to $203** to the cost of the vehicle.[398]	
Benefit-Costs Studies	
NHSTA's benefit-cost analysis showed the net cost per equivalent life saved for camera systems ranges from $11.8 to $19.7 million. According to its model, this exceeds the current cost estimate of the value of a statistical life of $6.1 million.[399]	

Object Detection

An object detection system warns the driver of an object (front, side or back) that is in the path or adjacent to the path of the vehicle. The most common application of this technology is as a parking aid for passenger vehicles.

Object Detection
Costs
Sample System Costs of ITS Deployments
United States: Blind spot monitoring provides warnings to drivers that another vehicle is in one of the "blind" spots to the side and rear of the car. One such system available on the U.S. market utilizes digital camera-based sensors mounted on the exterior side mirrors and provides a visual warning when another vehicle is in the blind spot. This system is available as an option and is priced at approximately **$500 per vehicle**. Other mirror-mounted blind spot detection systems are in development, but will utilize 24 GHz radar. Production costs for these systems, installed on both side mirrors, are estimated at **$400 to $500 per vehicle**.[400] **United States**: A commercially available object detection system for transit buses that bundled forward object detection and side object detection cost **$2750**. Installation was estimated at **$94**, training was **$120**, and annual operating and maintenance costs were **$141**, bringing the total cost to **$3065**.[401]
Benefit-Cost Studies
A Side Object Detection System (SODS) for transit buses was cost-effective with a baseline benefit-cost ratio of 1.43 and a ratio range of 0.37-3.55. Results showed that the SODS was a cost-effective system, with a benefit-cost ratio ranging from 0.37 to 3.55. The cost-effectiveness of SODS is attributable to the fact that sideswipe collisions occur relatively frequently, and a high proportion of them are avoidable, rendering the potential for savings relatively high.[402]

Adaptive Cruise Control

ACC systems maintain a driver-set speed without a lead vehicle or a specified following time if there is a lead vehicle and it is traveling slower than the set speed. Research and testing of Cooperative Adaptive Cruise Control (CACC) systems that will enhance the vehicle-following capabilities beyond those of a conventional ACC system is underway. CACCs can safely allow for shorter gaps between vehicles, thereby improving traffic flow and efficiency.[403]

Adaptive Cruise Control	
Benefits	
ITS Goals	**Selected Findings**
Safety	A field evaluation in Michigan tested ACC combined with forward collision warning to form an automotive collision avoidance system (ACAS). The study found that ACAS could reduce exposure to driving conflicts leading to rear-end crashes by 8 to 23 percent and estimated that the combined system could eliminate about 10 percent of all rear-end crashes.[404] An earlier study of stand-alone ACC found that the technology was effective at reducing risky lane changes in response to slower traffic, but drivers of these vehicles took 0.3 seconds longer than manually-controlled vehicles to respond to lead vehicle brake lights.[405]
Safety	Survey results from ACC users in Southern California found that more than half of the respondents agreed that when they use ACC they tend to change lanes less frequently. However, many drivers were not aware of the limitations of their systems, an observation that raises safety concerns. Many drivers thought their ACC systems would help avoid a collision in situations outside the capability of the equipment including: • Encountering a stopped vehicle in the lane ahead (43 percent) • Following a vehicle in stop-and-go traffic (24 percent) • Following a vehicle on a curve (27 percent) Drivers need to be better informed about situations in which their ACC will not react. The writers conclude that more research is needed to determine the overall safety impact of these systems.[406]
Customer Satisfaction	Interviews were conducted with drivers who participated in a field operational test of ACC as part of an Integrated Vehicle Based Safety System. Approximately half of the drivers interviewed indicated that the ACC system reduced accident risk by helping to maintain safer distances and approximately 60 percent indicated that the technology changed their driving habits.[407]
Customer Satisfaction	The AAA Safety Foundation conducted a survey with 1659 respondents, including 370 who had Adaptive Cruise Control (ACC). A majority of those who currently have ACC said if they purchased the same vehicle again, they would want to get the technology again. Nearly half of the respondents agreed that using ACC relieves them of stress while driving. However, approximately 30 percent of respondents reported a need for improvements in the systems. The most frequently suggested areas for improvement were related to the occurrence of unsafe or uncomfortable reductions or increases in speed, and the area of coverage or sensitivity of the system.[408]

Adaptive Cruise Control
Benefit-Cost Studies
United States: A 2007 societal benefit-cost analysis of the installation of a bundle of ACC, a CWS, and an advanced braking system on tractor-trailer commercial vehicles found the installation of the systems to be economically justified in two of six modeled scenarios (with benefit-cost ratios ranging from 1.1 to 1.3). None of the six evaluated scenarios for deployment of the technologies on all types of commercial vehicles yielded a benefit-cost ratio greater than 1:1.[409]

Intelligent Speed Control

Intelligent speed control systems limit maximum vehicle speed via a signal from the infrastructure to an equipped vehicle.

Intelligent Speed Control	
Benefits	
ITS Goals	**Selected Findings**
Safety	An overview of studies conducted in the United Kingdom, Finland, the Netherlands, Sweden, Denmark, and Australia reported that mandatory dynamic automatic controlling Intelligent Speed Assistance (ISA) could reduce fatal crashes over the entire road network by more than 50 percent, whereas static informing ISA could still give a reduction of almost 20 percent. For all types of ISA promising effects are predicted, particularly regarding safety. Automatic controlling ISA is most effective, but at the same time has the lowest driver acceptance. A lack of user acceptance along with possible legal problems can impede a large scale implementation of this ISA type.[410]
Energy and Environment	An overview of studies conducted in the United Kingdom, Finland, the Netherlands, Sweden, Denmark, and Australia reported that when all vehicles are equipped, mandatory dynamic automatic controlling ISA could reduce fuel consumption and harmful emissions by 4 to 11 percent.[411]
Energy and Environment	In Los Angeles, California, a simulation study transmitted optimal speed values to an in-vehicle display and drivers were able to limit vehicle speeds to those recommended by the system servers. As a "control" a second vehicle was operated in the same traffic except the recommended speed information was not provided. The study found that eco-driving with dynamic speed recommendations can reduce fuel consumption by 10 to 20 percent and lower carbon dioxide emissions without drastically increasing freeway travel times.[412]

Lane Keeping Assistance

Lane keeping assistance systems make minor steering corrections if the vehicle detects an imminent lane departure without the use of a turn signal.

Lane Keeping Assistance	
Benefits	
ITS Goals	**Selected Findings**
Safety	Using Integrated Vehicle-Based Safety Systems (IVBSS) for light vehicles, the system had a statistically significant effect on the frequency of lane departures, decreasing the rate from 14.6 departures per 100 miles during baseline driving to 7.6 departures per 100 miles during the treatment condition. For heavy trucks, the integrated crash warning system had no effect on lane departure frequency, but a trend towards a decrease in lane departures was observed for 13 of the 18 drivers.[413]
Customer Satisfaction	Overall, drivers stated that the IVBSS made them more aware of the traffic environment around their vehicles and their position in the lane, and that integrated crash warning systems would increase their driving safety. Fifteen (15) of 18 truck drivers responded that they would prefer driving a truck equipped with the integrated warning system to an unequipped truck, and would recommend the purchase of such systems. However, these drivers indicated that they would be willing to pay no more than $750 for such a system.[414]

Roll Stability Control

Roll stability control systems take corrective action, such as throttle control or braking, when sensors detect that a vehicle is in a potential rollover situation.

Roll Stability Control	
Benefits	
ITS Goals	**Selected Findings**
Safety	Through use of Roll Stability Control (RSC) systems, it was estimated that between 1,422 and 2,037 combination vehicle rollover crashes in curves could be prevented, resulting in effectiveness rates of 37 percent and 53 percent, respectively.[415]

Drowsy Driver Warning Systems

Drowsy driver warning systems monitor driver performance and driver psycho physiological status (primarily eye closures) and issue alerts to the driver when drowsiness is detected. Several car manufacturers have begun to add these systems to their high-end vehicles.[416]

Drowsy Driver Warning Systems	
Benefits	
ITS Goals	**Selected Findings**
Safety	In a Field Operational Tests of Drowsy Driver Warning System, analysis revealed that drivers in the Test Group had a lower percentage of eye-closure (PERCLOS) values overall as compared to other experimental conditions. These results suggest that providing the driver with feedback as to his or her level of arousal would lead to an overall reduction of instances of drowsy driving.[417]

Drowsy Driver Warning Systems
Benefit-Cost Studies
In Sweden, payback periods for a drowsy driver warning system were estimated based upon initial expected crash cost, reductions due to the warning system, and the installation costs as follows: • Passenger cars, 5 to 75 years before installation costs recovered. • Trucks, 3 to 36 years before installation costs recovered. • Heaviest trucks (load capacity 16,000 to 17,000 kg), 0.8 to 10 years before installation costs recovered.[418]

On-Board Monitoring

On-board monitoring applications track and report cargo conditions, safety and security, and the mechanical condition of vehicles equipped with in-vehicle diagnostics. This information can be presented to the driver immediately, transmitted off-board, or stored. In the event of a crash or near-crash, in-vehicle event data recorders can record vehicle performance data and other input from video cameras or radar sensors to improve post-crash processing of data. In-vehicle data recorders (IVDR) have emerged as new tools to collect data on driving behavior and provide feedback to drivers, either in real time or through a post-trip report. A recent commercial application is to use On-board Monitoring System data to report mileage and other vehicle utilization patterns to the driver's insurance company in return for a discount on insurance premiums.[419]

Another promising application for On-Board monitory systems has emerged in the area of Eco-driving. Eco-driving information applications provide training programs or recommendations via an On-Board Unit to promote energy efficient driving techniques. These applications can include attaching the On-Board Unit to the controller area network (CAN) bus to provide real-time vehicle energy efficiency data (e.g., energy use and gear shift indicators). Eco-driving assistance pilot projects have demonstrated the potential to reduce emissions by 3 to 15 percent.[420] However, applications that provide eco-driving information do not passively reduce emissions. Drivers must actively engage and follow provided directions in order to reduce emissions.

In the area of concierge services, competitors to GM's OnStar® have emerged in recent years, which should drive down the price of such services. Ford and Hyundai have entered the market, with Hyundai offering a subscription rate of $79 per year for the basic service level of BlueLink, which bundles automatic collision notification and assistance, SOS emergency assistance, enhanced roadside assistance and a monthly report of the vehicle systems' status. [421]

On-Board Monitoring	
Benefits	
ITS Goals	**Selected Findings**
Safety	In Israel, the use of an In-Vehicle Data Recorder system can identify various maneuver types that occur in the raw measurements, and use this information to calculate risk indices that indicate overall trip safety. Drivers received feedback through various summary reports, real-time text messages or an in-vehicle display unit. The results of the study show a statistically significant reduction of 38 percent in crash rates, but not in fault crash rates, which were only reduced by 5 percent.[422]

On-Board Monitoring	
Benefits	
ITS Goals	**Selected Findings**
Safety	Use of Low Cost Driving Behavior Management Systems (DBMS) reduces recorded safety events by 38 to 52 percent. Participating drivers from two motor carriers (identified as Carrier A and Carrier B) drove an instrumented vehicle for 17 consecutive weeks while they made their normal, revenue-producing deliveries. Carrier A significantly reduced the mean rate of recorded safety-related events per 10,000 vehicle miles traveled (VMT) from baseline to intervention by 38.1 percent, while Carrier B significantly reduced the mean rate of recorded safety events per 10,000 VMT from baseline to intervention by 52.2 percent.[423]
Productivity	By using an In-Vehicle Data Recorder (IVDR) to enable PAYDAYS car insurance, drivers can save up to 60 percent on their car insurance premiums. Beginning in 2004, Progressive began its TripSense Program in Minnesota, Michigan, and Oregon. TripSense collected data—including miles and the time of day driven, hard acceleration, braking, and speed—from vehicle on-board diagnostic systems (which did not record driving location). Drivers can earn discounts of up to 25 percent of their car insurance based on mileage driven.[424]
Productivity	An insurance company uses data from widely used On-Board Monitoring System (OBMS) to provide customers with insurance premium discounts of 5 to 54 percent. Beginning in 2004, GMAC Insurance and OnStar® began to offer drivers with active OnStar® accounts discounts of five percent to 54 percent on their car insurance, depending on which of seven mileage categories the amount of their driving fell. The OnStar® OBMS is used to communicate vehicle mileage to GMAC Insurance. A discount of 54 percent is given to drivers driving 2,500 or fewer miles per year and a discount of 13 percent is given to those driving between 12,501 and 15,000 miles per year.[425]

Chapter 18 Collision Notification

Source: ©thinkstockphotos.com/hemera

Collision notification systems detect and report the location and severity of incidents to agencies and services responsible for coordinating appropriate emergency response actions. These systems can be activated manually (Mayday) or automatically (automated collision notification (ACN)), to establish wireless data and voice communications with call centers who can relay information to emergency response services. Data transmitted typically include vehicle location and the description and nature of the emergency. More advanced ACN systems use in-vehicle crash sensors, global positioning system (GPS) technology, and wireless communication systems to automatically determine the severity, location, condition, and orientation of vehicles involved in a crash, and communicate this information to emergency responders. With Advanced CAN, responders can determine the type of equipment needed in an emergency (basic services or advanced life support), mode of transport (air or ground), and the location of the nearest trauma center.

Currently, over a dozen commercial Mayday/ACN products are available. Many of these products are available as factory-installed options on high-end luxury cars; others are installed as after-market products. The typical Mayday/ACN product utilizes location technology, wireless communication,

Categories

Mayday/Automated Collision Notification

Advanced Automated Collision Notification

and a third-party response center to notify the closest public safety answering point (PSAP) for emergency response.

The emergency management chapter also discusses ACN systems. In addition, the traffic incident management chapter discusses Enhanced 9-1-1 (E9-1-1) service as a means of detecting incidents.

In addition to the ITS technologies profiled in this chapter, the U.S DOT continues to explore Next Generation 9-1-1 (NG9-1-1) to improve transportation safety and efficiency on the nation's highways and rural roadways. Building on lessons learned from earlier work on wireless E9-1-1, NG9-1-1 can offer broader coverage and increased functionality using an Internet (IP) based approach. A wide variety of communication devices (wired, wireless, or Internet) can be supported by NG9-1-1 enabling voice, data, and video to be transmitted to Public Safety Answering Point (PSAP) dispatch centers and trauma centers simultaneously. With real-time detailed information available on crash characteristics, emergency responders and trauma centers can prioritize response actions and promptly transport crash victims to prepared medical facilities.

The cost, value, and risk of implementing NG9-1-1 have been evaluated by the U.S. DOT on a national scale and published in a series of reports. For more information, please visit the ITS JPO's Web site: www.its.dot.gov/ng911.

Findings

As of July 2011, there were 11 evaluation summaries of Collision Notification applications in the Knowledge Resource databases, as shown in Figure 18-1, with six summaries in the Advanced Automated Collision Notification category, and five summaries in the Mayday/Automated Collision Notification category, as shown in Figure 18-2.

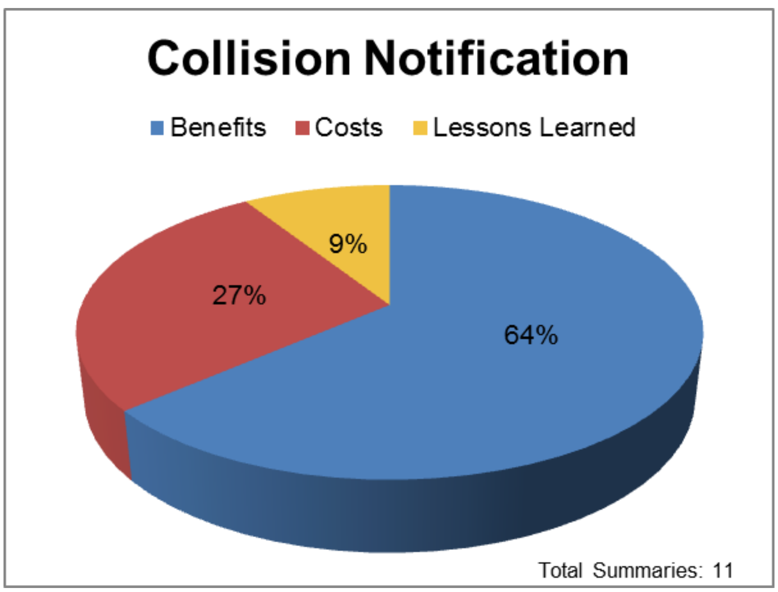


Figure 18-1. Collision Notification Summaries in the Knowledge Resources

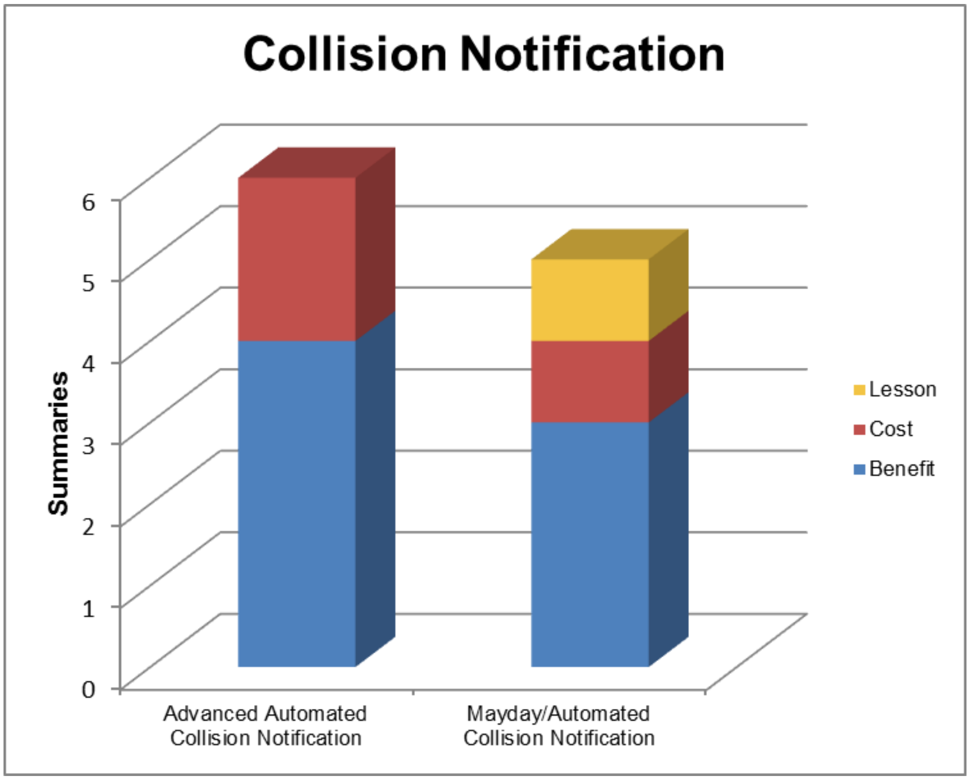


Figure 18-2. Summaries in the Knowledge Resources by Collision Notification Category

Benefits

ACN systems can improve emergency response times for severely injured crash victims who need immediate attention at an appropriate facility. Studies estimate that ACN systems can reduce road traffic deaths by 1.5 to 15 percent.[426] In trauma care, seriously injured patients that arrive at an operating room of a trauma center with an experienced team of appropriately specialized trauma surgeons within the first 60 minutes (the golden hour) after a crash have a much greater chance of survivability compared to those that arrive within 90 minutes. In rural areas, timely notification, response, and decisions regarding medical care prior to transport, can save lives.

