Intelligent Transportation Systems Benefits, Costs, and Lessons Learned

2014 Update Report

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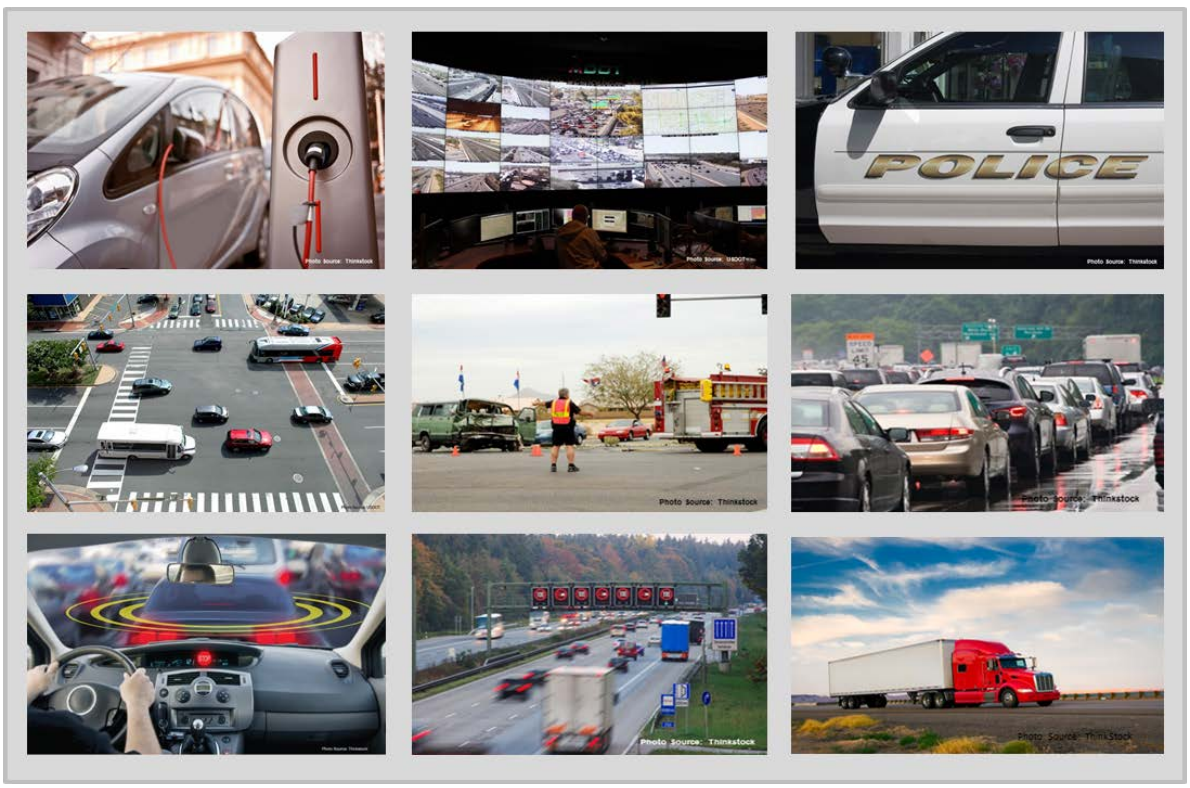

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16. Abstract

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 (U.S. DOT) 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, and lessons learned regarding ITS planning, deployment, and operations obtained from almost twenty years of evaluation data.

The report is based upon three 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 eighteen years of summaries of the benefits, costs, and lessons learned 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.

The report has been developed as a collection of factsheets presenting information on the performance of deployed ITS, as well as information on the costs, and lessons learned regarding ITS deployment and operations. The report has been designed to be flexible for the user. There are a total of 20 factsheets representing the 16 taxonomy areas. Four of the taxonomy areas (arterial management, freeway management, transit management, and driver assistance) have enough data to require more than one factsheet.

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Preface/Acknowledgements

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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.

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Findings

As of April 2, 2014, there were a total of 1,668 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. Of the 1,668 summaries, 325 summaries have been added since the last report was completed in late 2011.

Table ES-1: Summaries in the Knowledge Resources Databases.

Summary Type	Number of Summaries
Benefits	804
Costs	282
Lessons Learned	582
Total	1,668

Table ES-2: Summaries by Taxonomy/Application Area.

Taxonomy/Application Area	Number of Benefit Summaries	Number of Cost Summaries	Number of Lesson Summaries
Arterial Management	147	54	67
Freeway Management	104	48	100
Roadway Operations & Maintenance	63	29	36
Crash Prevention & Safety	83	37	16
Road Weather Management	61	47	37
Transportation Management Centers	17	47	67
Alternative Fuels	1	0	0
Traffic Incident Management	71	40	66
Transit Management	106	45	74
Emergency Management	16	17	39
Traveler Information	85	39	73
Driver Assistance	85	22	18
Information Management	10	8	28
Commercial Vehicle Operations	63	21	18

Taxonomy/Application Area	Number of Benefit Summaries	Number of Cost Summaries	Number of Lesson Summaries
Intermodal Freight	20	3	13
Electronic Payment & Pricing	81	36	73

An important addition to the Knowledge Resources in the last three years is the inclusion of benefit, cost, and lessons learned summaries for the Connected Vehicle Program, the Urban Partnership Agreement Program and the Integrated Corridor Management (ICM) Program. As these programs continue to evolve and become deployed across the country, the number of summaries will continue to increase, providing timely data to those interested in deploying similar technologies. Table ES-3 below shows the number of summaries in each of these areas.

Table ES-3: Summaries by Program Area.

Program Area	Number of Benefit Summaries	Number of Cost Summaries	Number of Lesson Summaries
Connected Vehicle	16	0	0
Urban Partnerships	4	0	7
ICM	6	3	13

Geographic Location of Summaries

Figure ES-1 shows the distribution of the summaries across the United States. There are also 214 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 section 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, 229 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 from survey results across the U.S.