Advanced ACN systems could improve the outcomes of more than 15,000 drivers involved in moderate to high severity crashes each year.

As shown in Table 18-1, evaluations to date have documented strong customer satisfaction with ACN systems and also show that notification times can be improved demonstrating potentially significant safety benefits.[427]

Table 18-1. Collision Notification Benefits Summary

Collision Notification Benefits Summary						
	Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction
Mayday/Automated Collision Notification	●					●
Advanced Automated Collision Notification	●					

● – substantial positive impacts	◉ – positive impacts
○ – negligible impacts	⇅ – mixed results
✖ – negative impacts	(blank) – not enough data

Costs

In a study of private sector deployment of ITS, the costs of telecommunications- and location-based services designed to assist motorists were estimated at $350 per unit. The first year's subscription was included in the retail price of the vehicle with subsequent subscriptions sold on an annual basis. One basic safety and security subscription package cost $199 per year with other packages costing $399 and $799 per year. The basic safety and security package included advanced safety features such as Advanced ACN.

Over a 20-year lifecycle, NG9-1-1 would likely cost about the same as maintaining the status quo of today's 9-1-1 environment, but deliver significantly more value.

Selected Highlights from the ITS Knowledge Resources on Collision Notification

Advanced Automated Collision Notification

Advanced ACN systems use in-vehicle crash sensors, GPS technology, and wireless communications systems to supply public/private call centers with crash location information, and in some cases, the number of injured passengers and the nature of their injuries.

Advanced Automated Collision Notification	
Benefits	
ITS Goals	**Selected Findings**
Safety	Implementing an enhanced Automatic Collision Notification (ACN) system in all passenger vehicles in the United States could help improve outcomes for over 15,200 drivers each year involved in moderate to high severity crashes. ACN enables 75.9 percent of injured occupants to be correctly identified as seriously injured, by using only data automatically collected and transmitted by the vehicles.[428]
Costs	
Sample Costs of ITS Deployments	
United States: An ACN system that detects not only airbag deployment, but also determines the severity of a crash, direction of impact, multiple impacts, and rollover (if equipped with the appropriate sensors) is available in a basic safety and security subscription service package for **$199 per year**, as of 2003.[429] **United States:** In 2008, the U.S. DOT estimated that the total expected risk adjusted lifecycle cost to implement and operate a nationwide NG9-1-1 system would cost roughly **$82.0 billion** to **$86.3 billion** over the next 20 years. Similar lifecycle costs estimates for the current 9-1-1 system ranged from **$66.1 billion** to **$94.2 billion**.[430]	

Conclusion

In the fifteen years that the ITS Joint Program Office has been tracking the evaluation of ITS technologies, there has been steady growth in the number of studies documenting the benefits, costs and lessons learned of ITS. Looking back over the last three years, the most recent additions to the ITS Knowledge Resources indicate the following evaluation trends:

- Collision avoidance, driver assistance systems, and road weather management systems evaluations are capturing numerous safety impacts that should continue to increase as more of these systems are implemented.
- Mobility impacts are often captured for arterial management, electronic payment and pricing systems, freeway management, traffic incident management, transit management, and traveler information systems. Service patrols, advances in traffic signal timing, and incident detection have all had impacts on getting travelers moving.
- The highest productivity impacts (such as cost savings, benefit-cost ratio, or cost-effectiveness measures) are found in commercial vehicle operations, intermodal freight, road weather management systems, freeway management, traffic incident management, transit management and traveler information evaluations.
- Traveler information, electronic payment pricing, and transit management systems are often associated with high customer satisfaction benefits which enhances the success of these ITS applications.
- Transit management and electronic payment and pricing systems are often associated with efficiency benefits, such as increased passenger throughput.
- Although a substantial number of summaries capture energy and environmental impacts, many ITS evaluations are still not addressing this important goal area. Recent trends indicate that traveler information systems, arterial management, driver assistance, and freeway management applications are more likely to document these measures.

In the last three years, productivity and efficiency goal areas constitute a higher percentage of the total benefits, costs, and lessons learned in the Knowledge Resource databases than in previous years. It appears that evaluators have given greater priority to these goal areas in an environment where budgets are limited and investments are subject to greater scrutiny. In this new and changing landscape, transportation decision-makers will look to the Knowledge Resources for evaluation guidance in choosing ITS investments and making improvements in their operations.

This report has presented many benefits based on evaluations of deployed of ITS, deployment and operations costs, as well as lessons learned during ITS planning and operation. The level of ITS deployment in the United States and worldwide continues to increase. As experience with ITS deployment and operations continues to accrue, the Web-based ITS Knowledge Resources developed by the ITS Joint Program Office will be updated to provide convenient access to this information, enabling informed ITS decision making.

As documented in this report, significant amounts of information are available for many ITS services, but gaps in knowledge also exist. Readers are encouraged to submit additional evaluation reports discussing system impacts, costs, or lessons learned via the online databases. Documented cost data for implemented ITS applications are also welcome and will help keep the unit and systems costs data up to date. The reader is reminded to check online for the most current information on deployment, benefits, costs, and lessons learned at www.ITSKnowledgeResources.its.dot.gov.

Appendix A: Benefit Summaries by Goal Areas

The table below depicts the frequency with which goal areas were captured for benefit summaries added to the Knowledge Resources since December 31, 2008, broken down by application area. The light blue shading indicates that greater than eight or more summaries addressed that particular goal area. For instance, 12 benefit summaries were added over the last three years that address the safety impacts of collision avoidance systems. These recent additions to the ITS Knowledge Resources indicate that collision avoidance systems evaluations are capturing numerous safety impacts.

The overall totals documented at the bottom of the table provide an overall distribution of the evaluation goal areas captured over the last three years as compared to the goal distribution at the beginning of this period. Although these distributions are fairly similar, the productivity and efficiency evaluation goals, highlighted in red, constitute a higher percentage of the total than the previous distribution. This may be a reflection of a trend to give greater priority to these goal areas in an environment where budgets are limited and investments are subject to greater scrutiny. If this is the case, then it stands to reason that transportation decision-makers are specifying that these measures be addressed within the scope of ITS evaluations for which they are responsible.

Table A-1. Frequency of Goal Areas for Benefit Summaries Added Since Dec 31 2008 (blue shading shows greater than 8 summaries)

ITS Application	Safety	Mobility	Productivity	Customer Satisfaction	Energy & Environment	Efficiency
Arterial Management	4	11	4	4	5	3
Collision Avoidance	12	0	3	5	0	0
Collision Notification	3	0	0	0	0	0
Commercial Vehicle Operations	4	0	9	2	3	1
Crash Prevention & Safety	3	0	0	0	0	0
Driver Assistance	11	2	5	4	4	3
Electronic Payment & Pricing	0	16	4	8	2	13

ITS Application	Safety	Mobility	Productivity	Customer Satisfaction	Energy & Environment	Efficiency
Emergency Management	0	0	0	0	0	2
Freeway Management	5	15	6	4	4	3
Information Management	0	0	4	0	0	0
Intermodal Freight	0	2	9	0	0	0
Road Weather Management	6	2	12	0	0	0
Roadway Operations & Maintenance	2	5	1	1	1	0
Traffic Incident Management	5	10	6	3	3	4
Transit Management	4	14	21	25	2	19
Transportation Management Centers	3	4	2	0	0	1
Traveler Information	1	12	9	12	8	1
Totals	63 (16%)	93 (23%)	95 (24%)	68 (17%)	32 (8%)	50 (12%)
Goals Distribution through 2008	206 (23%)	212 (23%)	172 (19%)	183 (20%)	76 8%	53 (6%)

Appendix B: List of Acronyms

ACAS	Automotive Collision Avoidance System
ACC	Adaptive Cruise Control
ACN	Automated Collision Notification
ADMS	Archived Data Management System
AMBER	America's Missing: Broadcast Emergency Response
ARTIMIS	Advanced Regional Traffic Interactive Management and Information Systems
ATIS	Advanced Traveler Information System
ATMS	Advanced Transportation Management System
AVL	Automated Vehicle Location
AWIS	Automated Work Zone Information Systems
BART	Bay Area Rapid Transit (California)
BRT	Bus Rapid Transit
BWI	Baltimore/Washington International Thurgood Marshall Airport
CA	Commercial Vehicle Administration (Unit Cost Subsystem)
CAD	Computer-Aided Dispatch
CAD	Canadian Dollars
Caltrans	California Department of Transportation
CARS	Condition Acquisition and Reporting System
CARTS	Capital Area Rural Transportation System (Austin, Texas)
CC	Commercial Vehicle Check Station (Unit Cost Subsystem)
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CICAS	Cooperative Intersection Collision Avoidance Systems
CMAQ	Congestion Mitigation/Air Quality
CORTRAN	Central Ohio Regional Transportation and Emergency Management Center
COTS	Commercial Off-The-Shelf
CRRAFT	Client Referral, Ridership, and Financial Tracking (New Mexico)
CV	Commercial Vehicle On-Board (Unit Cost Subsystem)
CVISN	Commercial Vehicle Information Systems and Network
CVO	Commercial Vehicle Operations
CWS	Collision Warning System
DGPS	Differential Global Positioning System
DMS	Dynamic Message Signs
DOT	Department of Transportation
EFM	Electronic Freight Management
EMS	Emergency Medical Services
ER	Emergency Response Center (Unit Cost Subsystem)
ESCM	Electronic Supply Chain Manifest

ESS	Environmental Sensor Station
ETC	Electronic Toll Collection
EV	Emergency Vehicle On-Board (Unit Cost Subsystem)
EVP	Emergency Vehicle Preemption
FAST	Fixed Automated Spray Technology (Road Weather Management)
FAST	Freeway and Arterial System of Transportation (Nevada DOT)
FAQ	Frequently Asked Questions
FCW	Forward Collision Warning
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FM	Fleet Management (Unit Cost Subsystem)
FMCSA	Federal Motor Carrier Safety Administration
FOT	Field Operational Test
FTA	Federal Transit Administration
FY	Fiscal Year
GIS	Geographical Information Systems
GPS	Global Positioning System
HAR	Highway Advisory Radio
HAZMAT	Hazardous Materials
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle
ICM	Integrated Corridor Management
ICTransit	Intelligent Coordinated Transit
IDOT	Illinois Department of Transportation
IFTA	International Fuel Tax Agreement
IMTC	International Mobility and Trade Corridor
IPR	Intellectual Property Rights
IRP	International Registration Plan
ISP	Information Service Provider (Unit Cost Subsystem)
ITN	Invitation to Negotiate
ITS	Intelligent Transportation Systems
IVU	In-Vehicle Unit
JPO	Joint Program Office
LAN	Local Area Network
LDW	Lane Departure Warning
LED	Light Emitting Diode
LLKR	Lessons Learned Knowledge Resource
LRTP	Long Range Transportation Plan
M&O	Management and Operations
MDI	Model Deployment Initiative
MdSHA	Maryland State Highway Administration
MDSS	Maintenance Decision Support System
MDT	Mobile Data Terminal
MDT	Montana Department of Transportation
Mn/DOT	Minnesota Department of Transportation

MSAA	Mobility Services for All Americans
MSP	Maryland State Police
MTA	Mass Transportation Authority (Flint, Michigan)
NCHRP	National Cooperative Highway Research Program
NG9-1-1	Next Generation 9-1-1
NHTSA	National Highway Traffic Safety Administration
NORPASS	North American Pre-clearance and Safety System
O&M	Operations and Maintenance
ODOT	Ohio Department of Transportation
ORT	Open Road Tolling
PD	Personal Devices (Unit Cost Subsystem)
PennDOT	Pennsylvania Department of Transportation
PM	Parking Management (Unit Cost Subsystem)
PRUEVIIN	Process for Regional Understanding and Evaluation of Integrated ITS Networks
PSAP	Public Safety Answering Point
RFC	Regional Fare Card
RM	Remote Location (Unit Cost Subsystem)
RMA	Regional Mobility Authorities
R-RC	Roadside Rail Crossing (Unit Cost Subsystem)
RS-C	Roadside Control (Unit Cost Subsystem)
RS-D	Roadside Detection (Unit Cost Subsystem)
RS-I	Roadside Information (Unit Cost Subsystem)
R-RC	Roadside Rail Crossing (Unit Cost Subsystem)
RS-TC	Roadside Telecommunications (Unit Cost Subsystem)
RTA	Riverside Transit Authority (California)
RWIS	Road Weather Information System
SAFER	Safety and Fitness Electronic Record
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users
SIE	Safety Information Exchange
SIRV	Severe Incident Response Vehicle (Florida DOT, District IV)
SOV	Single-Occupancy Vehicle
SOW	Statement of Work
SR	State Route
STC	Smart Traffic Center
SUV	Sport Utility Vehicle
SWIFT	Seattle Wide-area Information for Travelers (Washington State)
TA	Toll Administration (Unit Cost Subsystem)
TCOS	TransCorridor Operating System
TCP/IP	Transmission Control Protocol/Internet Protocol
TEA-21	Transportation Efficiency Act for the 21st Century
TM	Transportation Management Center (Unit Cost Subsystem)
TMC	Transportation Management Center
TMDD	Traffic Management Data Dictionary
TOC	Traffic Operations Center

TP	Toll Plaza (Unit Cost Subsystem)
TR	Transit Management Center (Unit Cost Subsystem)
TRANSCOM	Transportation Operations Coordinating Committee
TriMet	Tri-County Metropolitan Transportation District of Oregon
TSIP	Truck Safety Improvements Project (I-25 in Colorado)
TV	Transit Vehicle On-Board (Unit Cost Subsystem)
TxDOT	Texas Department of Transportation
UK	United Kingdom
U.S.	United States
U.S. DOT	United States Department of Transportation
USCS	United States Customs Service
USGS	United States Geological Survey
VCTC	Ventura County Transportation Commission (California)
VDOT	Virginia Department of Transportation
VII	Vehicle Infrastructure Integration
VS	Vehicle On-Board (Unit Cost Subsystem)
VSL	Variable Speed Limit
VSP	Virginia State Police
WIM	Weigh In Motion
WMATA	Washington Metropolitan Area Transit Authority
WSDOT	Washington State Department of Transportation

Endnotes

[1] Turner, Shawn, et al. *2010 Urban Mobility Report*, Texas Transportation Institute, Texas A&M University. College Station, TX. December 2010. Web site URL: http://mobility.tamu.edu/. Last Accessed 16 September 2011.

[2] "Traffic Safety Facts," National Highway Traffic Association, Report No. DOT HS 811 451. April 2011. Web site URL: http://www-nrd.nhtsa.dot.gov/Pubs/811451.pdf. Last Accessed 16 September 2011.

[3] "Facts at a Glance," American Public Transportation Association. 2011. Web site URL: http://www.publictransportation.org/news/facts/Pages/default.aspx. Last Accessed 16 September 2011.

[4] *Our Nation's Highways 2010*, U.S. DOT Federal Highway Administration, Report No. FHWA-PL-10-023. 2010. Web site URL: http://www.fhwa.dot.gov/policyinformation/pubs/hf/pl10023/onh2010.pdf. Last Accessed 16 September 2011.

[5] *National Strategy to Reduce Congestion on America's Transportation Network*, U.S DOT. May 2006.

[6] "Integrated Corridor Management (ICM)," U.S. DOT Research and Innovative Technology Administration. Web site URL: www.its.dot.gov/icms/index.htm. Last Accessed 20 September 2011.

[7]Hu, Wen, et al. *Effects of Red Light Camera Enforcement on Fatal Crashes in Large US Cities,* Insurance Institute for Highway Safety. February 2011. Benefit ID: 2011-00665

[8] The estimate of $3000 is based on information from the following sources:

Conversation with Mr. Jerry Luor. Traffic Engineering Supervisor, Denver Regional Council of Governments (DRCOG). October 2006. Cost ID: 2007-00117

Fee Estimate – Millennia Mall Retiming and Scope and Schedule – Millennia Mall Retiming, Bid submitted by TEI Engineering to the City of Orlando, FL. October 2005. Cost ID: 2007-00113

Heminger, S. "Regional Signal Timing Program – 2005 Cycle Program Performance," Memorandum to the California Metropolitan Transportation Commission's Operations Committee. Oakland, CA. October 2006. Cost ID: 2007-00112

Harris, J. "Benefits of Retiming Traffic Signals: A Reference for Practitioners and Decision Makers About the Benefits of Traffic Signal Retiming," Paper Presented at the ITE 2005 Annual Meeting and Exhibit. Melbourne, Australia. 7–10 August 2005. Cost ID: 2007-00115

Sunkari, Srinivasa. "The Benefits of Retiming Traffic Signals," *ITE Journal*, April 2004. Cost ID: 2007-00116

The National Traffic Signal Report Card: Technical Report 2007, National Transportation Operations Coalition. Washington, DC. 2007. Cost ID: 2011-00222

[9] *The National Traffic Signal Report Card: Technical Report 2007*, National Transportation Operations Coalition. Washington, DC. 2007. Cost ID: 2011-00222

[10] Rodier, Caroline J., et al. *Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration - Final Report*, University of California, Report No. UCB-ITS-PRR-2008-5. Berkeley, CA. June 2008. Costs ID: 2011-00215

[11] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[12] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[13] Bergmann Associates. *Monroe County New York: ITS Camera Deployment & Systems Integration Evaluation – Final*. Monroe County, NY. August 2006. Benefit ID: 2009-00594

[14] Bergmann Associates. *Monroe County New York: ITS Camera Deployment & Systems Integration Evaluation – Final*. Monroe County, NY. August 2006. Cost ID: 2009-00180

[15] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[16] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[17] Remkes, C., et al. *NM 68, Riverside Drive City of Espanola, New Mexico ITS Project Final Evaluation Report,* U.S. DOT, EDL No. 14464. September 2008. Benefit ID: 2009-00598

[18] *City of Fort Collins Advanced Traffic Management System Final Report*, U.S. DOT, EDL No. 14452. June 2008. Benefit ID: 2009-00593.

[19] The estimate of $2,500 to $3,100 is based on information from the following resources:

Conversation with Mr. Jerry Luor. Traffic Engineering Supervisor, Denver Regional Council of Governments (DRCOG). October 2006. Cost ID: 2007-00117

"Fee Estimate – Millennia Mall Retiming and Scope and Schedule – Millennia Mall Retiming," Orlando, FL. October 2005. Cost ID: 2007-00113

Heminger, S. "Regional Signal Timing Program – 2005 Cycle Program Performance," Memorandum to the California Metropolitan Transportation Commission's Operations Committee. Oakland, CA. October 2006. Cost ID: 2007-00112

Harris, J. "Benefits of Retiming Traffic Signals: A Reference for Practitioners and Decision Makers About the Benefits of Traffic Signal Retiming," Paper Presented at the ITE 2005 Annual Meeting and Exhibit. Melbourne, Australia. 7–10 August 2005. Cost ID: 2007-00115

Sunkari, Srinivasa. "The Benefits of Retiming Traffic Signals," *ITE Journal*. April 2004. Cost ID: 2007-00116

The National Traffic Signal Report Card: Technical Report, National Transportation Operations Coalition. Washington, DC. 2005. Cost ID: 2007-00114

The National Traffic Signal Report Card: Technical Report 2007, National Transportation Operations Coalition. Washington, DC. 2007. [Cost ID: 2011-00222]

[20] *The National Traffic Signal Report Card: Technical Report 2007*, National Transportation Operations Coalition. Washington, DC. 2007. [Cost ID: 2011-00222]

[25] Remkes, C., et al. *NM 68, Riverside Drive City of Espanola, New Mexico ITS Project Final Evaluation Report,* U.S. DOT, EDL No. 14464. September 2008. [Cost ID: 2009-00181]

[22] Briglia, Peter, M.Jr. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects*. Washington State DOT. Olympia, WA. June 2009. [Cost ID: 2010-00198]

[23] Park, Byungkyu (Brian) and Yin Chen. *Quantifying the Benefits of Coordinated Actuated Traffic Signal Systems: A Case Study*. Prepared by the University of Virginia for the Virginia DOT, Report No. VTRC 11-CR2. Charlottesville, VA. September, 2010. [Benefit ID: 2011-00658]

[24] Robinson Town Centre Boulevard/Summit Drive Park SINC Project Summary, Southwestern Pennsylvania Commission, August 2011. [Benefit ID: 2011-00756].

[25] *City of Fort Collins Advanced Traffic Management System Final Report*, U.S. DOT, EDL No. 14452. June 2008. [Lesson ID: 2009-00469]

[26] *Intelligent Transportation Systems for Planned Special Events: A Cross-Cutting Study*, U.S. DOT, EDL No. 14436. November 2008. [Lesson ID: 2008-00466]

[27] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[28] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[29] Rodier, Caroline J., et al. *Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration - Final Report*, University of California, Report No. UCB-ITS-PRR-2008-5. Berkeley, CA. June 2008. [Benefit ID: 2011-00695]

[30] Rodier, Caroline J. and Susan A. Shaheen. *Transit–Based Smart Parking in the U.S.: Behavioral Analysis of San Francisco Bay Area Field Test*, Institute of Transportation Studies, University of California, Report No. UCD-ITS-RR-06-19. Davis, CA. December 2006. [Benefit ID: 2008-00510]

[31] *Automated Parking Information System Operational Test Evaluation for WMATA Glenmont Parking Facility*, U.S. DOT Federal Transit Administration. December 2010. [Benefit ID: 2010-00702]

[32] *Advanced Parking Management Systems: A Cross–Cutting Study – Taking the Stress out of Parking*, U.S. DOT, Report No. FHWA-JPO-07-011, EDL No. 14318. January 2007. [Cost ID: 2008-00131]

[33] Shaheen, Susan A. and Caroline Rodier. "Research Pays Off – Smart Parking Management to Boost Transit, Ease Congestion: Oakland, California, Field Test Shows Promise," *TR News,* No. 251, Transportation Research Board. Washington, DC. July–August 2007. [Cost ID: 2008-00134]

[34] Rephlo, J., et al. *Evaluation of Transit Applications of Advanced Parking Management Systems: Final Evaluation Report,* U.S. DOT, Report No. FHWA-JPO-08-052, EDL No. 14432. May 2008. [Cost ID: 2009-00183]

[35] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[36] Kamal, M.A.S., et al. "Development of Ecological Driving Assist System: Model Predictive Approach in Vehicle Control," Paper Presented at the 16th ITS World Congress. Stockholm, Sweden. 21–25 September 2009. Benefit ID: 2010-00645

[37] Decina, Lawrence E., et al. *Automated Enforcement: A Compendium of Worldwide Evaluations of Results*, U.S. DOT National Highway Traffic Safety Administration, Report No. DOT HS 810 763. July 2007. Benefit ID: 2008-00505

[38] Washington, Simon and Kangwon Shin. *The Impact of Red Light Cameras (Automated Enforcement) on Safety in Arizona*, Arizona DOT, Report No. 550. Phoenix, AZ. June 2005. Benefit ID: 2008-00512

[39] Hu, Wen, et al. *Effects of Red Light Camera Enforcement on Fatal Crashes in Large US Cities,* Insurance Institute for Highway Safety. Arlington, VA. February 2011. Benefit ID: 2011-00665

[40] "Integrated Corridor Management (ICM)," U.S. DOT Research and Innovative Technology Administration Web site URL: www.its.dot.gov/icms/index.htm. Last Accessed 14 July 2011.

[41] Mortazavi, A.; X. Pan; E. Jin; M. Odioso; and Z. Sun. *Travel Times on Changeable Message Signs Volume II – Evaluation of Transit Signs,* California Center for Innovative Transportation, University of California. Berkeley, CA. September 2009. Benefit ID: 2010-00657

[42] Bhatt, K.; T. Higgins; and J.T. Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report* U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Benefit ID: 2010-00626

[43] Bham, G.H., et al. E*valuation of Variable Speed Limits on I-217/I-255 in St. Louis*, Missouri DOT. Jefferson City, MO. October 2010. Benefit ID: 2011-00735

[44] Washington, S.; K. Shin; and I. Schalkwyk. *Evaluation of the City of Scottsdale Loop 101 Photo Enforcement Demonstration Program: Final Report AZ-684*. U.S. DOT Federal Highway Administration. November 2007. Benefit ID: 2011-00734 and Benefit ID: 2011-00747

[45] *I-95 Corridor Coalition – Vehicle Probe Project: General Benefits White Paper*. I-95 Corridor Coalition. August 2010. Benefit ID: 2010-00650

[46] *I-95 Corridor Coalition – Vehicle Probe Project: General Benefits White Paper*. I-95 Corridor Coalition. August 2010. Benefit ID: 2010-00649

[47] *I-95 Corridor Coalition – Vehicle Probe Project: General Benefits White Paper*. I-95 Corridor Coalition. August 2010. Benefit ID: 2010-00653.

[48] Briglia, Jr., P. M. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects*. Washington State DOT. Seattle, WA. June 2009. Cost ID: 2009-00197

[49] Cambridge Systematics. *Integrated Corridor Management: Analysis, Modeling, and Simulation Results for the Test Corridor*, U.S. DOT. September 2008. Cost ID: 2009-00194

[50] Alexiadis, Vassili; Brian Cronin; Steven Mortensen; and Dale Thompson. "Integrated Approach: Inside Story on the ICM Test Corridor," *Traffic Technology International*, 2009, pp. 46-50. Benefit ID: 2009-00614

[51] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[52] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[53] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[54] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[55] Cambridge Systematics. *Integrated Corridor Management: Analysis, Modeling, and Simulation for the I-15 Corridor in San Diego, California*. U.S. DOT. September 2010. Benefit ID: 2011-00736

[56] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[57] Alexiadis, Vassili. *Integrated Corridor Management: Analysis, Modeling, and Simulation Results for the Test Corridor*, Prepared by Cambridge Systematics for the U.S. DOT. September 2008. Cost ID: 2009-00194

[58] *Innovative Traffic Control Technology and Practice in Europe*. U.S. DOT Federal Highway Administration, Office of International Programs, Report No. FHWA-PL-99-021. August 1999. Benefit ID: 2007-00355

[59] Bham, G.H. *Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis.* Jefferson City, MO. October 2010. Benefit ID: 2011-00735

[60] Haas, et al. *iFlorida Model Deployment Final Evaluation Report*, Prepared by SAIC for the U.S. DOT Federal Highway Administration, EDL No. 14480. 2009. Lesson ID: 2009-00508

[61] Barth, M. and K. Boriboonsom. "Energy and emissions impacts of a freeway-based dynamic eco-driving system" *Transportation Research Part D: Transport and Environment*, Volume 14, Issue 6, August 2009, pp. 400-410. Benefit ID: 2010-00646

[62] Eidswick, Jaime, et al. *Grand Canyon National Park Dynamic Message Sign (DMS) Highway Advisory Radio (HAR) Pilot Deployment Evaluation*. Prepared for the U.S. Federal Lands Highway Division. 2009. Benefit ID: 2011-00664

[63] Peter, M. Jr. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects*. Washington State DOT. Olympia, WA. June 2009. Cost ID: 2009-00197

[64] Sources that support these findings:

"FHWA Safety," U.S. DOT Federal Highway Administration, Web site URL: http://safety.fhwa.dot.gov/intersection. Last Accessed 28 June 2011.

Torbic, Darren J., et al. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 7: A Guide for Reducing Collisions on Horizontal Curves*, Transportation Research Board, National Cooperative Highway Research Program (NCHRP), Report No. 500. Washington, DC. 2004.

Pedestrian and Bicyclist Intersection Safety Indices: Final Report, U.S. DOT Highway Safety Research Center for the Turner–Fairbank Highway Research Center, Report No. FHWA-HRT-06-125. November 2006.

[65] "FHWA. Horizontal Curve Safety," U.S. DOT Federal Highway Administration. Web site URL: http://safety.fhwa.dot.gov/roadway_dept/horicurves/cmhoricurves. Last accessed 27 July 2011.

[66] Sources supporting these findings:

National Highway traffic Safety Administration (NHTSA) Traffic Safety Facts 2009 Data: *Pedestrians, 2011*. U.S. DOT NHTSA. Web site URL: http://www-nrd.nhtsa.dot.gov/Pubs/811394.pdf. Last accessed 27 July 2011.

National Highway traffic Safety Administration (NHTSA) Traffic Safety Facts 2009 Data; Bicyclists and other cyclists, U.S. DOT NHTSA. 2011. Web site URL: http://www-nrd.nhtsa.dot.gov/Pubs/811386.pdf. Last accessed 27 July 2011.

[67] Qi, Yi, et al. *Vehicle infrastructure integration (VII) based road-condition warning system for highway collision prevention*. Prepared by Texas Southern University for Texas A&M University. College Station, TX. 27 May 2009. Benefit ID: 2011-00729

[68] *2009 ITS Annual Report.* Minnesota Department of Transportation Office of Traffic, Safety and Technology ITS Section, Minnesota DOT. St. Paul, MN .2009. Benefit ID: 2011-00690

[69] *2009 ITS Annual Report* Minnesota Department of Transportation Office of Traffic, Safety and Technology ITS Section, Minnesota DOT. St. Paul, MN .2009. Benefit ID: 2011-00688

[70] *2010 ITS Deployment Tracking National Survey: Summary Report - Freeway Management*, U.S. DOT Federal Highway Administration. 10 February 2011.

[71] Qi, Yi, et al. *Vehicle infrastructure integration (VII) based road-condition warning system for highway collision prevention*. Prepared by Texas Southern University for Texas A&M University. College Station, TX. 27 May 2009. Benefit ID: 2011-00729

[72] Pitale, Jaswandi Tushar, et al. *Benefit:Cost Analysis of In-Vehicle Technologies and Infrastructure Modifications as a Means to Prevent Crashes Along Curves and Shoulders*, Prepared by the University of Minnesota for the Minnesota DOT. St. Paul, MN. December 2009. Benefit ID: 2011-00728

[73] Mlot, Stephanie. "CSX bridge clearance warning is doing its job" *Frederick News Post*. 2 April 2011. Web site URL: http://www.fredericknewspost.com/sections/news/display.htm?storyid=119321 Last Accessed 16 September 2011. Benefit ID: 2011-00750

[74] Mlot, Stephanie. "CSX bridge clearance warning is doing its job" *Frederick News Post*. 2 April 2011. Web site URL: http://www.fredericknewspost.com/sections/news/display.htm?storyid=119321. Last Accessed 16 September 2011. Cost ID: 2011-00233

[75] *2010 ITS Deployment Tracking National Survey: Summary Report - Arterial Management*, U.S. DOT Federal Highway Administration. 10 February 2011.

[76] *2010 ITS Deployment Tracking National Survey: Summary Report - Arterial Management*, U.S. DOT Federal Highway Administration. 10 February 2011.

[77] *2009 ITS Annual Report,* Minnesota Department of Transportation Office of Traffic, Safety and Technology ITS Section. St. Paul, MN. 2009. Benefit ID: 2011-00690

[78] *2009 ITS Annual Report*, Minnesota Department of Transportation Office of Traffic, Safety and Technology ITS Section. St. Paul, MN. 2009. Benefit ID: 2011-00749

[79] *2010 ITS Deployment Tracking National Survey: Summary Report - Arterial Management*, U.S. DOT Federal Highway Administration. 10 February 2011.

[80] *Pedestrian safety engineering and intelligent transportation system-based countermeasures program for reduced pedestrian fatalities, injuries, conflicts and other surrogate measures: Miami-Dade site*. Prepared by the University of Florida for the U.S. DOT Federal Highway Administration. 25 August 2008. Benefit ID: 2011-00686

[81] *2010 ITS Deployment Tracking National Survey: Summary Report - Arterial Management*, U.S. DOT Federal Highway Administration. 10 February 2011.

[82] *2009 ITS Annual Report*, Minnesota Department of Transportation Office of Traffic, Safety and Technology ITS Section. St. Paul, MN. 2009. Benefit ID: 2011-00688

[83] *Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services*, The National Academy of Sciences, National Research Council. Washington, DC. April 2004.

[84] "US DOT Perspective," U.S. DOT Federal Highway Administration, Briefing at Weather Policy Forum. 25 May 2010.

[85] Pisano, Paul, et al. "U.S. Highway Crashes in Adverse Road Weather Conditions," paper presented at the American Meteorological Society Annual Meeting. New Orleans, LA. 20–24 January 2008; and

Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services, The National Academy of Sciences, National Research Council. Washington, DC. April 2004.

[86] Goodwin, L. *Weather Impacts on Arterial Traffic Flow*, Mitretek Systems. Falls Church, VA. December 2002.

[87] Sources with supporting information:

"Clarus Initiative," U.S. DOT Federal Highway Administration. Web site URL: www.clarusinitiative.org. Last Accessed 21 July 2011.

"Road Weather Management Program," U.S DOT Federal Highway Administration. Web site URL: ops.fhwa.dot.gov/weather/mitigating_impacts/programs.htm#3. Last Accessed 21 July 2011.

[88] Cluett, Chris, et al. *Weather Information Integration in Transportation Management Center Operations*, U.S. DOT Federal Highway Administration. 2 January 2011.

[89] Sources that support these findings:

Evaluation of Rural ITS Information Systems along U.S. 395, Spokane, Washington, U.S. DOT Federal Highway Administration, EDL No. 13955. 8 January 2004. Benefit ID: 2004-00274

Final Evaluation Report: Evaluation of the Idaho Transportation Department Integrated Road–Weather Information System, U.S. DOT Federal Highway Administration, EDL No. 14267. 2 February 2006. Benefit ID: 2008-00522

[90] Sources that support these findings:

Cooper, B.R. and Helen E. Sawyer. *Assessment Of M25 Automatic Fog–Warning System – Final Report*, Safety Resource Centre, Transportation Research Laboratory. Crowthorne, Berkshire, United Kingdom. 1993. Benefit ID: 2005-00283

Fog Project on I–75 between Chattanooga and Knoxville, Tennessee ITS State Status Report. October 2000. Benefit ID: 2001-00219

Hogema, Jeroen and Richard van der Horst. *Evaluation of A16 Motorway Fog–Signaling System with Respect to Driving Behavior,* Transportation Research Board, Report No. TRR 1573. Washington, DC. 1995. Benefit ID: 2000-00022

Kumar, Manjunathan and Christopher Strong*. Comparative Evaluation of Automated Wind Warning Systems*, Prepared by the Montana State of University for the California DOT, Oregon DOT, and U.S. DOT. February 2006. Benefit ID: 2008-00523

Perrrin, Joseph and Brad Coleman. *Adverse Visibility Information System Evaluation (ADVISE): Interstate 215 Fog Warning System – Final Report*, Prepared by the University of Utah for the Utah DOT, Report No. UT-02.12. Salt Lake City, UT. June 2003. Benefit ID: 2005-00281

Ulfarsson, Gudmundur F., et al. *TRAVELAID*, Prepared by the University of Washington for the Washington State Transportation Commission and the U.S. DOT. December 2001. Benefit ID: 2002-00240

[91] Sources that support these findings:

Cooper, B.R. and Helen E. Sawyer. *Assessment of M25 Automatic Fog–Warning System: Final Report*, Safety Resource Centre, Transportation Research Laboratory. Crowthorne, Berkshire, United Kingdom. 1993. Benefit ID: 2005-00283

Fog Project on I–75 between Chattanooga and Knoxville, Tennessee ITS State Status Report. October 2000. Benefit ID: 2001-00219

Hogema, Jeroen and Richard van der Horst. *Evaluation of A16 Motorway Fog–Signaling System with Respect to Driving Behavior,* Transportation Research Board, Report No. TRR 1573. Washington, DC. 1995. Benefit ID: 2000-00022

Kumar, Manjunathan and Christopher Strong*. Comparative Evaluation of Automated Wind Warning Systems*, Prepared by the Montana State of University for the California DOT, Oregon DOT, and U.S. DOT. February 2006. Benefit ID: 2008-00523

Perrrin, Joseph and Brad Coleman. *Adverse Visibility Information System Evaluation (ADVISE): Interstate 215 Fog Warning System – Final Report*, Prepared by the University of Utah for the Utah DOT, Report No. UT-02.12. Salt Lake City, UT. June 2003. Benefit ID: 2005-00281

[92] Strong, Christopher and Xianming Shi. "Benefit–Cost Analysis of Weather Information for Winter Maintenance: A Case Study," *Transportation Research Record: Journal of the Transportation Research* Board, No. 2055, 2008, pp. 119–127. Benefit ID: 2008-00691

[93] Ye, et al. *Cost Benefits of Weather Information for Winter Road Maintenance*, Iowa DOT, Ames, IA. April 2009. Benefit ID: 2011-0693.