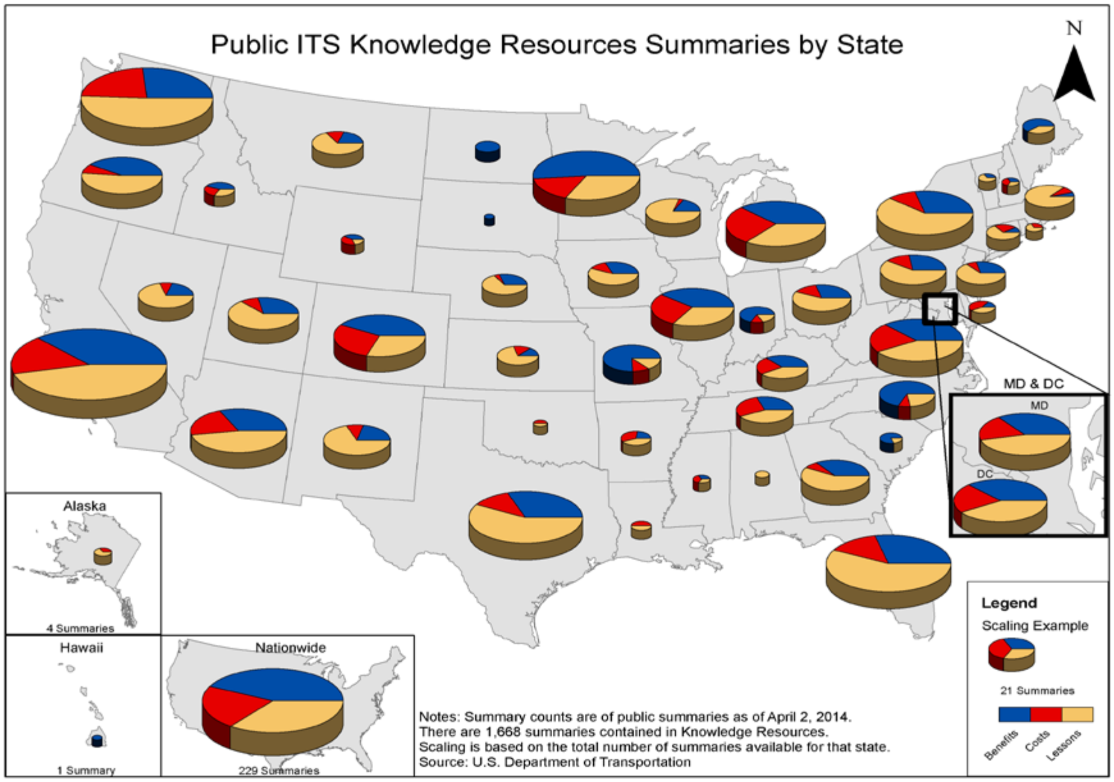


Figure ES-1: ITS Knowledge Resource Summaries by State.

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 is 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.
- 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 and Washington, for example, consistently do 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.

ITS Evaluation Highlights

In the eighteen 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 highlights from each of the Application Areas:

Arterial Management

- A Bay Area Rapid Transit (BART) smart parking system found that more efficient management of transit station parking lots improved parking space utilization rates and increased BART ridership (2011-00695).
- Local traffic measures such as controlling traffic demand, banning heavy duty vehicles or restricting speeds during periods of peak pollution can contribute to significant reductions in air quality measures (2011-00754).
- SPaT applications, used in the connected vehicle environment, have the potential to increase safety, mobility, and reduce environmental impact at traffic signals.
- Improved traffic signal control continues to be one of the most cost effective ways to improve safety and mobility in most jurisdictions.

Freeway Management

- Technologies such as adaptive ramp metering, variable speed limits, dynamic merging, dynamic pricing, and information dissemination can influence traveler behavior in real-time to improve safety, reduce emissions, and improve system efficiency and reliability.
- Variable Speed Limit (VSL) systems have been shown to reduce crash occurrence and can also reduce system travel time and vehicle emissions through increased uniformity in traffic speeds.
- With Integrated Corridor Management (ICM), transportation professionals can manage the transportation corridor as a multimodal system rather than a fragmented network of individual assets. ICM solutions projected benefit-cost ratios range from 10:1 to 25:1 over 10 years.

Roadway Operations & Maintenance

- Mitigation strategies for roadway operations have shifted from a capacity-oriented approach that relies on increasing capacity to reduce travel times, to a reliability-oriented approach that focuses on maintaining existing capacity while minimizing disruptions to improve travel time reliability.
- Portable Traffic Management Systems (PTMS) can be rapidly deployed to improve safety and mobility regardless of work zone location. These systems can automatically monitor traffic conditions and communicate with vehicles and drivers to improve situational awareness, harmonize traffic flow, and lessen the impacts of reduced capacity at work zones.

Crash Prevention & Safety

- Crash avoidance technologies have been shown to decrease crashes and can reduce occurrences of driver injury and fatalities by up to 57 percent.
- The new wave of crash prevention and safety strategies includes the integration of vehicle and infrastructure safety systems and implementation of connected vehicle technologies for safety applications.

Road Weather Management

- Three types of mitigation measures may be employed in response to environmental threats: advisory, control, and treatment strategies. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Treatment strategies supply resources to roadways to minimize or eliminate weather impacts.
- Weather-Responsive Traffic Management systems have the potential to reduce rear-end conflicts by approximately 22 percent for moderate volume levels and 43 percent for high volume.

Alternative Fuels

- Wireless charging technologies will allow drivers to charge their electric vehicles in small amounts on a more frequent basis. Dynamic charging may complement local stationary charging, removing range anxiety. As a result, electric batteries could be smaller, with the resulting reduction in electric vehicle cost and weight.
- The potential benefits of a catenary-accessible hybrid truck platform may be significant. Trucks, when connected to the catenary system, will have zero-emissions which can significantly reduce overall emissions along a corridor.

Transportation Management Centers

- Recent initiatives and concepts such as Integrated Corridor Management (ICM) and Active Traffic and Demand Management (ATDM) integrate more functionality into a single center for more responsive or even predictive traffic operation strategies.
- TMCs are collecting more and more data with the potential to collect data directly from vehicles in the near future. Social media is being used to disseminate traveler information, while crowdsourced data is being used to gather data from drivers to get travel times, incidents, and other roadway information from driver reports.

Traffic Incident Management

- Benefit-cost analysis of Incident Management Systems show that these systems have a high return on investment with B/C ratios ranging from more than 4:1to over 38:1.
- Incident management programs have the ability to significantly reduce the duration and clearance time of traffic incidents, resulting in significant reductions in vehicle delay, fuel consumption and secondary crashes.

Transit Management

- Providing transit travel times and departure information on highways can lead to a 1.6 to 7.9 percent mode shift from automobile to transit.
- The use of traveler information tools such as trip planners and station parking information encourages individuals who have never tried transit options to take them at least once and encourages existing riders to use the transit system more frequently.
- Deploying ITS technologies for transit operations and fleet management can help improve service reliability; decrease running time; reduce bus delays at intersections, missed trips, and emissions; and allow for increased service without additional staff or vehicles.

Emergency Management

- Tools and operational strategies that help manage traffic operations can be used in emergency operations for the purpose of increasing traffic capacity on evacuation routes and responding to traffic incidents that hinder the evacuation effort.
- Research shows that the effects of transit signal priority on emergency evacuation clearance times for transit vehicles can provide significant time savings without having a significant impact on evacuation clearance times or evacuee travel times for non-transit vehicles.

Traveler Information

- The next generation of en-route traveler information is in-vehicle traveler information through connected vehicle technologies and other "infotainment" applications.
- Researchers indicate that a well-designed trip planning website should be more than just an itinerary-trip planner; it should be able to effectively capture and convey real-world factors that make transit an increasingly attractive option.

Driver Assistance

- Connected Eco-Driving shows potential for reduction in fuel consumption and emissions for individual drivers as well as fleets.
- Vehicle platooning has great potential to combine several technologies for safety, mobility, and environmental benefits for drivers and the transportation system.

- Cooperative Adaptive Cruise Control (CACC) Systems have the potential to be in every vehicle in the future, are very easy for drivers to use, and have the potential for up to a 37 percent reduction in fuel consumption in some scenarios.
- Costs for Dedicated Short Range Communication (DSRC) based On-Board Equipment for connected vehicle technology are expected to be priced in the $200-233 range in 2017 for aftermarket devices.
- Following on the success of in-vehicle navigation, driver assistance technologies are now moving into the marketplace.

Commercial Vehicle Operations

- With sufficient economies-of-scale, a network wide deployment of Smart Roadside applications can yield benefit-cost ratios ranging from 3.5:1 to 6.2:1 over 10 years.
- Dynamic mobility applications that improve data sharing among commercial vehicle drivers can improve freight travel times up to 20 percent.

Intermodal Freight

- Using wireless communications with GPS vehicle positioning systems can improve commercial vehicle utilization by reducing empty container miles.
- Intermodal terminal gate appointment systems have the potential to dramatically improve operations inside the terminal and at the gate, resulting in reduced congestion on the roadway system and reduced harmful emissions in neighboring communities.

Electronic Payment & Pricing

- Recent lessons learned show that educating the public about the benefits of congestion pricing and engaging political champions early in the process lead to successful congestion pricing projects.
- The benefits of HOV to HOT conversions and expansion have been maintained over time with lower operating costs.

Information Management

- The 2012 transportation reauthorization law Moving Ahead for Progress in the 21st Century (MAP-21) will require greater use of real time and archived data to support development and monitoring of performance measures.
- Information management systems incorporate data fusion from multiple sources and/or agencies, integration of both real time and archived information, and in some cases, data visualization.
- Data archiving enhances ITS integration and allows for coordinated regional decision making.

1 Introduction

In 2014, the U.S. transportation system faces the ongoing challenges of improving safety, meeting rising demand, and mitigating congestion and environmental impacts. Motor vehicle crashes continue to be the leading cause of death among Americans aged one to 34 years old, with the total societal cost of crashes exceeding $230 billion annually [1]. Fatalities from motor vehicle crashes rose 5.3 percent in 2012, the first time since 2005 that fatalities have gone up [2]. In 2011, congestion caused urban Americans to travel an extra 5.5 billion hours and to purchase an extra 2.9 billion gallons of fuel for a congestion cost of $121 billion, up one billion dollars from the year before and translating to $818 per U.S. commuter [3]. The Texas Transportation Institute estimated the additional carbon dioxide (CO2) emissions attributed to traffic congestion at 56 billion pounds – about 380 pounds per auto commuter [3].

1.1 ITS Leads the Way

Over the past 30 years, the demand for the use of public roads has increased approximately 95 percent, as measured in vehicle miles traveled (VMT). Over this same period the number of lane miles on public roads has increased less than 9 percent. These statistics indicate a sharp rise in demand while capacity, in terms of the number of lane miles, has stayed relatively constant [4].

The ITS Knowledge Resources Database can be accessed at http://www.ITSKnowledgeResources.its.dot.gov

Recognizing that we can no longer build our way out of these problems, transportation professionals have turned to information and communications technology for solutions. 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. Connected vehicle technology has the potential to enable many services provided by infrastructure or vehicle based ITS by benefiting from enhanced communication between vehicles and the infrastructure.

1.2 The 2014 ITS Benefits, Costs and Lessons Learned Factsheets

This collection of factsheets presents information on the performance of deployed ITS, as well as information on the costs, and lessons learned regarding ITS deployment and operations. The factsheets, and the collection of three Web-based resources upon which it is based, have been developed by the ITS Joint Program Office (JPO) of the U.S. Department of Transportation (U.S. DOT) to support informed decision making regarding ITS planning and deployment.

1.3 Measuring ITS Performance

ITS deployment impacts transportation system performance in six key goal areas: safety, mobility, efficiency, productivity, energy and environment, and customer satisfaction, each with its own set of performance measures.

- Safety is measured through changes in crash rates or other surrogate measures such as vehicle speeds, traffic conflicts, or traffic law violations.
- Mobility improvements are measured in travel time or delay savings, as well as travel time savings, and on-time performance. Travel time reliability is emerging as a new measure of travel dependability.
- Efficiency is typically represented through increases in capacity or level of service within existing road networks or transit systems.
- Productivity improvements can be documented in cost savings to transportation providers, travelers, or shippers.
- Energy and Environment benefits are typically documented through fuel savings and reduced pollutant emissions.
- Customer Satisfaction findings document the perception of deployed ITS by the traveling public, usually in the form of survey results.

Each factsheet highlights recent benefits, costs and lessons learned for the ITS technologies used in a specific application area. The findings presented include reference information and short identification numbers that are hyperlinked directly to the ITS Knowledge Resource database source for the information. These links provide additional information on each finding cited, along with links to the original source documents, when available.

1.4 ITS Knowledge Resources

The ITS Knowledge Resources (KR) database (www.ITSKnowledgeResources.its.dot.gov) contains summaries of the benefits, costs, and lessons learned regarding ITS deployment and operations. The Knowledge Resources organize eighteen years of information on specific ITS implementations, drawn primarily from written sources such as ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers. The database is maintained by the U.S. DOT's ITS JPO Evaluation Program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS.

- **The ITS Benefits Database** provides measures of the effects of ITS on transportation operations according to the six goals identified by the U.S. DOT: safety, mobility, efficiency, productivity, energy and environmental impacts, and customer satisfaction. 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 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 ITS Lessons Learned Database** provides access to the knowledge gained through the experience of deploying ITS experience primarily from case studies, best practice compendiums, planning and design reviews, and evaluation studies.

The ITS Knowledge Resources Home page integrates the Knowledge Resources databases described above, as well as provides a mapping application, help information, an upload feature to encourage the collection of new information sources, and comment and feedback mechanisms.

1.5 2013 Taxonomy Update

The ITS Knowledge Resources are organized according to a taxonomy of 16 application areas, with sub-categories for each application area. With the emerging research in ITS technologies such as connected vehicles, the taxonomy has been updated and reorganized since the last ITS Benefits, Costs, Deployment, and Lessons Learned Update in 2011.

The most significant change to the previous taxonomy classifications is the removal of the division between Intelligent Vehicle and Intelligent Infrastructure technologies. As emerging ITS technologies make use of the integration between vehicles and infrastructure, the new taxonomy of ITS Applications no longer uses the first level category and has organized all application areas under one umbrella of ITS. For example, in the previous taxonomy classification, the Crash Prevention and Safety application area fell under the Intelligent Infrastructure category, while the Collision Avoidance application area was categorized under the Intelligent Vehicle category. In the new classification scheme, these two areas have been combined under Crash Prevention and Safety with sub-categories representing both crash prevention and safety technologies and collision avoidance technologies.

Another improvement is the addition of specific application categories and sub-categories for new emerging research areas and trends. Some examples include alternative fuels, congestion and emissions pricing, speed harmonization and performance management. In addition, the new taxonomy includes an accompanying document with detailed definitions of all taxonomy categories and sub-categories.

As ITS research continues to evolve, additional updates to the taxonomy, including new application areas and sub-categories, may be identified.

1.6 Report Organization

This report has been designed to be flexible for the user. The purpose is to make the information readily available, whether by accessing it through the web, a mobile device or tablet, or by printing sections on one or more application areas. There are a total of 20 factsheets representing the 16 taxonomy areas. Four of the taxonomy areas (arterial management, freeway management, transit management, and driver assistance) have enough data to require more than one factsheet.

The factsheets include tables, charts, images, and case studies that are available to use in reports or briefings as needed to convey the advantages of using ITS technologies and applications in specific areas or regions. The citation for these resources is: U.S. DOT. *ITS Benefits, Costs, and Lessons Learned: 2014 Update Report*. 2014. Publication Number: FHWA-JPO-14-115.