[94] Western Transportation Institute & Iteris Inc. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs*, South Dakota DOT, Office of Research, Report No. SD2006-10, Final Report. May 2009

[95] Ye, Zhirui, Christopher Strong, Xianming Shi, and Steven Conger. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs*, South Dakota Department of Transportation, Pierre, SD. 12 May 2009. Cost ID: 2011-00209, Cost ID: 2011-00210, and Cost ID: 2011-00211.

[96] Shi, Xianming, et al. *Vehicle–Based Technologies for Winter Maintenance: The State of the Practice – Final Report*, Transportation Research Board, NCHRP, Project 20-7/Task 200. Washington, DC. September 2006. Cost ID: 2008-00142

[97] Sources that support these findings:

Andrle, Stephen J., et al. *Highway Maintenance Concept Vehicle – Final Report: Phase Four*, Iowa State University, Center for Transportation Research and Education. Ames, IA. June 2002. Cost ID: 2008-00143

Kack, David and Eli Cuelho. *Needs Assessment and Cost–Benefit Analysis of RoadView™ Advanced Snowplow Technology System*, Sixth International Symposium on Snow Removal and Ice Control Technology, Transportation Research Circular, Number E–C063. Washington, DC. June 2004. Cost ID: 2008-00144

[98] Powell, Nancy. *Kansas City Scout Weather Integration Plan*. Kansas City. MO. March 2010. Cost ID: 2011-00225.

[99] Cox, Kevin M. *Wyoming Department of Transportation TMC Weather Integration Plan*. Cheyenne, WY. 15 December 2010. Cost ID: 2011-00227.

[100] Krechmer, Dan, et al. *Benefit–Cost Evaluation Techniques for Rural ITS Deployments,* Michigan DOT. January 2010, Cost ID: 2011-00212.

[101] Ye, et al. *Cost Benefits of Weather Information for Winter Road Maintenance*, Iowa DOT. Ames, IA. April 2009. Benefit ID: 2011-0693.

[102] Murphy, Ray. "MDSS Participation as of April 12, 2011," PowerPoint Presentation Prepared by the Road Weather Management Program, U.S. DOT Federal Highway Administration. April 2011.

[103] Shi, X., et al. *Evaluation of Utah Department of Transportation's Weather Operations/RWIS Program: Phase I*, Prepared by the Montana State University for the Utah DOT. February 2007. Benefit ID: 2008-00527

[104] Powell, Nancy. *Kansas City Scout Weather Integration Plan*. Kansas City, MO. March 2010. Cost ID: 2011-00225.

[105] Cluett, Chris, et al. *Weather Information Integration in Transportation Management Center (TMC) Operations*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-11-058. February 2011. Cost ID: 2011-00225.

[106] Cox, Kevin M. *Wyoming DOT TMC Weather Integration Plan*. Cheyenne, WY. 15 December 2010. Cost ID: 2011-00227.

[107] Krechmer, Dan, et al. *Benefit–Cost Evaluation Techniques for Rural ITS Deployments,* Michigan DOT. January 2010. Cost ID: 2011-00212.

[108] Ye, et al. *Cost Benefits of Weather Information for Winter Road Maintenance*, Iowa DOT. Ames, IA. April 2009. Cost ID: 2011-00214.

[109] Krechmer, D., et al. "Benefit-Cost Evaluation Techniques for Rural ITS Deployments," Paper Presented at ITS World Congress. November 2008. Benefit ID: 2011-00685.

[110] Ye, et al. *Cost Benefits of Weather Information for Winter Road Maintenance*, Iowa DOT. Ames, IA. April 2009. Benefit ID: 2011-0693.

[111] Strong, Christopher and Xianming Shi. "Benefit–Cost Analysis of Weather Information for Winter Maintenance: A Case Study," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2055, 2008, pp. 119-127. Benefit ID: 2008-00691

[112] Ye, et al. *Cost Benefits of Weather Information for Winter Road Maintenance*, Iowa DOT. Ames, IA. April 2009. Cost ID: 2011-00214.

[113] Cluett, Chris and Fred Kitchener. *Implementation and Evaluation of the Sacramento Regional Transportation Management Center Weather Alert Notification System,* U.S. DOT Federal Highway Administration *Report No.* FHWA-JPO-10-063, August 2010. Benefit ID: 2011-00671.

[114] Briglia, Peter, Jr. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects*, Prepared for Washington State Department of Transportation. Olympia, WA. June 2009. Cost ID: 2009-00197.

[115] Cortelazzi, Lou, et al. *Pennsylvania Turnpike Commission's Advanced Traveler Information System (ATIS) Phase III Project*. Prepared by DMJM Harris for the Pennsylvania Turnpike Commission, EDL No. 14308. Harrisburg, PA. April 2006. Cost ID: 2008-00168

[116] Cluett, Chris, et al. *Weather Information Integration in Transportation Management Center (TMC) Operations*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-11-058. February 2011. Lesson ID: 2011-00586

[117] Buddemeyer, J., et al*. Variable Speed Limits System for Elk Mountain Corridor*, Wyoming DOT. Cheyenne, WY. October 2010. Benefit ID: 2011-00733

[118] Cluett, Chris, Deepak Gopalakrishna, and Leon Osborne. *Road Weather Management Program Performance Metrics: Implementation and Assessment,* U.S. DOT Federal Highway Administration. Report No. FHWA-JPO-09-061, August 2009.

[119] Cluett, Chris and Jeffery Jenq. *A Case Study of the Maintenance Decision Support System (MDSS) in Maine,* U.S. DOT ITS Joint Program Office, Report No. FHWA-JPO-08-001, 10 September 2007. Benefit ID: 2011-00655

[120] Cluett, Chris and Deepak Gopalakrishna. *Benefit-Cost Assessment of a Maintenance Decision Support System (MDSS) Implementation: The City and County of Denver*, U.S. DOT ITS Joint Program Office, Report No. FHWA-JPO-10-018. 7 December 2009. Benefit ID: 2010-00654

[121] Boselly, Edward S. *Benefit/Cost Study of RWIS and Anti–icing Technologies: Final Report*, Transportation Research Board, NCHRP, Report No. 20-7(117). Washington, DC. March 2001. Benefit ID: 2007-00470

[122] Ye, Zhirui., et al. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs, South Dakota Department of Transportation,* Report No. SD2006-10-F. Pierre, SD. May 2009. Cost ID: 2011-00211

[123] McClellan, T.; P. Boone; and M. Coleman. *Maintenance Decision Support System (MDSS): Indiana Department of Transportation (INDOT) - Statewide Implementation,* Final Report for FY09. January 2009. Cost ID: 2010-00203

[124] Ye, Zhirui., et al. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs, South Dakota Department of Transportation, Report No.* SD2006-10-F. Pierre, SD. May 2009. Cost ID: 2011-00210

[125] Ye, Zhirui., et al. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs, South Dakota Department of Transportation, Report No.* SD2006-10-F. Pierre, SD. May 2009. Cost ID: 2011-00209

[126] Ye, Zhirui., et al. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs, South Dakota Department of Transportation, Report No.* SD2006-10-F. Pierre, SD. May 2009. Benefit ID: 2011-00668

[127] Sources that support these findings:

Fontaine, M.D.; P. Carlson; and G. Hawkins. *Use of Innovative Traffic Control Devices to Improve Safety at Short–Term Rural Work Zones*, Texas Transportation Institute, Report No. 1879-S. College Station, TX. 2000. Benefit ID: 2007-00331

Garber, N. and S. Patel. *Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones,* Virginia Transportation Research Council, Report No. VTRC-95-R4. Charlottesville, VA. 1994. Benefit ID: 2007-00332

Garber, N. and S. Srinivasan. *Effectiveness of Changeable Message Signs with Radar in Controlling Vehicle Speeds in Work Zones*, Virginia Transportation Research Council, Report No. VTRC-98-R10. Charlottesville, VA. 1998. Benefit ID: 2007-00330

McCoy, P. J.; J. Bonneson; and J. Kollbaum. "Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways," Transportation Research Board, Report No. TRR 1509. Washington, DC. 1995. Benefit ID: 2007-00329

[128] Sources that support these findings:

Fontaine, M.; P. Carlson; and G. Hawkins. *Use of Innovative Traffic Control Devices to Improve Safety at Short–Term Rural Work Zones*, Prepared by the Texas Transportation Institute for the Texas DOT. 2000. Benefit ID: 2007-00331

Fontaine, Michael D. and Steven D. Schrock. "Feasibility of Real–Time Remote Speed .Enforcement in Work Zones," Paper Presented at the 81st Annual Transportation Research Board Meeting. Washington, DC. 13–17 January 2002. Benefit ID: 2007-00490

Garber, N. and Surbhi T. Patel, *Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones: Final Report*, Virginia Transportation Research Council, Report No. VTRC 95-R4. Charlottesville, VA. August 1994. Benefit ID: 2007-00332

McCoy, P. J.; J. Bonneson; and J. Kollbaum. *Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways*, Transportation Research Board, Report No. TRR 1509. Washington, DC. 1995. Benefit ID: 2007-00329

[129] Sources that support these findings:

Evaluation of 2004 Dynamic Late Merge System, Prepared by URS for the Minnesota DOT. St. Paul, MN. 28 December 2004. Benefit ID: 2007-00318

Intelligent Transportation Systems in Work Zones: A Case Study – Dynamic Lane Merge System, U.S. DOT Federal Highway Administration, EDL No. 14011. October 2004. Benefit ID: 2007-00403

[130] *ATIS Evaluation Framework*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-066, EDL No. 14313. April 2005. Benefit ID: 2008-00537

[131] Sources that support these findings:

Bushman, R. and C. Berthelot. "Estimating the Benefits of Deploying Intelligent Transportation Systems in Work Zones," Presentation at the 83rd Annual Transportation Research Board Meeting. Washington, DC. 11–15 January 2004. Benefit ID: 2007-00326

Chu, L.; H. Kim; H. Liu; and W. Recker. "Evaluation of Traffic Delay Reduction from Automatic Workzone Information Systems Using Micro–simulation," Presentation to the Transportation Research Board 84th Annual Meeting. Washington, DC. 9–13 January 2005. Benefit ID: 2007-00400

Lee, Eul–Bum and Changmo Kim. "Automated Work Zone Information System (AWIS) on Urban Freeway Rehabilitation: California Implementation," Paper Presented at the 85th Annual Meeting of the Transportation Research Board. Washington, DC. 22–26 January 2006. Benefit ID: 2006-00293

[132] Fontaine, Mike. "Operational and Safety Benefits of Work Zone ITS," Presentation to "ITS in Work Zones" Workshop/Peer Exchange. September 2005. Cost ID: 2006-00109

[133] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[134] *Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones*. Federal Highway Administration, October 2008, Report No. FHWA-HOP-09-002. Benefit ID: 2009-00600

[135] Meyer, Eric and I. Ahmed. “Benefit-Cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance,” Paper presented at the 83rd Annual Meeting of the Transportation Research Board,” Washington DC. 11-15 January 2004. Benefit ID: 2008-00536

[136] Shi, et al. “Vehicle-Based Technologies for Winter Maintenance: The State of the Practice*,”* Paper presented at the 86th Transportation Research Board Annual Meeting, Washington, DC. January 2007.

[137] Haas, R.; Mark Carter; Eric Perry, et al. “i Florida Model Deployment Final Evaluation Report .” Prepared for the United States Department of Transportation. January 2009. Lesson ID: 2009-00492.

[139] Luttrell, Tim., et al. Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zoned. Federal Highway Administration, Report No. FHWA-HOP-09-002. October 2008. Benefit ID: 2009-00605

[140] Fudala, Nocholas J. and Michael D. Fontaine. “Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues,” Virginia Transportation Research Council, Prepared for Virginia Department of Transportation and Federal Highway Administration. March 2010.

[141] Luttrell, Tim., et al. Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones. Federal Highway Administration. Report No. FHWA-HOP-09-002, October 2008. Benefit ID: 2009-00604

[142] Luttrell, Tim., et al. *Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones*. Federal Highway Administration, Report No. FHWA-HOP-09-002. October 2008. Benefit ID: 2009-00606

[143] Fontaine, Mike. “Operational and Safety Benefits of Work Zone ITS: Presentation to ITS in Work Zones Workshop.” September 2005. Cost ID: 2006-00109.

[144] Luttrell, Tim., et al. *Comparative Analysis Report: The Benefits of Using Intelligent Transportation Systems in Work Zones*.” Prepared for the U.S. DOT. January 2009. Lesson ID: 2009-00482.

[145] "National Transit Database," U.S. DOT Federal Transit Administration. Web site URL:http://www.ntdprogram.gov/ntdprogram/data.htm. Last Accessed 11 July 2011 (2009 data).

[146] Dickens, Matthew and John Neff. *2011 Public Transportation Fact Book 62nd Edition*, American Public Transportation Association. Washington DC. April 2011.

[147] Furth, Peter G., et al. *TCRP Report 113: Using Archived AVL–APC Data to Improve Transit Performance and Management*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2006.

[148] Biernbaum, Lee, et al. *Multimodal Trip Planner System Final Evaluation Report*, Prepared by Volpe for the U.S. DOT Federal Transit Administration, Report No. FTA-MA-ITS-2011.1. Washington DC. May 2010.

[149] Diaz, Roderick B. and Dennis Hinebaugh. *National Bus Rapid Transit Institute, Characteristics of Bus Rapid Transit for Decision-Making (CBRT) 2009 Update*, U.S. DOT Federal Transit Administration Office of Research, Demonstration and Innovation (TRI), Report No. FTA-FL-26-7109.2009.1. Washington DC. February 2009.

[150] "Mobility Services for All Americans," U.S. DOT ITS Joint Program Office. Web site URL: www.its.dot.gov/msaa/index.htm. Last Accessed 14 July 2011.

[151] "Transit Impact Matrix," U.S. DOT. Web site URL: itsweb.mitretek.org/its/aptsmatrix.nsf/viewbyEfficiency?OpenView. Last Accessed 12 December 2007.

[152] Bruun, Eric C. "Technological Maturity of ITS and Scheduling and Integrated Service Options to Transit Planners," Paper Presented at the 86th Annual Meeting of the Transportation Research Board. Washington, DC. 21–25 January 2007.

[153] Burt, Matt; Deepak Gopalakrishna; and Chris Cluett. *Phase III (Final) Evaluation Report National Evaluation of FY01 Earmark: Area Transportation Authority of North Central Pennsylvania – Regional GIS/ITS Initiative*. ITS Joint Program Office U.S. DOT Research and Innovative Technology Administration, EDL 14493. Washington DC. August 2009. Benefit ID: 2011-00710

[154] Sources that support these findings:

APTS Benefits, U.S. DOT Federal Transit Administration. November 1995. Benefit ID: 2000-00028

Strathman, J., et al. "Evaluation of Transit Operations: Data Applications of Tri–Met's Automated Bus Dispatching System," *Transportation*, Vol. 29, No. 3. August 2002. Cited in Furth, Peter G., et al. *Uses of Archived AVL–APC Data to Improve Transit Performance and Management: Review and Potential*, Transit Cooperative Research Program Web Document No. 23. June 2003. Benefit ID: 2000-00151

Milwaukee County Transit System, Status Report, Milwaukee County. Milwaukee, WI. July 1995. Benefit ID: 2000-00110

[155] Sources with results used to construct this range of impacts include (listed alphabetically by study location):

Chada, Shireen and Robert Newland. *Effectiveness of Bus Signal Priority: Final Report*, Prepared by the University of South Florida for the Florida DOT and U.S. DOT, Report No. NCTR-416-04, EDL No. 13651. Tallahassee, FL. January 2002. Benefit ID: 2007-00345

Crout, David. "Transit Signal Priority Evaluation," Paper Presented at the ITS America 13th Annual Meeting and Exposition, Minneapolis, MN. May 2003. Benefit ID: 2003-00265

Dion, Francois, et al. "Evaluation of Transit Signal Priority Benefits along a Fixed–Time Signalized Arterial," Paper Presented at the 81st Annual Meeting of the Transportation Research Board, Washington, DC. 13–17 January 2002. Benefit ID: 2007-00348

Greenough and Kelman. "ITS Technology Meeting Municipal Needs – The Toronto Experience," Paper Presented at the 6th World Congress Conference on ITS. Toronto, Canada. 8–12 November 1999. Benefit ID: 2007-00362

"ITS developed by Japanese Police," Japan Traffic Management Technology Association, Institute of Urban Traffic Research. (Undated) Benefit ID: 2000-00073

Lehtonen, Mikko and Risto Kulmala. "The Benefits of a Pilot Implementation of Public Transport Signal Priorities and Real–Time Passenger Information," Paper Presented at the 81st Annual Transportation Research Board Meeting. Washington, DC. 13–17 January 2002. Benefit ID: 2007-00392

Los Angeles Metro Rapid Demonstration Program: Final Report, Prepared by Transportation Management and Design, Inc. for the Los Angeles County Metropolitan Transportation Authority and the Los Angeles DOT. March 2002. Benefit ID: 2008-00544

"Telematics Applications Programme, 4th Framework Programme," RTD&D 1994–1998, Web site URL: www.cordis.lu/telematics/tap_transport/research/10.html. Last Accessed 15 November 2004. Benefit ID: 2000-00135

Wang, Yinhai, et al. *Comprehensive Evaluation on Transit Signal Priority System Impacts Using Field Observed Traffic Data*, TransNow Report (TNW2007-06), University of Washington. Seattle, WA. 15 June 2007. Benefit ID: 2008-00538

[156] Harman, Lawrence J. and Uma Shama. *TCRP Synthesis 70: Mobile Data Terminals – A Synthesis of Transit Practice*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2007. Cost ID: 2008-00147

[157] Reports that support this finding:

Kittelson and Associates, et al. *TCRP Report 118: Bus Rapid Transit Practitioner's Guide*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2007. Cost ID: 2008-00148

Diaz, Roderick B, and Dennis Hinebaugh. *National Bus Rapid Transit Institute, Characteristics of Bus Rapid Transit for Decision-Making (CBRT) 2009 Update*, U.S. DOT Federal Transit Administration Office of Research, Demonstration and Innovation (TRI), Report No. FTA-FL-26-7109.2009.1. February 2009.