The online versions of the factsheets feature interactive graphs that contain various metrics represented by the bars of the graphs. The bars represent a numeric range, indicating the range of impacts reported by sources in the databases. Each metric has a number after the text, representing the number of data points used to create the range; no number means only there was only one data point. When moused over and selected or clicked, the bar opens a 'tooltip' with more detailed information. The tooltip contains the sub-headline of each benefit or cost entry with the data point from the entry that is incorporated into the range of the bar. The text is hyperlinked to the entry on the ITS Knowledge Resource website (www.itsknowledgeresources.its.dot.gov). All data depicted is from 2003 to 2014 unless otherwise stated in the factsheet. To remove the tooltip from the screen, select or click the same bar a second time and the tooltip will disappear.

The findings presented in these factsheets include reference information and short identification numbers that are hyperlinked directly to the ITS Knowledge Resource database source. These links provide additional information on each finding cited, along with links to the original source documents, when available online.

1.7 ITS Evaluation Trends

Looking back over the last three years, the most recent additions to the ITS knowledge resources indicate the following trends:

- Increasing benefits from congestion pricing, not only in added revenue, but also in better utilization of excess capacity in High Occupancy Vehicle (HOV) lanes achieved through HOV to High Occupancy Toll (HOT) conversions. There is increasing acceptance among travelers of paying for reliable trip times (2011-00769).
- Advances in Integrated Corridor Management (ICM) strategies that allow transportation subsystems to operate in a coordinated and integrated manner. ICM solutions developed for three busy commuter corridors had projected benefit-cost ratios ranging from 10:1 to 22:1 over 10 years (2011-00736, 2011-00757, 2012-00804).
- The emergence of crash avoidance technologies that utilize advanced radar and sensor technologies. In 2011, NHTSA evaluated an Advanced Collision Mitigation Braking System (A-CMBS) designed with forward sensing radar, an on-board electronic control unit, and sensors to monitor vehicle speed, brake pressure, steering angle, and yaw to predict and warn drivers of impending collisions, and automatically implement countermeasures to avoid or mitigate collisions. The report found that light vehicles that automatically activate in-vehicle alerts, seat belt tensioners, and braking systems can reduce fatalities by 3.7 percent (2013-00833).
- Integration of new and traditional data sources to support performance measurement required by MAP-21 (2013-00649), and adoption of regional approaches to collecting and maintaining such data, such as the Regional Integrated Transportation Information System (RITIS) for the Washington DC metro area (2011-00583).
- The adoption of adaptive signal control and transit signal priority to improve traffic flow resulting in reduced fuel consumption and emissions. For example, installation of adaptive signal control systems in two corridors in Colorado reduced fuel consumption by 2 to 7 percent and pollution emissions by up to 17 percent (2012-00808).
- Demonstrations of connected vehicle technologies, such as the initial deployment of Smart Roadside Inspection Stations (SRIS), are showing the potential to reduce emissions and save money. SRIS showed the potential to reduce emissions annually by 6.57 metric tons by eliminating needless commercial vehicle inspections. SRIS enables

inspectors to improve efficiency while maintaining enforcement levels at lower cost. At an average agency personnel cost of $45 per hour, the system would save $1,149,750 per year (2013-00859).

1.8 Moving to a Future Connected Vehicle and Autonomous Vehicle Environment

Connected vehicle research represents an opportunity to improve a number of the vehicle-based ITS applications described in the factsheets. 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. Advances in autonomous vehicles offer the prospect of vehicle control systems that automatically accelerate and brake with the flow of traffic, preventing crashes, reducing congestion, and conserving fuel. Mobility for those disabilities will be greatly enhanced if the basic driving functions could be safely performed by the vehicle itself. For more information on connected vehicle and autonomous vehicle research activities, visit the website: www.its.dot.gov/connected_vehicle/connected_vehicle.htm.

2 Arterial Management

2.1 Overview

2.1.1 Introduction

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 microwave or 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.

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.

Education and engineering solutions continue to be important in combatting red light running and reducing speeding; however, automated enforcement is another effective tool.

Transportation agencies can share information collected by arterial management systems with road users through technologies within the arterial network, such as DMS and HAR. They may also share this information with travelers via broader traveler information programs such as 511, the Internet, and most recently with smartphone applications. Arterial management systems may also include automated enforcement programs that increase compliance with speed limits, traffic signals, or other traffic control devices. 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.

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.

The most prevalent ITS technologies used along arterials are traffic signal systems. There are many different applications for traffic signals including advanced systems, adaptive systems, and different types of preemption and priority. The arterial management taxonomy has been divided into two chapters: one addressing the benefits, costs and lessons of traffic control technologies and this chapter addressing other technologies such as parking management, variable speed limits, automated enforcement and information dissemination.

In addition, regional operations can provide coordinated strategies and applications that tie arterial management systems with other applications such as freeway management, transit management and transportation management centers. An example of this coordination is the Integrated Corridor Management (ICM) program. Additional information on the interaction of arterial management systems with these other technologies is further explored in other chapters within this report.

2.1.2 **Benefits**

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.

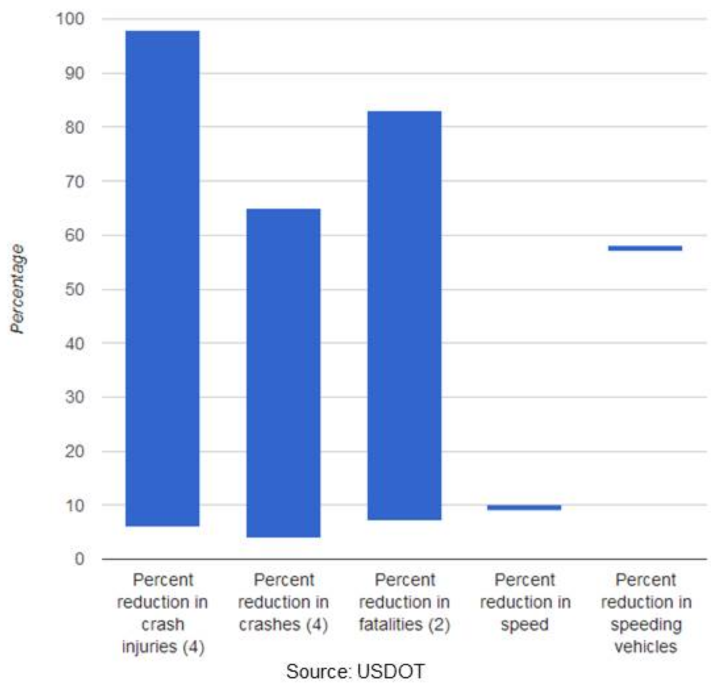


Figure 2-1: Safety Benefit Metrics Used in Studies of Speed Enforcement (Source: ITS Knowledge Resources).

Variable Speed Limits

Variable speed limits are speed limits that change relative to road, traffic, and environmental conditions. Traffic managers use variable speed limits to warn the driver that driving conditions are not conducive to the normal posted speed and speeds should be adjusted accordingly. Variable speed limit systems use sensors and/or vehicle probe data to monitor prevailing traffic, weather, and environmental conditions to determine the most efficient speed limits. Speed limits may be communicated to drivers via in-vehicle systems or DMS. These speed limits may or may not be enforced the same as normal speed limit signs, depending on the policies of state and local jurisdictions.