[158] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[159] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[160] Dickens, Matthew and John Neff. *2011 Public Transportation Fact Book 62nd Edition*, American Public Transportation Association. Washington DC. April 2011.

[161] Sources that support these findings:

APTS Benefits, Report Prepared by the U.S. DOT Federal Transit Administration. November 1995.

Milwaukee County Transit System, Status Report, Milwaukee County. July 1995. Benefit ID: 2000-00110

Strathman, J., et al. "Evaluation of Transit Operations: Data Applications of Tri–Met's Automated Bus Dispatching System," *Transportation,* Vol. 29, No. 3. August 2002. Cited in Furth, Peter G., et al. *Uses of Archived AVL–APC Data to Improve Transit Performance and Management: Review and Potential*, Transit Cooperative Research Program Web Document No. 23. June 2003. Benefit ID: 2000-00151

[162] Wu, Tina; Matt Weatherford; Ancila Kaiparambil; and Linna Zhang. *Regional Transportation Commission of Washoe County Intelligent Transportation System Implementation Evaluation Study*, U.S. DOT Federal Transit Administration, Report No. FTA- NV-26-7005-2010.1. May 2010. Benefit ID: 2011-00707

[163] Kittelson and Associates, et al. *TCRP Report 118: Bus Rapid Transit Practitioner's Guide*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2007. Benefit ID: 2009-00612

[164] Hiller, William. *Transit Operations Decision Support System (TODSS) Core Requirements Prototype Development Case Study And Lessons Learned,* Prepared by Booz Allen Hamilton for the U.S. DOT Federal Transit Administration Research and Innovative Technology Report No. FTA-IL-26-7009-2009.2. February 2010. Benefit ID: 2011-0714

[165] Kittelson and Associates, et al. *TCRP Report 118: Bus Rapid Transit Practitioner's Guide*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2007. Cost ID: 2008-00148

[166] Parker, Doug J. *AVL Systems for Bus Transit: Update (TCRP Synthesis 73)*, Transportation Research Board Transit Cooperative Research Program. Washington DC. 2008. Cost ID: 2009 - 00190

[167] Jia, Xudong; Edward Sullivan; Cornelius Nuworsoo; and Neil Hockada. *EDAPTS Benefit/Cost Evaluation*, PATH University of California, Report No. UCB-ITS-PRR-2008-19. Berkeley, CA. July 2009. Cost ID: 2011 - 00216

[168] Kack, David and Philip Deepu. *An Evaluation of RouteMatch Software in the Billings MET Special Transit System*, Montana State University. Bozeman, MT. 2 May 2007. Cost ID: 2008-00149

[169] Parker, Doug J. *AVL Systems for Bus Transit: Update (TCRP Synthesis 73)*, Transportation Research Board Transit Cooperative Research Program. Washington DC. 2008. Lesson ID: 2009-00494

[170] Sources with results used to construct this range of impacts include (listed alphabetically by study location):

Chada, Shireen and Robert Newland. *Effectiveness of Bus Signal Priority: Final Report*, Prepared by the University of South Florida for the Florida DOT and the U.S. DOT, Report No. NCTR-416-04, EDL No. 13651. Tallahassee, FL. January 2002. Benefit ID: 2007-00345

Crout, David. "Transit Signal Priority Evaluation," Paper Presented at the ITS America 13th Annual Meeting and Exposition, Minneapolis, MN. 19–22 May 2003. Benefit ID: 2003-00265

Dion, Francois, et al. "Evaluation of Transit Signal Priority Benefits along a Fixed–Time Signalized Arterial," Paper Presented at the 81st Annual Meeting of the Transportation Research Board., Washington, DC. 13–17 January 2002. Benefit ID: 2007-00348

Greenough and Kelman. "ITS Technology Meeting Municipal Needs – The Toronto Experience," Paper Presented at the 6th World Congress Conference on ITS. Toronto, Canada. 8–12 November 1999. Benefit ID: 2007-00362

"ITS developed by Japanese Police," Japan Traffic Management Technology Association, Institute of Urban Traffic Research. (Undated) Benefit ID: 2000-00073

Lehtonen, Mikko and Risto Kulmala. "The Benefits of a Pilot Implementation of Public Transport Signal Priorities and Real–Time Passenger Information," Paper Presented at the 81st Annual Transportation Research Board Meeting. Washington, DC. 13–17 January 2002. Benefit ID: 2007-00392

Los Angeles Metro Rapid Demonstration Program: Final Report, Prepared by Transportation Management and Design, Inc. for the Los Angeles County Metropolitan Transportation Authority and the Los Angeles DOT. Los Angeles, CA. March 2002. Benefit ID: 2008-00544

"Telematics Applications Programme, 4th Framework Programme," RTD&D 1994–1998, Web site URL: www.cordis.lu/telematics/tap_transport/research/10.html. Last Accessed 15 November 2004. Benefit ID: 2000-00135

[171] Wang, Yinhai, et al. *Comprehensive Evaluation on Transit Signal Priority System Impacts Using Field Observed Traffic Data*, TransNow Report (TNW2007-06), University of Washington. Seattle, WA. 15 June 2007. Benefit ID: 2008-00538

[172] *98 B–line Bus Rapid Transit Evaluation Study,* Prepared by the IBI Group for Transport Canada. 29 September 2003. Benefit ID: 2008-00545

[173] Rephlo, Jennifer and R. Hass. *Sacramento-Watt Avenue Transit Priority and Mobility Enhancement Demonstration Project Phase III Evaluation Report*, Prepared by SAIC for the U.S DOT Federal Highway Administration, EDL No. 14299. Washington DC. April 2006. Lesson ID: 2008-00431

[174] *Acadia National Park Field Operational Test: Visitor Survey*, U.S. DOT Federal Highway Administration, EDL No. 13806. February 2003. Benefit ID: 2007-00438

[175] Lehtonen, Mikko and Risto Kulmala. "*The Benefits of a Pilot Implementation of Public Transport Signal Priorities and Real–Time Passenger Information*," Paper Presented at the 81st Annual Transportation Research Board Meeting. Washington, DC. 13–17 January 2002. Benefit ID: 2007-00391

[176] Haas, R.; E. Perry; and J. Rephlo. *Chattanooga SmartBus Project: Phase III Evaluation Report*, Prepared by SAIC for the U.S Office Research and Innovative Technology Administration, EDL 14937. Washington DC. June 2010. Benefit ID: 2011-00715

[177] Schweiger, Carol L. *TCRP Synthesis 48: Real-Time Bus Arrival Information Systems*, Transportation Research Board Transit Cooperative Research Program. Washington DC. 2003. Benefit ID: 2011-00737

[178] Sources that support this finding:

Mortazavi, Ali, et al. *Evaluation of Displaying Transit Information on Changeable Message Signs Final Report,* California Path Program Institute of Transportation University of California. Berkeley, CA. September 2009. Benefit ID: 2010-00657

Rodier, Caroline J.; Susan A. Shaheen; and Charlene Kemmerer. *Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration - Final Report*, California Path Program Institute of Transportation Studies University of California, Report No. UCB-ITS-PRR-2008-5. Berkeley, CA. June 2008. Benefit ID: 2011-00695

[179] Usui, Tomotaka, et al. *Development and Validation of Internet-Based Personalized Travel Assistance System for Mobility Management,* Paper Presented at the 15th ITS Word Congress. New York City, NY, 16-20 November 2008. Benefit ID: 2010-00644

[180] Biernbaum, Lee; Lydia Rainville; and Arlen Spiro. *Multimodal Trip Planner System Final Evaluation Report*, Prepared by Volpe for the U.S. DOT Federal Transit Administration, Report No. FTA-MA-ITS-2011.1. May 2010. Cost ID: 2011-00228

[181] Rephlo J.; R. Haas; L. Feast; and D. Newton. *Evaluation of Transit Applications of Advanced Parking Management Systems: Final Evaluation Report*, Prepared by SAIC for the U.S. DOT Office Research and Innovative Technology Administration, Report No. FHWA-JPO-08-052, EDL No. 14432. Washington DC. May 2008. Cost ID: 2009 - 00183

[182] Reports that support this finding:

Kittelson and Associates, et al. *TCRP Report 118: Bus Rapid Transit Practitioner's Guide*, Transportation Research Board, Transit Cooperative Research Program. Washington, DC. 2007. Cost ID: 2008-00148

Diaz, Roderick B. and Dennis Hinebaugh. *National Bus Rapid Transit Institute, Characteristics of Bus Rapid Transit for Decision-Making (CBRT) 2009 Update*, U.S. DOT Federal Transit Administration Office of Research, Demonstration and Innovation (TRI), Report No. FTA-FL-26-7109.2009.1. February 2009. Cost ID: 2011-00234

[183] Burt, Matt; Deepak Gopalakrishna; and Chris Cluett. *Phase III (Final) Evaluation Report National Evaluation of FY01 Earmark: Area Transportation Authority of North Central Pennsylvania – Regional GIS/ITS Initiative*. ITS Joint Program Office U.S. DOT Research and Innovative Technology Administration, EDL 14493. August 2009. Benefit ID: 2011-00710

[184] *Transportation Disadvantaged Populations: Some Coordination Efforts Among Programs Providing Transportation Services, but Obstacles Persist*, U.S. General Accounting Office, Report to Congressional Requestors, Report No. GAO-03-697. June 2003. Benefit ID: 2011-00661

[185] Bruun and Marx. *OmniLink – A Case Study of a Successful Flex–Route Capable ITS Implementation*, Transportation Research Board, Report No. TRR 1971. Washington, DC. 2006. Cited in Bruun, Eric C. "Technological Maturity of ITS and Scheduling and Integrated Service Options to Transit Planners," Paper Presented at the 86th Annual Meeting of the Transportation Research Board. Washington, DC. 21–25 January 2007. Benefit ID: 2008-00542

[186] Wu, Tina; Matt Weatherford; Ancila Kaiparambil; and Linna Zhang. *Regional Transportation Commission of Washoe County Intelligent Transportation System Implementation Evaluation Study*, Prepared by Regional Transportation Commission, Washoe County, for the U.S DOT Federal Transit Administration, Report No. FTA- NV-26-7005-2010.1. Washington DC. May 2010. Benefit ID: 2011- 00708

[187] Kack, David and Philip Deepu. *An Evaluation of RouteMatch Software in the Billings MET Special Transit System*, Montana State University. Bozeman, MT. 2 May 2007. Cost ID: 2008-00149

[188] *Rural Transit ITS Best Practices*, U.S. DOT Federal Highway Administration, Report No. FHWA-OP-03-077, EDL No. 13784. March 2003. Cost ID: 2004-00074

[189] Correspondence with Mr. Eric F. Holm, Program Manager, Alliance for Transportation Research Institute. 23 March 2005. Cost ID: 2008-00153

[190] *Intelligent, Coordinated Transit Smart Card Technology (ICTransit Card)*, University of New Mexico, Alliance for Transportation Research (ATR) Institute. Albuquerque, NM. September 2005. Cost ID: 2008-00154

[191] Correspondence with Mr. Eric F. Holm, Program Manager, Alliance for Transportation Research Institute. 23 March 2005. Cost ID: 2008-00153

[192] Mishra, Santosh and Carol Schweiger. *Monterey Salinas Transit ITS Augmentation Project: Phase III Evaluation Report*, Prepared by TranSystems for the U.S DOT Office Research and Innovative Technology Administration, Report No. FTA-TRI-11-2009.1, EDL No. 14938. December 2009 Benefit ID: 2011-00711

[193] *Advanced Public Transportation Systems: State of the Art – Update 2006*, U.S. DOT Federal Transit Administration, Report No. FTA-NJ-26-7062-06.1. 30 March 2006. Cost ID: 2008-00133

[194] Diaz, Roderick B. and Dennis Hinebaugh. *National Bus Rapid Transit Institute, Characteristics of Bus Rapid Transit for Decision-Making (CBRT) 2009 Update*, U.S. DOT Federal Transit Administration Office of Research, Demonstration and Innovation (TRI), Report No. FTA-FL-26-7109.2009.1. February 2009. Cost ID: 2011-00234

[195] Haas, et al. *iFlorida Model Deployment Final Evaluation Report*, Prepared by SAIC for the U.S. DOT Federal Highway Administration, EDL No. 14480. 2009. Lesson ID: 2010-00519

[196] "TMS Performance Monitoring, Evaluation, and Reporting," Presentation by the University of Virginia and SAIC. March 2006.

[197] Sources and supporting information:

Integration of Emergency and Weather Elements into Transportation Management Centers, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-06-090, EDL No. 14247. 28 February 2006.

Guidelines for Transportation Management Systems Maintenance Concept and Plans, U.S. DOT Federal Highway Administration, Report No. FHWA-OP-04-011, EDL No. 13882. 31 December 2002.

[198] *Transportation Management Center Concepts of Operation: Implementation Guide*, .U.S. DOT Federal Highway Administration, Report No. FHWA-OP-99-029, EDL No. 11494. December 1999.

[199] Sources supporting this range include:

*2006 Annual Report S*MART SunGuide Transportation Management Center (TMC), Florida DOT, District IV. January 2007. Cost ID: 2007-00120

Burk, Brian D. "Combined Transportation, Emergency and Communications Center: A Partnership of Performance," Presented at 14th ITS America Annual Meeting. San Antonio, TX. May 2004. Cost ID: 2005-00093

Krueger, C., et al. *The Chicago Traffic Management Center Preliminary Design Study Planning Effort*, Chicago DOT. 2003. Cost ID: 2008-00157

Lake County TMC Study: Implementation Phasing Plan – Version 2.0, Prepared by the National Engineering Technology Corporation. Report No. DCN 2020IIPPR2.0. Arlington Heights, IL. September 2003. Cost ID: 2008-00158

Perrin, Joseph; Rodrigo Disegni; and Bhargava Rama. *Advanced Transportation Management System Elemental Cost Benefit Assessment*, Prepared by the University of Utah for the Utah DOT and the U.S. DOT Federal Highway Administration. March 2004. Cost ID: 2004-00086

[200] Sources supporting this range include:

2005 Annual Report SMART SunGuide Transportation Management Center (TMC), Florida DOT, District IV. January 2006. Correspondence with Mr. Steve Corbin, FDOT District IV, ITS Operations Manager. 28 March 2006. Cost ID: 2006-00097

2006 Annual Report SMART SunGuide Transportation Management Center (TMC), Florida DOT, District IV. January 2007. Correspondence with Mr. Steve Corbin, FDOT District IV, ITS Operations Manager. February 2007. Cost ID: 2007-00120

MAG Regional Concept of Transportation Operations, Technical Memorandum No. 5/6, Prepared by Kimley–Horn for the Maricopa Associated of Governments (MAG). Phoenix, AZ. 7 January 2004. Cost ID: 2008-00159

Transportation Management Center: Business Planning and Plans Handbook, U.S. DOT Federal Highway Administration, TMC Pooled Fund Study. December 2005. Cost ID: 2008-00160

Transportation Management Center Staffing and Scheduling for Day–to–Day Operations, U.S. DOT Federal Highway Administration. January 2006. Cost ID: 2008-00161

[201] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[202] *I-95 Corridor Coalition - Vehicle Probe Project General Benefits White Paper,* I-95 Corridor Coalition 12 August 2010. Benefit ID: 2010-00653

[203] Meitin, Omar and Rory Santana*. FDOT District Six ITS ANNUAL REPORT (Fiscal Year 2008/2009).* FDOT District 6. 2009. Benefit ID: 2010-00643

[204] Shi, Xianming, et al. *Evaluation of Utah Department of Transportation's Weather Operations/RWIS Program: Phase I.* Prepared by the Western Transportation Institute for the Utah DOT. February 2007. Benefit ID: 2008-00527

[205] Cluett, Chris and Fred Kitchener. *Implementation and Evaluation of the Sacramento Regional Transportation Management Center Weather Alert Notification System,* U.S. DOT Federal Highway Administration. August 2010. Benefit ID: 2011-00671

[206] *Lake County TMC Study: Implementation Phasing Plan – Version 2.0*, Prepared by the National Engineering Technology Corporation. Report No. DCN 2020IIPPR2.0. Arlington Heights, IL. September 2003. Cost ID: 2008-00158

[207] *2006 Annual Report SMART SunGuide Transportation Management Center (TMC)*, Florida DOT, District IV. January 2007. Correspondence with Mr. Steve Corbin, FDOT District IV, ITS Operations Manager. February 2007. Cost ID: 2007-00120

[208] Peter M. Briglia, Jr. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects.* June 2009 Cost ID: 2010-00198

[209] Nelson, John V. and Steven J. Sabinash, P.E*. Colorado Transportation Management Center (CTMC) Integration Project (FY01 Earmark) Local Evaluation Report*, U.S DOT. November 2007. Cost ID: 2009-00186.