Information Dissemination

Motorists are able to receive relevant information on location-specific traffic conditions in a number of ways, including DMS, HAR, and in-vehicle messages.

Transportation operations staff can share information collected by sensors or vehicles associated with arterial management systems with road users through technologies within the arterial network, such as DMS or HAR. Traffic management staff may also send information to in-vehicle devices capable of displaying traveler information. Coordination with regional or multimodal traveler information efforts, as well as freeway and incident management programs, can increase the availability of information on arterial travel conditions.

Table 2-1: Benefits of Arterial Management.

Application	Selected Findings
Parking Management	In St. Paul, Minnesota, an advanced parking management system reduced travel times by nine percent. (2008-00508)
Parking Management	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. (2011-00702)
Parking Management	A Bay Area Rapid Transit (BART) smart parking system encouraged 30 percent of surveyed travelers to use transit instead of driving alone to their place of work. The smart parking project found that more efficient management of transit station parking lots improved parking space utilization rates and increased BART ridership. (2011-00695)
Information Dissemination	An overheight warning system at a CSX bridge in Maryland decreased the number of tractor-trailer incidents by 75 percent. (2011-00750)
Information Dissemination	Simulation models show that real-time on-board driver assistance systems that recommend proper following distances can improve fuel economy by approximately 10 percent. (2010-00645)
Traffic Control/Variable Speed Limits	Local traffic measures such as controlling traffic demand, banning heavy duty vehicles or restricting speeds activated only during periods of peak pollution can contribute to significant reductions in air quality measures. (2011-00754)

Automated enforcement systems, such as speed enforcement and stop/yield enforcement, improve safety, reduce aggressive driving, and assist in the enforcement of traffic signals and speed limit compliance. Still or video cameras, activated by detectors or radar, can record vehicles traveling through a red signal or traveling faster than the speed limit. Speed enforcement cameras can also be portable and set up along the side of the roadway or even within a vehicle such as a van to enable more flexibility in the enforcement strategy.

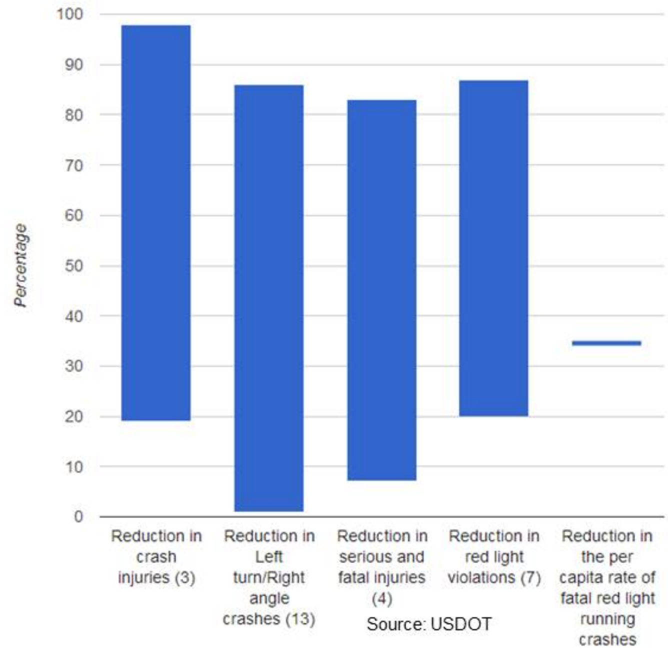


Figure 2-2: Range of Benefits for Automated Red Light Running Enforcement (Source: ITS Knowledge Resources).

The Governors Highway Safety Association strongly supports the use of automated enforcement to enforce red light running and speeding violations. Education and engineering solutions continue to be important in combatting red light running and reducing speeding; however, automated enforcement is another effective tool [5]. Automated enforcement continues to demonstrate that it is a successful, cost-effective means of reducing traffic accidents, injuries, and deaths.

2.1.3 **Costs**

A smart parking field test conducted for the California Department of Transportation and the Bay Area Rapid Transit estimated capital cost at $150 to $250 per space; O&M costs were estimated at $40 to $60 per space. The smart parking system permitted pre-trip as well as en-route trip planning. Motorists could reserve a parking space at the Rockridge BART station up to two weeks in advance. While en-route and faced with congestion on Highway 24, motorists could see the display of real-time parking availability at the station lot and decide to use transit. Key passenger-interface technologies used in the field test were:

- Two portable DMSs, located on Highway 24, which displayed parking availability information to motorists.
- A centralized intelligent reservation system that enabled commuters to check the availability of parking spaces and then to reserve a space via telephone, mobile phone, Internet, or personal digital assistant (PDA). The intelligent reservation system used the up-to-the-minute counts of parking availability obtained through the vehicle count data from the entrance and exit sensors at the BART station parking lot.

Fifty (50) parking spaces, of the 920 total, were made available for the smart parking field test – 15 for advance reservations and the remaining for same-day reservations by commuters who, upon seeing the DMSs on Highway 24, opted to take BART (2008-00134).

2.1.4 **Lessons Learned**

In planning for a demand-responsive pricing based parking management system, involve executive leadership, seek strong intellectual foundations, strike the right balance between complexity and simplicity, and emphasize data collection and project evaluation.

The SFpark pilot project of the San Francisco Municipal Transportation Agency (SFMTA) uses a demand-based approach to adjusting parking rates at metered parking spaces in the SFpark pilot areas and at SFpark garages. SFpark's combination of time-of-day demand-responsive pricing and off-peak discounts at garages is expected to reduce circling and double-parking, as well as influence when and how people choose to travel. Lessons learned from the project planning aspect of the SFpark pilot project are presented below:

- **Do not underestimate the scope of work.** It is easy to underestimate the scope, magnitude, and technological sophistication necessary to offer real-time parking data and provide demand responsive pricing. Agencies should develop the scope carefully incorporating expectations as well as challenges.
- **Involve executive leadership.** Many challenges accompanied planning and implementing a ground-breaking project with complex technology, significant policy changes, and a large amount of discovery and uncertainty. The support of a dedicated executive at the agency was critical, as was having appropriate financial resources.
- **Understand the parking supply.** Starting with the maxim that "you can't manage what you can't measure," the SFMTA collected comprehensive data about San Francisco's publicly available parking supply, both on and off-street, including existing parking regulations. Enabled by data, understanding the existing parking supply characteristics was a critical first step in the planning and implementation of the SFpark pilot project and will be just as important for its evaluation.
- **Seek strong and coherent intellectual foundations.** SFpark parking management approach was based on the pioneering academic work of Professor Donald Shoup from University of California, Los Angeles. Those foundations made it easier to develop policies, goals, and tools that were easily communicated and understood by customers. An academic advisory team offered early guidance and support for the design of the SFpark demonstration and how it could offer valuable data for evaluation of outcome.
- **Strike the right balance between complexity and simplicity.** SFpark had to balance the potential complexity of managing parking effectively with the need to have something simple enough to be communicated clearly and quickly to customers. It had to strike a similar technological balance between what is desirable and what is feasible.
- **Emphasize data collection and project evaluation.** As a federally funded demonstration of a new approach to managing parking, the SFpark project is collecting an unprecedented data set to enable a thorough evaluation of its effectiveness. This improved the project's credibility among stakeholders.

The SFpark experience emphasizes the need for adequate planning when a demand-responsive pricing based parking management system is considered for implementation. Cities around the world are interested in the common and urgent goals of reducing traffic congestion and transportation related greenhouse gas emissions. To the extent that SFpark successfully manages parking supply and demand, rates, and reduces congestion and emissions, the project is relevant to other cities as well because it is easily replicable. SFpark is expected to improve traffic flow, reduce congestion and greenhouse gas emissions, increase safety for all road users, and enhance quality of life (2012-00621).

Install message signs at strategic locations to provide commuters en route with real-time information of the parking availability status at a major transit station.

An evaluation of automated parking information system in the vicinity of the Washington Metropolitan Area Transit Authority (WMATA) Glenmont Metro parking facility shows that the signs displayed at Georgia Avenue, Norbeck Road, and Glenallen Avenue are an effective tool to inform commuters about the parking availability at the Glenmont Metro Station parking facility. The system helps reduce congestion and improve mobility around the parking facility, and increases customer satisfaction. The automated parking information system at Glenmont Metro Station is intended to provide real-time information to commuters about the availability of parking spaces at the Glenmont Metro Station parking facility. If spaces are not available at the Glenmont facility, commuters are directed to use other lots with available spaces, especially the underutilized Norbeck Road park-and-ride lot and the Wheaton Metro Station parking facility (2011-00597).

2.3 Traffic Control

2.3.1 Introduction

Traffic signal control systems are the primary tools used to manage the flow of traffic on arterial street systems. The primary objectives of these systems are to improve traffic flow, reduce traffic delays, and increase 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 allow proactive traffic management by allowing traffic conditions to be actively monitored and archived, 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. Other related systems can be used to improve the safety of all road users at signalized intersections, including pedestrian detection, specialized countdown signal heads, and bicycle-actuated signals.

Connected vehicle technologies are facilitating research in new advanced signal systems. The Intelligent Transportation System (ITS) ITS Joint Program Office's (JPO) Dynamic Mobility Applications (DMA) program is researching advanced signal operations under the Multi-Modal Intelligent Traffic Signal System (MMITSS) research bundle. One significant outcome from this research area is the Intelligent Traffic Signal System (ISIG) application. This application uses high-fidelity data collected from vehicles through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications as well as from pedestrian and non-motorized travelers. This ISIG application seeks to control signals and maximize flows in real time. The ISIG application also plays the role of an overarching system optimization application, accommodating transit or freight signal priority, emergency vehicle preemption, and pedestrian movements to maximize overall network performance.

Collecting data from vehicles in a connected vehicle environment has the potential to help agencies optimize their signal systems according to the locally determined objectives, whether they are focused more on safety, mobility, or the environment. Other area of connected vehicle and traffic signal research is with signal phase and timing (SPaT) data. Several connected vehicle programs are researching the potential of broadcasting SPaT data at intersections, allowing approaching (equipped) vehicles to know the current state of the signal, and then to determine if they will be able to proceed safely through the green light. This data has the potential to increase safety and mobility, and reduce environmental impacts at traffic signals.

Benefit-cost ratios for Traffic Control Systems range from 1.58:1 to 62:1.

The ITS JPO's Applications for the Environment Real-time Information Synthesis (AERIS) program is also researching advanced signal systems to better understand and optimize for environmental goals. The AERIS Eco-Traffic Signal Timing application is similar to current adaptive traffic signal control systems; however, the application's objective is explicitly to optimize traffic signals for the environment rather than for mobility. See the case study below for more detailed information on this AERIS application.

2.3.2 **Benefits**

Arterial management systems manage traffic along arterial roadways, employing traffic detectors, traffic signals, and various means of communicating information to travelers. These systems make use of information collected by traffic surveillance devices to smooth the flow of traffic along travel corridors. **Advanced signal systems** include coordinated signal operations across neighboring jurisdictions, as well as centralized control of traffic signals which may include some technology applications for the later development of adaptive signal control.

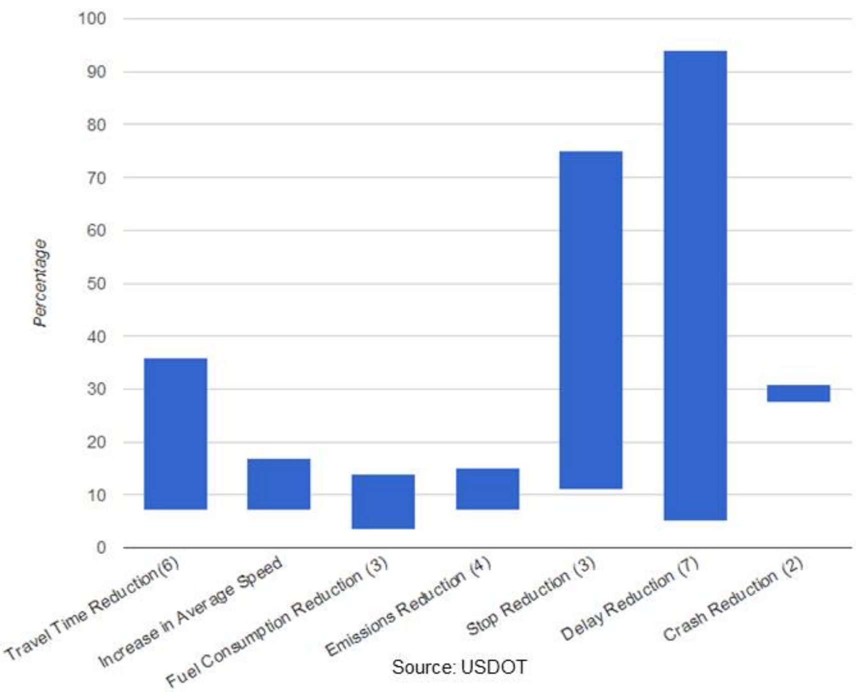


Figure 2-3: Advanced Signal Control benefits found in the Knowledge Resource database from 2003 to 2013 (Source: ITS Knowledge Resources).

Figure 2-3 shows the ranges of reported benefits from advanced signal control systems. Benefits range across several measures including safety, mobility and environmental improvements.

In August of 2012, New York City deployed an advanced traffic signal system that included an adaptive decision support system for 110 blocks of New York resulting in a 10 percent decrease in travel times throughout Midtown (2012-00810). The data collected through the technologies applied for this system has allowed the City to use historical data and analytics to develop more sophisticated algorithms to continually improve the movement of vehicles throughout the traffic signal system.

Adaptive Traffic Signal Systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions. As agencies continue to implement innovative technologies, and the costs to implement adaptive signal systems continue to decline, these systems become a viable solution to improve safety, mobility and the environment along an arterial.

According to FHWA's Every Day Counts (EDC) program, the main benefits of adaptive signal control technology over conventional signal systems are that it can:

- Continuously distribute green light time equitably for all traffic movements;
- Improve travel time reliability by progressively moving vehicles through green lights;
- Reduce congestion by creating smoother flow; and
- Prolong the effectiveness of traffic signal timing [6].