[210] Haas, R.; Mark Carter; Eric Perry; et al. *iFlorida Model Deployment Final Evaluation Report*, U.S DOT Federal Highway Administration, EDL No. 14480. January 2009. Lesson ID: 2010-00517

[211] Nelson, John V. and Steven J. Sabinash, P.E. *Colorado Transportation Management Center (CTMC) Integration Project (FY01 Earmark) Local Evaluation Report*, U.S DOT Federal Highway Administration. November 2007. Lesson ID: 2009-00484

[212] *National Strategy to Reduce Congestion on America's Transportation Network*, Prepared by the U.S. DOT. May 2006.

[213] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[214] Ryan, L.E. "A Return on Investment Study of the Hampton Roads Safety Service Patrol Program," Virginia Transportation Research Council. 2007. Benefit ID: 2011-00680.

[215] Dougald, L.E. and M.J. Demetsky. "Assessing the Return on Investment of Freeway Safety Service Patrol Programs," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2047, 2008. Benefit ID: 2011-00679.

[216] Rivera, D. and R. Santana. "FDOT District Six ITS Annual Report (Fiscal Year2007/2008)" Florida DOT District 6. Miami, FL. 2009. Benefit ID: 2010-00643

[217] Sources that support these findings:

"CDOT Launches Courtesy Patrol on I–70 West," Colorado DOT. Denver, CO. 4 March 2005. Cost ID: 2006-00101

"Freeway Service Patrol: About FSP and Facts at a Glance Web Site," Los Angeles Metropolitan Transportation Authority. 22 June 2006. Cost ID: 2006-00102

Hagen, Larry; Huaguo Zhou; and Harkanwal Singh. *Road Ranger Benefit–Cost Analysis*, Prepared by the University of South Florida for the Florida DOT. November 2005. Correspondence with the report authors (Larry Hagen and Huaguo Zhou). 2006. Cost ID: 2006-00103

HELP Annual Operating Report, July 1, 2004–June 30, 2005, Tennessee DOT. Nashville, TN. October 2005. Cost ID: 2006-00096

MDOT Freeway Courtesy Patrol in Southeast Michigan: 2004 Evaluation Report, Southeast Michigan Council of Governments. Detroit, MI. May 2005. Cost ID: 2006-00104

[218] Sun, Carlos, et al. *Evaluation of Freeway Motorist Assist Program: Final Report*, Missouri DOT. February 2010. Benefit ID: 2011-00666

[219] Ryan, T.; V. Chilukuri; T. Trueblood; and C. Sun. "Interim Report: Evaluation of Arterial Service Patrol Programs (I-64 Traffic Response)," Missouri DOT. Jefferson City, MO. 2009. Benefit ID: 2011-00667

[220] Remkes, C.; M. Montoya; and C. Magno. *NM 68, Riverside Drive City of Espanola, New Mexico ITS Project Final Evaluation Report*. Espanola, NM. 2008. Cost ID: 2009-00181

[221] Sallman, D and R. Sanchez. *National Evaluation of the FY 2003 Earmarked ITS Integration Project: Minnesota Traveler Information Guidance and Emergency Routing (TIGER) Project Final Phase II Evaluation Report*, U.S. DOT ITS Joint Program Office. Washington, DC. 2008. Lesson ID: 2011-00572

[222] Remkes, C.; M. Montoya; and C. Magno. *NM 68, Riverside Drive City of Espanola, New Mexico ITS Project Final Evaluation Report*. Espanola, NM. 2008. Benefit ID: 2009-00598

[223] Sources that support these findings:

Bertini, R., et al. *Evaluation of Region 2 Incident Response Program Using Archived Data*, Portland State University, Report No. PSU-CE-TRG-01-01. Portland, OR. June 2001. Benefit ID: 2007-00483

Dougald, L.E. "A Return on Investment Study of the Hampton Roads Safety Service Patrol Program" Virginia Transportation Research Council. 2007. Benefit ID: 2011-00680.

Performance Evaluation of CHART – Coordinated Highways Action Response Team – Year 2002, University of Maryland, College Park and Maryland State Highway Administration. College Park, MD. November 2003. Benefit ID: 2007-00425

Petrov, A., et al. "Evaluation of the Benefits of a Real–Time Incident Response System," Paper Presented at the 9th World Congress on Intelligent Transport Systems. Chicago, IL. 14–17 October 2002. Benefit ID: 2007-00485

1996 ITS Tour Report: Eastern North America, Institute of Transportation Engineers, 1996 ITS World Congress, Vol. 1, 1997. pp.4-5. Benefit ID: 2000-00123

[224] Sources that support these findings:

Bertini, Robert L., et al. *Evaluation of Region 2 Incident Response Program Using Archived Data*, Prepared by the Portland State University for the Oregon DOT, Report No. PSU-CE-TRG-01-01. 30 June 2001. Benefit ID: 2006-00298

Cuciti, P. and B. Janson. "Incident Management via Courtesy Patrol: Evaluation of a Pilot Program in Colorado," Paper Presented at the 74th Annual Meeting of the Transportation Research Board. Washington, DC. January 1995. Benefit ID: 2000-00068

Dougald, L.E. *A Return on Investment Study of the Hampton Roads Safety Service Patrol Program*, Virginia Transportation Research Council. 2007. Benefit ID: 2011-00681.

Highway Helper Summary Report – Twin Cities Metro Area, Minnesota DOT, Report No. TMC 07450-0394. St. Paul, MN. July 1994. Benefit ID: 2000-00009

Latoski, S., et al. "Cost–Effectiveness Evaluation of Hoosier Helper Freeway Service Patrol," *Journal of Transportation Engineering*, Vol. 125, No. 5. September/October 1999. Benefit ID: 2000-00002

Ryan, T.; V. Chilukuri; T. Trueblood; and C. Sun. *Interim Report: Evaluation of Arterial Service Patrol Programs (I-64 Traffic Response)*, Missouri DOT. Jefferson City, MO. 2009. Benefit ID: 2011-00667

[225] Sources that support these findings:

HELP Annual Operating Report: July 1, 2004–June 30, 2005, Published by the Office of Highway Incident Management, Tennessee DOT. October 2005.

Todd, P.N. "What the customer had to say," Virginia DOT Safety Service Patrol Report. 1997. Benefit ID: 2000-00029

[226]Ryan, T.; V. Chilukuri; T. Trueblood; and C. Sun. *Evaluation of Freeway Motorist Assist Program: Final Report*, Missouiri DOT. Jefferson City, MO. 2009. Benefit ID: 2011-00666

[227] Dougald, L.E. and M.J. Demetsky. ”Assessing the Return on Investment of Freeway Safety Service Patrol Programs,” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2047, 2008. Benefit ID: 2011-00679.

[228] Dougald, L.E. “A Return on Investment Study of the Hampton Roads Safety Service Patrol Program.” Virginia Transportation Research Council. Report No. VTRC07-R33. Charlottesville, VA. 2007. Benefit ID: 2011-00670.

[229] Ryan, T.; V. Chilukuri; T. Trueblood; and C. Sun. *Interim Report: Evaluation of Arterial Service Patrol Programs (I-64 Traffic Response)*, Missouri DOT. Jefferson City, MO. 2009. Benefit ID: 2011-00667

[230] Newton, D.; N. Owens; M. Carter; and C. Mitchell. *New York Integrated Incident Management System Evaluation Project: Final Report*, U.S. DOT Federal Highway Administration. 2007. Lesson ID: 2011-00571

[231] National ITS Architecture Documents: Security, U.S. DOT. May 2007.

[232] "Emergency Transportation Operations," U.S. DOT, ITS Joint Program Office, Web site URL: http://ops.fhwa.dot.gov/eto_tim_pse/index.htm. Last Accessed 16 September 2011.

[233] *Using highways during evacuation operations for events with advance notice: Routes to effective evacuation planning Primer Series*. U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-06-109. Lesson ID: 2008-00461

[234] *Hazardous Materials Safety and Security Technology Field Operational Test Volume II: Evaluation Final Report Synthesis*, U.S. DOT Federal Motor Carrier Safety Administration, EDL No. 14095. 11 November 2004. Benefit ID: 2007-00491

[235] Brown, V.J., et al. *Technical Report for Kentucky Commercial Vehicle Safety Applications Evaluation*. U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-08-025.2008. January 2008. Benefit ID: 2009-00616

[236] *Common Issues in Emergency Transportation Operations Preparedness and Response: Results of the FHWA Workshop Series*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-07-090. February 2007.

[237] "GIS–based Disaster Management Systems: a Cogent Data Framework," Paper Presented at the 85th Annual Meeting of the Transportation Research Board. Washington, DC. 22–26 January 2006.

[238] *Managing Demand Through Travel Information Services*, Prepared for the U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-05-005, EDL No. 14072. 2005. Benefit ID: 2007-00409

[239] *Hazardous Material Transportation Safety and Security Field Operational Test: Final Report – Deployment Team*, U.S. DOT Federal Motor Carrier Safety Administration. 31 August 2004. Cost ID: 2006-00100

[240] Sources that support these findings:

Benefits and Costs of Full Operations and ITS Deployment: A 2003 Simulation for Cincinnati, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-031, EDL No. 13979. May 2005. Cost ID: 2008-00164

Benefits and Costs of Full Operations and ITS Deployment: A 2003 Simulation for Seattle, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-033, EDL No. 13977. May 2005. Cost ID: 2008-00165

Benefits and Costs of Full Operations and ITS Deployment: A 2025 Forecast for Tucson, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-032, EDL No. 13978. May 2005. Cost ID: 2008-00166

[241] Rauscher, S., et al. *Enhanced Automatic Collision Notification System – Improved Rescue Care Due to Injury Prediction - First Field Experience,* U.S. DOT National Highway Traffic Safety Administration. 2009. Benefit ID: 2011-00673

[242] Rauscher, S., et al. *Enhanced Automatic Collision Notification System – Improved Rescue Care Due to Injury Prediction - First Field Experience*, U.S. DOT National Highway Traffic Safety Administration. 2009. Benefit ID: 2011-00672

[243] Haas, R. et al. *iFlorida Model Deployment Final Evaluation Report*, U.S. DOT Federal Highway Administration. 2009. Lesson ID: 2010-00518

[244] "Transportation and Emergency Services: Identifying Critical Interfaces, Obstacles, and Opportunities," Paper Presented at the 85th Annual Meeting of the Transportation Research Board. Washington, DC. 22–26 January 2006. Benefit ID: 2008-00546

[245] *ITS Implementation Plan*, Prepared by the IBI Group for the Flint Mass Transportation Authority. Flint, MI. June 2005. Cost ID: 2008-00151

[246] "An Operational Analysis of the Hampton Roads Hurricane Evacuation Traffic Control Plan," Paper Presented at the 86th Annual Meeting of the Transportation Research Board. Washington, DC. 21–25 January 2007. Benefit ID: 2008-00547

[247] Wilson-Goure, Stephanie; N. Houston; and A. Vann Easton. *Case Studies: Assessment of State of the Practice and State of the Art in Evacuation Transportation Management*, U.S DOT Federal Highway Administration, Report No. FHWA-HOP-08-014. February 2006. Lesson ID: 2008-00451

[248] Cortelazzi, Lou, et al. *Pennsylvania Turnpike Commission's Advanced Traveler Information System (*ATIS) Phase III Project, Pennsylvania Turnpike Commission, EDL No. 14308. April 2006. Cost ID: 2008-00168

[249] Wilson-Goure, Stephanie; N. Houston; A. Vann Easton. *Case Studies: Assessment of State of the Practice and State of the Art in Evacuation Transportation Management*, FHWA-HOP-08-014, U.S DOT Federal Highway Administration. February 2006. Lesson ID: 2008-00451 and Lesson ID: 2008-00450

[250] *Advanced Public Transportation Systems: State of the Art Update 2006*, U.S. DOT Federal Transit Administration, Report No. FTA-NJ-26-7062-06.1. 30 March 2006.

[251] *Congestion Pricing – A Primer Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-07-074. December 2006.

[252] "SR-167 HOT Lanes Pilot Project Performance Update, Winter 2010," Washington State DOT. Olympia, WA. Winter 2009/2010. Benefit ID: 2010-00630

[253] Sources that support these findings:

2005 Regional Value Pricing Corridor Evaluation and Feasibility Study: Dallas/Fort Worth – Value Pricing History and Experience, North Central Texas Council of Governments. Arlington, TX. June 2005. Benefit ID: 2008-00549

Douma, Frank; Johanna Zmud; and Tyler Patterson. "Pricing Comes to Minnesota: Baseline Attitudinal Evaluation of the I–394 HOT Lane Project," Paper Presented at the 85th Transportation Research Board Annual Meeting. Washington, DC. 22–26 January 2006. Benefit ID: 2008-00550

[254] *2005 Regional Value Pricing Corridor Evaluation and Feasibility Study: Dallas/Fort Worth – Value Pricing History* and Experience, North Central Texas Council of Governments. Arlington, TX. June 2005. Benefit ID: 2008-00549

[255] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Benefit ID: 2010-00626

[256] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report,* U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[257] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report,* U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[258] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[259] "SR-167 HOT Lanes Pilot Project Performance Update, Winter 2010," Washington State DOT. Olympia, WA. Winter 2009/2010. Benefit ID: 2010-00630

[260] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Benefit ID: 2010-00626

[261] Alexiadis, Vassili; Brian Cronin; Steven Mortensen; and Dale Thompson. "Integrated Approach: Inside Story on the ICM Test Corridor," *Traffic Technology International*, 2009, pp. 46-50. Benefit ID: 2009-00614

[262] Bhatt, Kiran and Thomas Higgins. Lessons *Learned From International Experience in Congestion Pricing - Final Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-047. August 2008. Benefit ID: 2010-00624

[263] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned* - Final Report, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Benefit ID: 2010-00626

[264] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned* - Final Report, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[265] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons* Learned - Final Report, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[266] Bhatt, Kira; Thomas Higgins; and John Berg. *Value Pricing Pilot Program: Lessons Learned - Final Report*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-023. August 2008. Cost ID: 2010-00201

[267] Button, Kenneth. *ITS Regional Integration: Task 6 (Pricing ITS) - Subtask 4 (Final Report)*, U.S. DOT Federal Highway Administration, Ref No. DTFH61-06-H-00014. September 2009. Cost ID: 2011-00213

[268] Alexiadis, Vassili; Brian Cronin; Steven Mortensen; and Dale Thompson. "Integrated Approach: Inside Story on the ICM Test Corridor," *Traffic Technology International*, 2009, pp. 46-50. Benefit ID: 2009-00614

[269] Lerner, Neil, et al. *Driver Use of En Route Real-Time Travel Time Information: Final Report,* Prepared by Westat for the U.S. DOT Federal Highway Administration. 30 July 2009.

[270] Usui, Tomotaka, et al. "Development and Validation of Internet-Based Personalized Travel Assistance System for Mobility Management," Paper Presented at the 15th ITS Word Congress. New York City, NY. 16-20 November 2008. Benefit ID: 2010-00644.

[271] Schuman, R. and E. Sherer. *ATIS U.S. Business Models Review - 2001*. U.S. DOT FHWA, Web site URL: http://www.ops.fhwa.dot.gov/travelinfo/resources/atis_bm.htm. Last Accessed 19 September 2011.

[272] *Surface Transportation: Efforts to Address Highway Congestion through Real-Time Traffic Information Systems are Expanding but Face Implementation Challenges*, U.S. Government Accountability Office, Report No. GAO-10-121R. November 2009.

[273] Zimmerman, C., et al. *Phoenix Metropolitan Model Deployment Initiative Evaluation* Report, Prepared by Battelle for the U.S. DOT, Report No. FHWA-OP-00-015. April 2000. Cost ID: 2003-00039

[274] Cambridge Systematics. *Evaluation of the Cape Cod Advanced Public Transit System Phases I and II – Final Report*, U.S. DOT Federal Highway Administration. January 2003.

[275] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[276] *Deployment of ITS: A Summary of the 2010 National Survey Results (Final Report),* Prepared by Oak Ridge National Laboratory for the U.S. DOT Research and Innovative Technology Administration. August 2011.

[277] Alexiadis, Vassili; Brian Cronin; Steven Mortensen; and Dale Thompson. "Integrated Approach: Inside Story on the ICM Test Corridor," *Traffic Technology International*, 2009, pp. 46-50. Benefit ID: 2009-00614

[278] Usui, Tomotaka, et al. "Development and Validation of Internet-Based Personalized Travel Assistance System for Mobility Management," Paper Presented at the 15th ITS Word Congress. New York City, NY. 16-20 November 2008. Benefit ID: 2010-00644.

[279] Briglia, Peter M. *ITS Evaluation Framework - Phase 2 Continuation (2009) Seventeen Projects*. University of Washington, Report No. WA-RD 672.2. Seattle, WA. June 2009. Cost ID: 2009-00197

[280] Mortazavi, Ali., et al. *Travel Times on Changeable Message Signs Volume II – Evaluation of Transit Signs,* University of California, Report No. UCB-ITS-CWP-2009-2. Berkeley, CA. September, 2009. Benefit ID: 2010-00657

[281] "I-95 Corridor Coalition - Vehicle Probe Project General Benefits White Paper," I-95 Corridor Coalition. Rockville, MD. 12 August 2010. Benefit ID: 2010-00650.

[282] *America's Travel Information Number: Implementation and Operational Guidelines for 511 Services Version 3.0*, 511 Deployment Coalition. September 2005. Benefit ID: 2007-00301

[283] Eidswick, Jaime; Zhirui Ye; and Steve Albert. *Grand Canyon National Park Dynamic Message Sign (DMS)/Highway Advisory Radio (HAR) Pilot Deployment/Evaluation*, Montana State University. Bozeman, MT. March 2009. Benefit ID: 2011-00664

[284] Eidswick, Jaime; Zhirui Ye; and Steve Albert. *Grand Canyon National Park Dynamic Message Sign (DMS)/Highway Advisory Radio (HAR) Pilot Deployment/Evaluation*, Montana State University. Bozeman, MT. March 2009. Cost ID: 2011-00205

[285] Susan Shaheen and Charlene Kemmerer. "Smart Parking Linked to Transit: Lessons Learned from the San Francisco Bay Area Field Test," Paper Presented at the 87th Annual Meeting of the Transportation Research Board. Washington, DC. January 2008. Lesson ID: 2008-00444

[286] Sources that support these findings:

Bertini, R.L. and A.M. El-Geneidy. "Modeling Transit Trip Time Using Archived Bus Dispatch System Data,"*Journal of Transportation Engineering*, American Society of Civil Engineers, Vol. 130, No. 1 January 2004.

Furth, Peter G., et al. *TCRP Report 113: Using Archived AVL-APC Data to Improve Transit Performance and Management*, Transit Cooperative Research Program, Transportation Research Board. Washington DC. 2006

Kothuri ,Sirisha; Kristin Tufte; Soyoung Ahn; Robert L. Bertini. "Using Archived ITS Data to Generate Improved Freeway Travel Time Estimates," Proceedings of the 86th Annual Meeting of the Transportation Research Board. Washington, DC. 2007.

Lyman, K. and R. Bertini. "Using Travel Time Reliability Measures to Improve Regional Transportation Planning and Operations," *Transportation Research Record: Journal of the Transportation Research Board*, 2008.

Bigazzi, A., and R.L. Bertini. "Adding Green Performance Metrics to a Transportation Data Archive," *Transportation Research Record*: *Journal of the Transportation Research Board*, No. 2121, 2009, pp. 30-40.

Mandelzys, Michael and Dr. Bruce Hellinga, P.Eng. "Automatically Identifying The Causes Of Bus Transit Schedule Adherence Performance Issues Using AVL APC Archived Data*,"* Paper Presented at the 89th Annual Meeting of the Transportation Research Board. Washington DC. January 2010.

Feng, et al. "Techniques to Visualize and Monitor Transit Fleet Operations 2 Performance in Urban Areas," Paper Presented at the 90th Annual Meeting of the Transportation Research Board. Washington DC. January 2011.

Feng, Wei and Miguel Figliozzi. "Using Archived AVL/APC Bus Data to Identify Spatial-Temporal 2 Causes of Bus Bunching," Portland State University, Paper Presented at the 90th Annual Meeting of the Transportation Research Board. Washington DC. January 2011.

[287] Sources that support these findings:

Kimpel, T.; J. Strathman; R. Bertini; and S. Callas. "Analysis of Transit Signal Priority Using Archived TriMet Bus Dispatch System Data*," Transportation Research Record: Journal of the Transportation Research Board,* 2004.

Bertini, Robert L.; Michael W. Rose; and Ahmed M. El-Geneidy *Using Archived Data to Measure Operational Benefits of ITS Investments: Region 1 Incident Response Program*, Portland State University Center for Transportation Studies. Portland, OR. 2004.

Bertini, Robert L.; Michael W. Rose; and Ahmed M. El-Geneidy. "Using Archived ITS Data Sources to Measure the Effectiveness of a Freeway Incident Response Program," *Transportation Research Record: Journal of the Transportation Research Board*, 2005.

Yang, Qingyan (Ken) and Heng Wei, Ph.D., P.E. "Data Archiving Testing and Initial Analysis in Supporting GLITS I-75 Integrated Corridor Project," Paper Presented at the TRB 87th Annual Meeting in Washington, DC. 13-17 January 2008

Monsere, C.; R. Bertini; O. Eshel; and S. Ahn. *Using Archived Data to Measure Operational Benefits of a System-Wide Adaptive Ramp Metering (SWARM) System*, Oregon DOT Research Unit and the U.S. DOT Federal Highway Administration, Repot No. SPR 645, OTREC-RR-08-190. Salem OR. December 2008.

Chavan, Priya, et al. "Extending the Use of Archived ITS Data As a Potential Management Tool to Evaluate Traveler Information on Dynamic Message Signs," Paper Presented at the 87th Annual Meeting of the Transportation Research Board. Washington, DC. 2008.

Alvarez, Patricio; Mohammed Hadi, Ph.D., P.E.; and Chengjun Zhan, Ph.D. "Using Intelligent Transportation Systems Data Archives for Traffic Simulation Applications," Florida International University, Paper Presented at the 89th Annual Meeting of the Transportation Research Board. Washington DC. January 2010.

[288] *Archived Data Management Systems: A Cross–Cutting Study*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-05-044, EDL No. 14128. December 2005. Cost ID: 2008-00173

[289] Pack, Michael L. "A Virtual Tour of the University of Maryland's Innovative Method of Collecting, Archiving and Disseminating Transportation and Transit Data for the DC Metro Area," *ITS America Webinar*, 8 June 2011. Cost ID: 2011-00220 .

[290]*Final Report, Montana Department of Transportation, FY01 Intelligent Transportation System (ITS), Integration Component of the ITS Deployment Program*, Montana DOT. Helena MT. 29 August 2005. Cost ID: 2009-00187.

[291] Furth, Peter G., et al*. Uses of Archived AVL–APC Data to Improve Transit Performance and Management: Review and Potential*, Transportation Research Board, Transit Cooperative Research Program, Web Document No. 23, Appendix A. Washington DC. June 2003. Benefit ID: 2008-00587

[292] Haas, R; E. Perry; and J. Rephlo. *Chattanooga SmartBus Project: Phase III Evaluation Report*, Prepared by SAIC for the U.S. DOT Office Research and Innovative Technology Administration. December 2009. Benefit ID: 2011-00713

[293] Li, Huan and Robert Lawrence Bertini. "Toward Sustainable Transit Operations and Performance Enhancement Using Archived Automatic Vehicle Location Data," Portland State University, Paper Presented at the 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services. Stokholm Sweden. 21-25 September 2009. Benefit ID: 2011-00730

[294] Zhang, Lin and Krista Jeannotte. *Applying Analysis Tools in Planning for Operations: Case Study #3 – Using Archived Data As a Tool for Operations Planning,* Prepared by Cambridge Systematics for the U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-10-004. September 2009. Benefit ID: 2011-00732

[295] Sources that support these findings:

National Evaluation of the TMC Applications of Archived Data Operational Test – ADMS Virginia, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-014, EDL No. 14250. August 2005. Benefit ID: 2008-00560

Smith, Brian L. and Ramkumar Venkatanarayana. "Usage Analysis of a First Generation ITS Data Archive: Lessons Learned in the Development of a Novel Information Technology Application," Paper Presented at the 85th Annual Transportation Research Board Meeting. Washington, DC. 22–26 January 2006.

[296] Pack, Michael L. "A Virtual Tour of the University of Maryland's Innovative Method of Collecting, Archiving and Disseminating Transportation and Transit Data for the DC Metro Area," *ITS America Webinar*. 8 June 2011. Cost ID: 2011-00220.

[297] Dhanaraju, Sharan; Yanfeng Ouyang; and Umit Deniz Tursun. *Regional Data Archiving and Management for Northeast Illinois*, University of Illinois, Illinois Center for Transportation. Urbanna, IL. June 2009. Cost ID: 2011-00221.

[298] *Archived Data Management Systems: A Cross–Cutting Study*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-05-044, EDL No. 14128.December 2005. Cost ID: 2008-00173

[299] Pack, Michael (Director of the Center for Advanced Transportation Technology, University of Maryland). "A Virtual Tour of the University of Maryland's Innovative Method of Collecting, Archiving and Disseminating

Transportation and Transit Data for the DC Metro Area," ITS America Webinar, Washington DC. 22 June 2011. Lesson ID: 2011-00583

[300] Zhang, Lin and Krista Jeannotte. *Applying Analysis Tools in Planning for Operations: Case Study #3 – Using Archived Data As a Tool for Operations Planning,* Prepared by Cambridge Systematics for the U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-10-004. September 2009. Lesson ID: 2011-00584

[301] Petty, Karl. "*Nobody Is Going To Pick This Up By Themselves Training is Important for ADUS Acceptance*," Berkeley Transportation Systems Presentation at the 2007 Archived Data User Services (ADUS) Workshop during the 86th Annual Transportation Research Board Meeting. Washington DC. January 2007. Web site URL: https://wiki.cecs.pdx.edu/bin/view/ItsWeb/ADUSWorkshop. Last Accessed 19 September 2011. Lesson ID: 2011-00585

[302] Sources that support these findings:

Jones, Crystal. "Perspective on Freight Congestion," *Public Roads*, Vol. 71, No. 1, July/August 2007.

Wilson, Rosalyn. "Embracing Security as a Core Business Function," 17th Annual State of Logistics Report, Sponsored by the Council of Supply Chain Management Professionals. Washington, DC. 19 June 2006.

[303] American Transportation Research Institute, *Critical Issues in the Trucking Industry*, Presented to the American Trucking Associations. Arlington, VA. October 2010.

[304] Lane, Julie, and Valerie Barnes. *Introductory Guide to CVISN Baseline Version 1.0*, Johns Hopkins University Applied Physics Laboratory. Laurel, MD. November 2008.

[305] Rodier, Caroline J., et al. "Virtual Commercial Vehicle Compliance Stations: A Review of Legal and Institutional Issues," Paper Presented at 85th Annual Transportation Research Board Meeting. Washington, DC. 22–26 January 2006.

[306] PrePass statistics from: "PrePass," PrePass, Web site URL: www.prepass.com/Pages/Home.aspx . Last Accessed 19 September 2011.

NORPASS statistics from: "NORPASS," North American Preclearance and Safety System, Web site URL: www.norpass.net/index.html. Last Accessed 14 July 2011.

[307] "Oregon.gov - Motor Carrier Transportation," Oregon DOT. Web site URL: www.oregon.gov/ODOT/MCT/GREEN.shtml. Last Accessed 19 September 2011.

[308] *The Electronic Freight Management Initiative*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-06-085, EDL No. 14246. April 2006.

[309] U.S DOT ITS Joint Program Office, "Mode Specific Research: Smart Roadside," Web site URL: http://www.its.dot.gov/research/smart_roadside.htm. Last Accessed 20 July 2011: and *White Paper: Scope of the Smart Roadside Initiative*, U.S DOT Federal Motor Carrier Safety Administration and the Federal Highway Administration. April 2010.

[310] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN,* U.S. DOT ITS Joint Program Office, EDL No. 14406. Washington DC. October 2007. Benefit ID: 2009-00609

[311] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 57.0 Motor Carrier Survey.* Prepared by Battelle for the U.S DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009.

[312] *Description of Costs Data from State Self–Evaluations of Commercial Vehicle Information Systems and Networks (CVISN) Deployments (October 2003 to October 2005)*, U.S. DOT Federal Motor Carrier Safety Administration, EDL No. 14347. 20 February 2006.

[313] Sources that support these findings:

Benefits and Costs of Full Operations and ITS Deployment: A 2003 Simulation for Cincinnati, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-031, EDL No. 13979. May 2005. Cost ID: 2008-00164

Benefits and Costs of Full Operations and ITS Deployment: A 2003 Simulation for Seattle, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-033, EDL No. 13977. May 2005. Cost ID: 2008-00165

Benefits and Costs of Full Operations and ITS Deployment: A 2025 Forecast for Tucson, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-032, EDL No. 13978. May 2005. Cost ID: 2008-00166

[314] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report*, Prepared by Battelle for the U.S DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009.

[315] "*CVISN, Who is in What Phase now?*," U.S. DOT Federal Motor Carrier Administration, Website URL: http://www.fmcsa.dot.gov/facts-research/cvisn/CVISN-deployment-status.htm. Last Accessed 19 September 2011.

[316] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 5.0 Motor Carrier Survey*, Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Benefit ID: 2011-00738

[317] *Description of Benefits and Lessons Learned from State Self–Evaluations of Commercial Vehicle Information Systems and Networks (CVISN) Deployments: Draft (October 2003 to August 2006),* U.S. DOT Federal Highway Administration. 28 February 2007. Benefit ID: 2008-00561

[318] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN,* U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Benefit ID: 2009-00609

[319] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 6.0 Cost Analysis,* Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Cost ID: 2011-00229

[320] *Description of Benefits and Lessons Learned from State Self-Evaluations of Commercial Vehicle Information Systems and Networks (CVISN) Deployments (October 2003 to August 2006),* Prepared by Battelle for the U.S. DOT Federal Highway Administration and Federal Motor Carrier Safety Administration. February 2007. Lesson ID: 2009-00499

[321] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 7.0 Safety Analysis*, Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Benefit ID: 2011-00739

[322] *Evaluation of the Commercial Vehicle Information Systems Networks (CVISN) Model Deployment Initiative (Volume 1: Final Report),* U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-04-082, EDL No. 13677. March 2002. Benefit ID: 2007-00489

[323] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 6.0 Cost Analysis*, Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Cost ID: 2011-00230

[324] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN,* U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Cost ID: 2009-00191

[325] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN*, U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Cost ID: 2009-00191

[326] Siekmann, Adam; Gary Capps; Oscar Franzese; and Mary Beth Lascurain. *Smart Infrared Inspection System Field Operational Test*, Oak Ridge National Laboratory. Oak Ridge TN. June 2011. Benefit ID: 2011-00740

[327] Cannata, Amy. *"*Another Eye on the Road: WSP's high-tech Patrol Van Detects Unsafe Trucks," *Spokesman Review*. Spokane WA. 11 April 2006. Benefit ID: 2011-00741.

[328] Birch, Dan. "Technology applies the heat to unsafe trucks*," OHS (Occupational Health & Safety) Canada*, 1 December 2008, p 18.

[329] Brown, V.J.; M.S. Anderson; R.N. Sell; J.A. Zewatsky; and J.E. Orban. *Technical Report for Kentucky Commercial Vehicle Safety Applications Evaluation,* Prepared for the U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-08-025.2008, EDL No. 14400. January 2008. Benefit ID: 2009-00616

[330] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN*, U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Benefit ID: 2009-00611

[331] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 5.0 Motor Carrier Survey*, Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Benefit ID: 2011-00742

[332] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN, U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Benefit ID: 2009-00611

[333] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 6.0 Cost Analysis,* Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Cost ID: 2011-00231

[334] Brown, V.J.; M.S. Anderson; R.N. Sell; J.A. Zewatsky; and J.E. Orban. *Technical Report for Kentucky Commercial Vehicle Safety Applications Evaluation*, Prepared for the U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-08-025.2008, EDL No. 14400. January 2008. Cost ID: 2009-00196

[335] Brown, V.J.; M.S. Anderson; P.J. Balducci; J.E. Orban; M.A. Kiefer; and A. Desautels. *Evaluation of the National CVISN Deployment Program: Volume 1 Final Report, Chapter 6.0 Cost Analysis*, Prepared by Battelle for the U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14459. 2 March 2009. Benefit ID: 2011-00739.

[336] Brown, V.J.; M.S. Anderson; R.N. Sell; J.A. Zewatsky; and J.E. Orban. *Technical Report for Kentucky Commercial Vehicle Safety Applications Evaluation*, Prepared for the U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-08-025. 2008, EDL No. 14400. January 2008. Lesson ID: 2010-00510

[337] Done, R.S. *Evaluation of the Integration of CVISN at the Nogales Port of Entry*, Arizona DOT. Tucson, AZ. July 2008. Benefit ID: 2011-00743

[338] Schackerford, S; J. Short; and D. Murray. “Assessing the Impact of the Ace Truck e-Manifest,” Paper Presented at the 87th Annual Meeting of the Transportation Research Board. Washington DC. January 2008. Benefit ID: 2011-00744

[339] Gorder, Valinda and Geri Knoebel. *Santa Teresa RFID E-Screening Demonstration Project Evaluation*, Prepared by the ATR Institute, University of New Mexico for the U.SDOT Federal Motor Carrier Safety Administration. October 2009. Benefit ID: 2011-00745

[340] *I–25 Truck Safety Improvements Project: Local Evaluation Report*, U.S. DOT Federal Highway Administration, Report No. FHWA–JPO–05–039, EDL No. 14121. 29 December 2004. Benefit ID: 2008-00562

[341] *I–25 Truck Safety Improvements Project: Local Evaluation Report*, U.S. DOT Federal Highway Administration, Report No. FHWA–JPO–05–039, EDL No. 14121. 29 December 2004. Benefit ID: 2008-00564

[342] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN*, U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Benefit ID: 2009-00611

[343] *Electronic Toll Collection/Electronic Screening Interoperability Pilot Test Final Report Synthesis*, U.S. DOT Federal Highway Administration, EDL No. 14256. 29 July 2005. Benefit ID: 2008-00563

[344] Brown, V.J.; P. Balducci; K. Mahadevan; D. Murray; W. McDonald; and M. McFadden. *Final Report: Economic Analysis and Business Case for Motor Carrier Industry Support of CVISN*, U.S. DOT Federal Highway Administration ITS Joint Program Office, EDL No. 14406. October 2007. Benefit ID: 2009-00611

[345] "Telematics Applications Programme, 4th Framework Programme," RTD&D 1994–1998. Benefit ID: 2008-00565

[346] “FMCSA Fleet Field Tests Show Promise for ATIS,” *Truckinginfo.com,* TPMS, 24 February 2011. Web Site URL: http://www.truckinginfo.com/news/news-detail.asp?news_id=73063. Last accessed 19 September 2011. Benefit ID: 2011-00746

[347] *Hazardous Material Transportation Safety and Security Field Operational Test: Final Report – Deploym*ent Team, U.S. DOT Federal Motor Carrier Safety Administration. 31 August 2004. Cost ID: 2006-00100

[348] Monsere, C.M.; M. Wolfe; H. Alawakiel; and M. Stephens. *Developing Corridor-Level Truck Travel Time Estimates and Other Freight Performance Measures From Archived ITS Data*. Oregon DOT. Salem OR. August 2009. Lesson ID: 2009-00497

[349] Stock, D., et al., *Hazardous Materials Safety and Security Technology Field Operational Test Volume II: Evaluation Final Report Synthesis*, U.S. DOT Federal Motor Carrier Safety Administration EDL No. 14095. November 2004. Benefit ID: 2007-00491

[350] *Hazardous Material Transportation Safety and Security Field Operational Test: Final Report – Deploym*ent Team, U.S. DOT Federal Motor Carrier Safety Administration. 31 August 2004. Cost ID: 2006-00100

[351] *Evaluation of U.S. Commercial Motor Carrier Industry Challenges and Opportunities: Final Report*, ICF Consulting. Fairfax, VA. 31 March 2003.