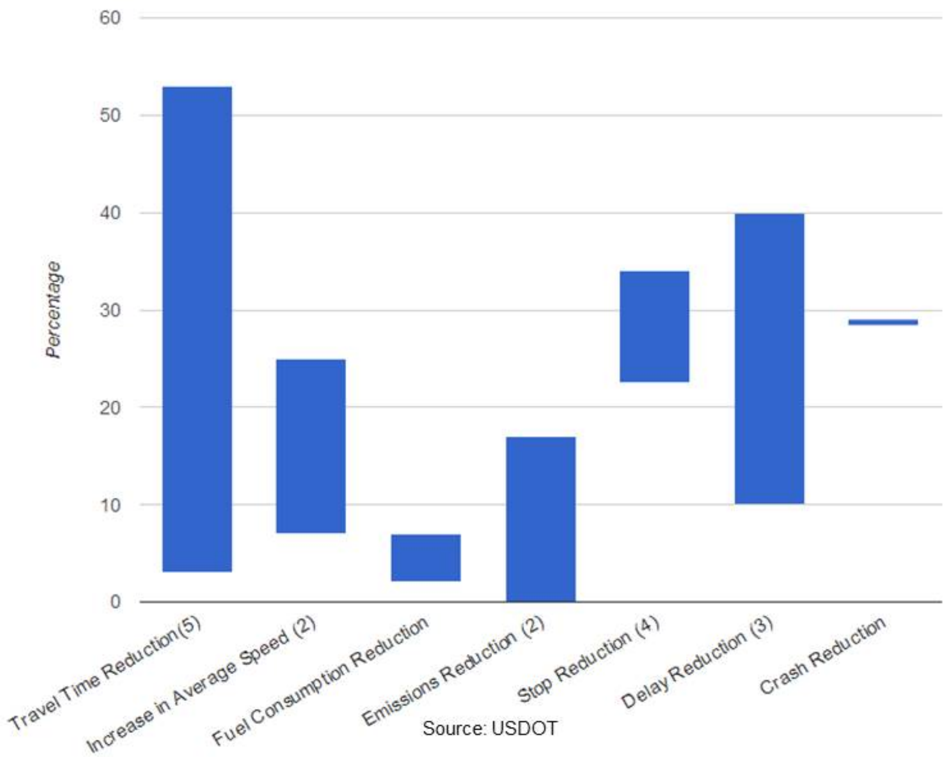


Figure 2-4: Adaptive Signal Control benefits found in the knowledge resource database from 2003 to 2013(Source: ITS Knowledge Resources).

Figure 2-4 shows the ranges of reported benefits from adaptive signal control systems. Benefits range across several measures including safety, mobility and environmental improvements. In July of 2012 the Colorado Department of Transportation (CDOT) released its evaluation of two different adaptive signal systems on two different corridors. The mobility benefits for both corridors combined included 9-19 percent improvement in travel times and an increase in average speed by 7-22 percent. The environmental benefits found by CDOT included a 2-7 percent reduction in fuel consumption and a reduction of pollution emissions by up to 17 percent (2012-00809).

Table 2-2: Benefit-cost Ratios for selected Traffic Control Systems.

Selected Findings	Benefit-cost Ratio
In Oakland County, Michigan a two-phase project to retime 640 traffic signals resulted in a benefit-cost ratio of 175:1 for the first phase and 55:1 for the second. (2007-00313)	175:1 Phase 1 55:1 Phase 2
The Traffic Light Synchronization program in Texas demonstrated a benefit-cost ratio of 62:1. (2008-00507)	62:1
Integrated Corridor Management (ICM) strategies that promote integration among freeways, arterials, and transit systems can help balance traffic flow and enhance corridor performance; simulation models indicate benefit-cost ratios for combined strategies range from 7:1 to 25:1. (2009-00614)	7:1 to 25:1
Adaptive signal control, transit signal priority, and intersection improvements implemented during the Atlanta Smart Corridor project produced a benefit-cost ratio ranging from 23.2:1 to 28.2:1. (2011-00758)	23.2:1 to 28.2:1
Installation of adaptive signal control systems in two corridors in Colorado had benefit-cost ratios ranging from 1.58 to 6.10. (2012-00807)	1.58:1 to 6.1:1
A decentralized adaptive signal control system has an expected benefit-cost ratio of almost 20:1 after five years of operation, if deployed city-wide in Pittsburgh. (2013-00822)	20:1

In addition to traffic signal control systems that primarily focus on vehicle interactions, there are traffic signal systems that are designed to improve pedestrian safety at roadway crossings. The High-Intensity Activated Crosswalk (HAWK) pedestrian beacon assists at pedestrian crossings by stopping vehicles so that pedestrians can cross the roadway and then permits the drivers to proceed as soon as the pedestrians have passed. A HAWK crossing uses several visual cues to alert drivers to the possible presence of a pedestrian. These visual cues include a unique beacon configuration, high visibility crosswalk markings, a stop bar approximately 50 feet from the crosswalk, 8 inch wide solid lane lines between through travel lanes, and signs that read “Pedestrian Crossing” or “School Warning.”

A HAWK pedestrian beacon deployment demonstrated a 69 percent reduction in crashes involving pedestrians. There was also a 15 percent reduction in severe crashes that result in injury and a 29 percent reduction in total crashes where the HAWK system was deployed (2013–00848).

2.3.3 **Costs**

ITS Knowledge Resource Cost database provides a variety of system costs for traffic control strategies including advanced and adaptive traffic control systems. As technology for adaptive traffic control systems continues to improve and mature, the costs to implement such systems continue to go down.

Adaptive signal control technologies (ASCTs) have been proven effective in providing operational benefits, but agencies in the United States have been slow to adopt these technologies. One of the major reasons for slow ASCT implementation is lack of knowledge about the operational and safety benefits and costs of ASCT. A nationwide report found that the cost of ASCT per intersection was estimated between $46,000 and $65,000. Excluding the outliers, with seven agencies reporting, the average cost to implement ASCT technologies averages to $28,725 per intersection to implement. The average cost of ASCT was given by the type of system as well as the type of detection technology. The average cost of ASCT per intersection was highest when used with video detection and lowest when used with magnetometer detection technology (2013-00278).

Table 2-3 provides system costs on a per intersection basis derived from several projects across the country. Details for each of these projects can be found in the Knowledge Resource Database.

Table 2-3: Adaptive Signal Control Project Costs.

Project Date	Total Project Cost	Number of Intersections	Cost per Intersection	Region	Cost ID
January 2013	$28,725	1	$28,725 (Average based on responses from 8 agencies)	Nationwide	2013-00278
July 2012	$176,300	8	$22,037	Colorado	2012-00273
July 2012	$905,500	11	$82,318 (Includes infrastructure upgrades)	Colorado	2012-00272
2010	$65,000	1	$65,000	Nationwide	2012-00249
2010	$1,708,029	18	$94,890 (includes infrastructure upgrades)	Georgia	2011-00237

2.3.4 **Lessons Learned**

Commit to acquiring the proper level of staffing and knowledge required for the operations and maintenance of Adaptive Traffic Control System (ATCS) prior to deployment.

Adaptive Traffic Control Systems (ATCSs) are powerful and complex tools that require a level of expertise for proper maintenance and operations. While ATCS may be viewed as a labor-reducing way of deploying signal timing plans, the experience of domestic and international ATCS agencies demonstrates the importance of having the level of staffing and knowledge in ATCS required for maintenance and operations. Key recommendations for ATCS agencies to consider in training, operations, and maintenance include the following.

- Beware of the perception that an ATCS is a hands-off type of system that will lower the labor or expertise requirements compared to standard traffic control systems.
- Be certain to receive ATCS training not only during the initial deployment of ATCS, but continuously throughout initial validation to solve operational problems or issues as they arise.