[352] Troup, K., et al. *Columbus Electronic Freight Management Evaluation: Achieving Business Benefits with EFM Technologies*, U.S. DOT Research and Innovative Technology Administration, Report No. FHWA–HOP–09–053. March 2009. Benefit ID: 2011-00677

[353] Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[354] Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[355]Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[356] Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[357] Troup, K., et al. *Columbus Electronic Freight Management Evaluation Final Report*, U.S. DOT Research and Innovative Technology Administration, Ref No. DTFH61-02-C-00061. June 2008. Benefit ID: 2009-00592

[358] Zhengyi, Shon; Jinn-Tsai Wong; and Teng-Wei Wang. "Measuring the Cost Savings of Applying Electronic Supply Chain Manifest in Air Cargo Terminals," Paper Presented at the 85th Annual Meeting of the Transportation Research Board. Washington, DC. 22-26 January 2006. Benefit ID: 2008-00566

[359] Troup, K., et al. *Columbus Electronic Freight Management Evaluation: Achieving Business Benefits with EFM Technologies*, U.S. DOT Research and Innovative Technology Administration, Report No. FHWA–HOP–09–053. March 2009. Benefit ID: 2011-00677

[360] Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[361] Battelle and HDS. *Kansas City EFM Deployment Case Study*. Washington, DC. 24 June 2009. Benefit ID: 2011-00687

[362] *Cross-Town Improvement Project: Freight Travel Demand Management (TDM) - Case Study*, Prepared by Delcan for the Intermodal Freight Technology Working Group (IFTWG). Calverton, MD. October 2007. Benefit ID: 2011-00684

[363] Sources that support these findings:

Carnell, Robert C. and Nancy J. McMillan."Conditional Analysis of Safety Benefits of a Collision Warning System and Adaptive Cruise Control in Commercial Trucks," Paper Presented at the 86th Annual Meeting of the Transportation Research Board. Washington, DC. 21–25 January 2007. Benefit ID: 2008-00570

Ference, Jack. "The Integrated Vehicle–Based Safety Systems Initiative," Paper Presented at the 13th World Congress Conference on ITS. London, U.K. 8–12 October 2006.

Kanianthra, Joseph N. and Allen A. Mertig. *Opportunities for Collision Countermeasures Using Intelligent Technologies*, U.S. DOT National Highway Traffic Safety Administration. 1997.

[364] Sources that support these findings:

Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test Version 1.3: Final Report, U.S. DOT, Report No. FHWA-JPO-07-016, EDL No. 14352. 5 January 2007. Benefit ID: 2008-00571

Shladover, Steven E., et al. *Assessment of the Applicability of Cooperative Vehicle–Highway Automation Systems to Bus Transit and Intermodal Freight: Case Study Feasibility Analyses in the Metropolitan Chicago Region*, University of California, PATH Program, Report No. UCB-ITS-PRR-2004-26. Berkeley, CA. 19 August 2004. Benefit ID: 2007-00459

[365] *Integrated Vehicle Based Safety Systems: A Major ITS Initiative*, U.S. DOT, Report No. FHWA-JPO-05-019, EDL No. 14084. August 2005. Benefit ID: 2008-00572

[366] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Cost ID: 2009-00193

[367] Rephlo, J., et al. *Side Object Detection System Evaluation: Final Evaluation Report*, U.S. DOT Research and Innovative Technology Administration and Federal Transit Administration. 15 December 2008. Benefit ID: 2010-00632

[368] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Benefit ID: 2009-00615

[369] Rephlo, J., et al. *Side Object Detection System Evaluation: Final Evaluation Report*, U.S.DOT Research and Innovative Technology Administration and U.S.DOT Federal Transit Administration. 15 December 2008. Cost ID: 2010-00200

[370] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Cost ID: 2009-00193

[371] Rephlo, J., et al. *Side Object Detection System Evaluation: Final Evaluation Report*, U.S.DOT Research and Innovative Technology Administration and U.S.DOT Federal Transit Administration. 15 December 2008. Lesson ID: 2010-00509

[372] Sayer, J., et al. *Integrated Vehicle-Based Safety Systems Field Operational Test Final Program Report*, U.S. DOT Research and Innovative Technology Administration, Report No. DOT HS 811 482. June 2011. Benefit ID: 2011-00727

[373] Sayer, J., et al. *Integrated Vehicle-Based Safety Systems Field Operational Test Final Program Report*, U.S. DOT Research and Innovative Technology Administration, Report No. DOT HS 811 482. June 2011. Benefit ID: 2011-00726

[374] Peirce, Sean and Jane Lappin. *Private Sector Deployment of Intelligent Transportation Systems: Current Status and Trends*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-028. February 2006. Cost ID: 2008-00175

[375] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Benefit ID: 2009-00615

[376] Houser, Amy et al. *Analysis of Benefits and Costs of Lane Departure Warning Systems for the Trucking Industry*, U.S. DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRT-09-022. February 2009. Benefit ID: 2011-00721

[377] Peirce, Sean and Jane Lappin. Private Sector Deployment of Intelligent Transportation Systems: Current Status and Trends, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-028. February 2006. Cost ID: 2009-00175

[378] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Cost ID: 2009-00193

[379] Houser, Amy, et al. *Analysis of Benefits and Costs of Lane Departure Warning Systems for the Trucking Industry*, U.S. DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRT-09-022. February 2009. Cost ID: 2011-00217

[380] Murray, Dan; Sandra Shackelford; and Amy Houser. *Analysis of Benefits and Costs of Roll Stability Control Systems for the Trucking Industry*, U.S DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRT-09-020. February 2009. Benefit ID: 2009-00608

[381] Murray, Dan; Sandra Shackelford; and Amy Houser. *Analysis of Benefits and Costs of Roll Stability Control Systems for the Trucking Industry*, U.S DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRT-09-020. February 2009. Cost ID: 2009-00188

[382] Houser, Amy, et al. *Analysis of Benefits and Costs of Forward Collision Warning Systems for the Trucking Industry*, U.S. DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRT-09-021. February 2009. Benefit ID: 2011-00720

[383] Dunn, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*, U.S. DOT Federal Transit Administration. August 2007. Cost ID: 2009-00193

[384] Houser, Amy, et al. *Analysis of Benefits and Costs of Forward Collision Warning Systems for the Trucking Industry*, U.S. DOT Federal Motor Carrier Safety Administration, Report NoFMCSA-RRT-09-021. February 2009. Cost ID: 2011-00218

[385] *Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test Version 1.3: Final Report,* U.S. DOT, Report No. FHWA-JPO-07-016, EDL No. 14352. 5 January 2007. Benefit ID: 2008-00571

[386] "Conflicting Demands of Consumers and Lawmakers Create Huge Opportunities for Automotive Technology Providers," *J.D. Powers and Associates,* 27 May 2011. Web site URL: http://businesscenter.jdpower.com. Last Accessed 20 July 2011.

[387] *Use of Advanced In-Vehicle Technology by Younger and Older Early Adopters,* AAA Foundation for Traffic Safety. Washington, DC. September 2008. Benefit ID: 2011-00719.

[388] Sources that support these findings:

Farmer, C. *Effect of Electronic Stability Control on Automobile Crash Risk*, Insurance Institute for Highway Safety. Arlington, VA. 2004. Benefit ID: 2008-00577

Ohono and Shimura. *Results From the Survey on Effectiveness of Electronic Stability Control (ESC),* National Agency for Automotive Safety and Victims' Aid. 18 February 2005. Benefit ID: 2008-00578

Preliminary Results Analyzing the Effectiveness of Electronic Stability Control (ESC) Systems, U.S. DOT National Highway Traffic Safety Agency, Report No. DOT HS 809 790. September 2004. Benefit ID: 2008-00579

"Update on Electronic Stability Control," *Insurance Institute for Highway Safety*, Status Report, Vol. 41, No. 5, 13 June 2006. Benefit ID: 2008-00580

[389] "Update on Electronic Stability Control," *Insurance Institute for Highway Safety*, Status Report, Vol. 41, No. 5, 13 June 2006. Benefit ID: 2008-00580

[390] "Update on Electronic Stability Control," *Insurance Institute for Highway Safety*, Status Report, Vol. 41, No. 5, 13 June 2006. Benefit ID: 2008-00580

[391] "Conflicting Demands of Consumers and Lawmakers Create Huge Opportunities for Automotive Technology Providers," *J.D. Powers and Associates,* 27 May 2011. Web site URL: http://businesscenter.jdpower.com. Last Accessed 20 July 2011.

[392] "Ford Offers Radar-Based Adaptive Cruise Control at $1,195," *Geek.com*, 23 July 2011. Website URL: www.geek.com/articles/mobile/ford-offers-radar-based-adaptive-cruise-control-at-1195-20090818/. Last Accessed 19 September 2011.

[393] Lienart, Anita. "Hyundai's BlueLink System Undercuts Rivals," *Edmunds InsideLine*, 10 June 2011 Web site URL www.insideline.com. Last Accessed 27 July 2011.

[394] *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force. 2009.

[395] Kompfner, Paul and Wolfgang Reinhardt. *ICT for Clean and Efficient Mobility: Final Report*, Prepared by the Working Group on ICT for Clean and Efficient Mobility. Brussels. November 2008. Benefit ID: 2011-00723.

[396] "U.S. DOT Proposed Rear view Visibility rule to Protect Kids and the Elderly," National Highway Traffic Safety Administration Press Release. 3 December 2010. Web site URL: http://www.nhtsa.gov/PR/NHTSA-17-10. Last Accessed 19 September 2011.

[397] "Federal Motor Vehicle Safety Standard, Rearview Mirror; Notice of Proposed Rulemaking," 75 Federal Register 234, 7 December 2010, pp. 76186-76250. Benefit ID: 2011-00748.

398 "Federal Motor Vehicle Safety Standard, Rearview Mirror; Notice of Proposed Rulemaking," 75 Federal Register 234, 7 December 2010, pp. 76186-76250. Cost ID: 2011-00232.

399 "Federal Motor Vehicle Safety Standard, Rearview Mirror; Notice of Proposed Rulemaking," 75 Federal Register 234, 7 December 2010, pp. 76186-76250. Benefit ID: 2011-00748.

400 *Private Sector Deployment of Intelligent Transportation Systems: Current Status and Trends*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-028, EDL No. 14266. February 2006. Cost ID: 2008-00175

401 Dunn, Travis, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*. U.S. DOT Federal Transit Administration. August 2007. Cost ID: 2009-00193.

402 Dunn, Travis, et al. *Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses*. U.S. DOT Federal Transit Administration. August 2007. Benefit ID: 2009-00615.

403 Nowakowski, Christopher, et al. *Cooperative Adaptive Cruise Control: Testing Drivers' Choices of Following Distances*. California PATH Research Report for FHWA Exploratory Advanced Research Program Cooperative Agreement DTFH61-07-H-00038. January 2011.

404 *Evaluation of an Automotive Rear–End Collision Avoidance System*, U.S. DOT National Highway Traffic Safety Administration Report, Report No. DOT HS 810 569, EDL No. 14303. April 2006. Benefit ID: 2008-00576

405 *Evaluation of Intelligent Cruise Control System: Volume I – Study Results*, U.S. DOT, Report No. DOT-VNTSC-NHTSA-98-3, EDL No. 11843. October 1999. Benefit ID: 2007-00481

406 *Use of Advanced In-Vehicle Technology by Younger and Older Early Adopters*. AAA Foundation for Traffic Safety. Washington, DC. September 2008. Benefit ID: 2011-00722.

407 *Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test* Version 1.3 – Final Report, U.S. DOT, Report No. FHWA-JPO-07-016, EDL No. 14352. 5 January 2007. Benefit ID: 2008-00589.

408 *Use of Advanced In-Vehicle Technology by Younger and Older Early Adopters*. AAA Foundation for Traffic Safety. Washington, DC. September 2008. Benefit ID: 2011-00719.

409 *Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test Version 1.3 – Final Report*, U.S. DOT, Report No. FHWA-JPO-07-016, EDL No. 14352. 5 January 2007. Benefit ID: 2008-00581

410 Morsink, Peter, et al. "In-Car Speed Assistance to Improve Speed Management," Paper Presented at the 15th World Congress on ITS, New York, NY. November 2008. Benefit ID: 2011-00674

411 Morsink, Peter, et al. "In-Car Speed Assistance to Improve Speed Management," Paper Presented at the 15th World Congress on ITS, New York, NY. November 2008. Benefit ID: 2011-00675.

412 Barth, M. and K. Boriboonsomsin. "Energy and emissions impacts of a freeway-based dynamic eco-driving system,"*Transportation Research Part D: Transport and Environment*, Vol. 14, No. 6, August 2009. Benefit ID: 2010-00646.

413 Sayer, J. et al. *Integrated Vehicle-Based safety Systems Field Operational Test Final Program Report*, Prepared by University of Michigan Transportation Research Institute (UMTRI) for U.S. DOT ITS Joint Program Office. June 2011. Benefit 2011-00704.

[414] Sayer, J., et al. *Integrated Vehicle-Based safety Systems Field Operational Test Final Program Report*, Prepared by University of Michigan Transportation Research Institute (UMTRI) for U.S. DOT ITS Joint Program Office. June 2011. Benefit 2011-00705.

[415] Murray, D.; S. Shackelford; and A. Houser. *Analysis of Benefits and Costs of Roll Stability Control Systems for the Trucking Industry*, U.S. DOT Federal Motor Carrier Safety Administration. February 2009. Cost ID 2009-00193.

[416] Greenmeier, Larry. "Yawn: A new cue for drowsy driver warning systems," *Scientific American*, 29 July 2009. Web site URL: www.scientificamerican.com. Last Accessed 27 July 2011.

[417] Blanco, Myra, et al. *Assessment of a Drowsy Driver Warning System for Heavy-Vehicle Drivers: Final Report*. Prepared by Virginia Tech Transportation Institute for the U.S. DOT National Highway Traffic Safety Administration. April 2009. Benefit ID: 2011-00699.

[418] Jonsson, Lina. *DROWSI Project Cost Benefit Analysis*. Swedish National Road and Transport Research Institute. November 2008. Benefit ID: 2011-00716.

[419] Greenberg, Allen. *Non-Toll Pricing: A Primer, U.S. DOT Federal Highway Administration*, Report No. FHWA-HOP-08-044. January 2009. Benefit ID 2011-0717

[420] ERTICO ITS Europe. (2010, May 25). *eCoMove kicks off!* Web site URL: http://www.ertico.com/ecomove-kicks-off/ Last Accessed 17 December 2010.

[421] Lienart, Anita. "Hyundai's BlueLink System Undercuts Rivals," Edmunds InsideLine. 10 June 2011. Web site URL: www.insideline.com. Last Accessed 27 July 2011.

[422] Toledo, Tomer, et al. "In-vehicle Data Recorders for Monitoring and Feedback on Drivers' Behavior," *Transportation Research Part C 16*, 3 January 2008, pp. 320-333. Benefit ID: 2011-00697

[423] Hickman, Jeffrey and Richard Hoanoswki. *Evaluating the Safety Benefits of a Low-Cost Driving Behavior Management System in Commercial Vehicle Operations*, Prepared by Virginia Tech Transportation Institute for U.S. DOT Federal Motor Carrier Safety Administration, Report No. FMCSA-RRR-10-033. June 2010. Benefit ID: 2011-0698

[424] Greenberg, Allen. *Non-Toll Pricing: A Primer,* U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-044. January 2009. Benefit ID 2011-0717

[425] Greenberg, Allen. *Non*-Toll *Pricing: A Primer*, U.S. DOT Federal Highway Administration, Report No. FHWA-HOP-08-044. January 2009. Benefit ID 2011-0718

[426] ACEP Board of Directors. "Automatic Crash Notification and Intelligent Transportation Systems: Implications for the Emergency Physician - Policy Resource Education Paper," American College of Emergency Physicians (ACEP). Web site URL: http://www.acep.org/Content.aspx?id=29122. Last Accessed 30 June 2011. Benefit ID: 2011-00731

See also the following primary source documents supporting the estimate that ACN systems can reduce road traffic deaths by 1.5 to 15 percent:

Pieske O. "ACN (Automatic Collision Notification)- reducing fatalities in traffic accidents by automated accident," *Kongressbd Dtsch Ges Chir Kongr*. Vol. 119, 2002, pp.546-548. (Abstract)

Evanco W.M. "The potential impact of rural mayday systems on vehicular crash fatalities*," Accident Analysis & Prevention*, Vol. 31, 1999, pp. 455-462. (Abstract)

Clark and Cushing. "Predicted effect of automatic crash notification on traffic mortality," *Accident Analysis and Prevention*, Vol. 34, 2002, pp. 507-513. (Abstract)

Lahausse, J. "The Potential for Automatic Crash Notification Systems to Reduce Road Fatalities," *Association for the Advancement of Automotive Medicine*, Vol. 52, 2008, pp. 85-92. (Abstract)

[427] ACEP Board of Directors. "Automatic Crash Notification and Intelligent Transportation Systems: Implications for the Emergency Physician - Policy Resource Education Paper," American College of Emergency Physicians (ACEP). Web site URL: www.acep.org/Content.aspx?id=29122. Last Accessed 30 June 2011. Benefit ID: 2011-00731

[428] Rauscher, Stefan, et al. "Enhanced Automatic Collision Notification System – Improved Rescue Care Due to Injury Prediction - First Field Experience," National Highway Traffic Safety Administration, Paper Presented at the 21st International Technical Conference on the Enhanced Safety of Vehicles. June 2009. Benefit ID: 2011-00672

[429] *Private Sector Deployment of Intelligent Transportation Systems: Current Status and Trends*, U.S. DOT Federal Highway Administration, Report No. FHWA-JPO-06-028, EDL No. 14266. February 2006. Cost ID: 2008-00175

[430] *Next Generation 9-1-1 (NG9-1-1) System Initiative: Final Analysis of Cost, Value, and Risk*: *Version 1.0*, U.S. DOT Federal Highway Administration ITS Joint Program Office. 5 March 2009. Cost ID: 2011-00226

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-11-140

U.S. Department of Transportation
Research and Innovative Technology Administration