- Develop a working understanding of the principles of an ATCS.
- Beware that implementing successful ATCS operations may require a switch in the type of labor from maintenance to operations.

ATCS deployments can bring significant benefits to traffic performance, but it requires a commitment to training and acquiring proper levels of staffing for operations and maintenance. ATCS operations are sufficiently complex that traffic engineers, in general, need at least four to six months to acquire a general understanding of these systems (in contrast to an experienced signal timing engineer who needs about two months). Indeed, one of the most important ATCS issues for smaller agencies is retaining ATCS-proficient staff. Acquiring the proper knowledge and technical expertise to operate an ATCS empowers an agency to maintain the system and realize substantial benefits to users of the transportation network in which it is deployed (2012-00619).

2.3.5 **Case Study - Eco-Traffic Signal Timing: Preliminary Modeling Results**

The AERIS Eco-Traffic Signal Timing application is envisioned to be similar to current traffic signal systems; however the application's objective is to optimize the performance of traffic signals for the environment. The application collects data from vehicles, such as vehicle location, speed, and emissions data using connected vehicle technologies. It then processes these data to develop signal timing strategies focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region. The application evaluates traffic and environmental parameters at each intersection in real-time and adapts so the traffic network is optimized using available green time to serve the actual traffic demands while minimizing the environmental impact (2014-00912).

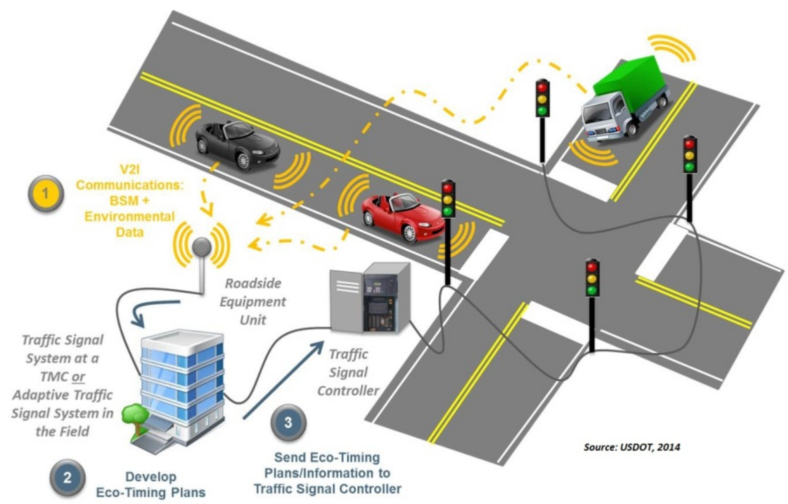


Figure 2-5: Diagram of the AERIS Eco-Traffic Signal Timing application (Source: U.S. DOT).

Methodology

Preliminary simulation and modeling was conducted for this application using a 6 mile segment of El Camino Real in Northern California. The corridor contains 27 signalized intersections operating actuated coordinated signal timing plans; however for the purposes of this analysis, the baseline conditions assumed fixed timing plans. The modeling team used a genetic algorithm to optimize the traffic signal timing plans for the corridor with the objective of reducing fuel consumption and emissions. The genetic algorithm determined an optimal cycle length for the corridor, green times for each phase, and signal offsets for each signalized intersection. Phase sequences were not changed. To determine the optimal timing plans, outputs from the Paramics microsimulation model were sent to an Application Programming Interface (API) that interfaced with the Environmental Protection

Agency's MOtor Vehicle Emissions Simulator (MOVES) model. Traffic and emissions outputs from Paramics and MOVES, respectively, were then sent to the genetic algorithm which developed new timing plans. These new timing plans were then sent back to Paramics and the process continued for numerous iterations until the genetic algorithm determined an optimal timing plan that reduced CO_2 emissions for the entire corridor. Sensitivity analysis included varying the following parameters: penetration rate of connected vehicles, congestion levels, percentage of trucks, and optimizing for emissions versus delay. The method used to determine optimized timing plans for this study considered an offline optimization approach. More advanced connected vehicle applications and algorithms may perform the optimization online, similar to adaptive signal control systems but leveraging connected vehicle data and technologies.

Conclusions

- There is up to 5 percent improvement in fuel consumption and environmental measures at full connected vehicle penetration, with a 1 to 4 percent improvement at partial connected vehicle penetration in a fully coordinated network.
- Optimizing for the environment resulted in a 5 percent fuel consumption reduction, whereas optimizing for mobility resulted in 2 percent reductions in fuel consumption.
- Driving a typical vehicle 8,000 miles per year on arterials equates to $70 of savings per year per vehicle.
- SUV (lower MPG) savings are $110 per year per driver.
- A fleet operator with 150 vehicles would save $16,500 per year.

3 Freeway Management

3.1 Overview

3.1.1 **Introduction**


Photo Source: Texas A&M Transportation Institute

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 able to receive relevant information on location-specific traffic conditions in a number of ways including dynamic message signs (DMS), highway advisory radio (HAR), and 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.

Many of the ITS strategies and applications are being used to actively manage traffic on our freeways today. Technologies such as adaptive ramp metering, variable speed limits, dynamic merging, dynamic pricing, and information dissemination can influence traveler behavior in real-time to improve safety, reduce emissions, and improve system efficiency and reliability.

Several other chapters of this report discuss ITS applications relevant to freeway management. There are chapters on Transportation Management Centers, Roadway Operations and Maintenance, Traffic Incident Management, Electronic Payment and Pricing, and Traveler Information, all of which use ITS technologies and applications that pertain to freeway management. In addition there is a separate chapter on Freeway Management: Integrated Corridor Management (ICM) that emphasizes the integration of freeway management, arterial management and transit management to combine strategies and apply a decision support system to operate facilities safely and efficiently.

3.1.3 **Benefits**

Ramp Control

Traffic signals on freeway ramps alternate between red and green signals to control the flow of vehicles entering the freeway. Metering rates may be altered based on freeway traffic conditions, ramp or local arterial traffic, or real-time vehicle emissions data. The Kansas City Scout program has implemented and evaluated ramp metering over the past few years. Selected results from these evaluations are listed in Table 3-1.

Table 3-1: Selected Benefits of Ramp Metering in Kansas City.

Selected Findings
Initial findings from a ramp meter evaluation in Kansas City were consistent with findings in other cities that show ramp metering can reduce crashes by 26 to 50 percent. (2012-00795)
The Kansas City Scout program used ramp meters to improve safety on a seven mile section of I-435; before and after data indicated that ramp meters decreased crashes by 64 percent. (2012-00799)
Initial findings from a ramp meter evaluation in Kansas City show that ramp meters make it easier for drivers to merge and reduce overall travel times. (2012-00796)
The implementation of ramp metering in Kansas City increased corridor throughput by as much as 20 percent and improved incident clearance by an average of four minutes, with these benefits remaining consistent in the long term. (2013-00852)
The Kansas City Scout program used ramp meters to improve traffic flow and reduce overall peak period travel times on a seven mile section of I-435 by 1 to 4 percent. (2012-00800)

Lane Management - Variable Speed Limits (VSL)

VSL systems have been used in a number of countries, particularly in Europe, as a method to improve flow and increase safety. VSL systems use detectors to collect data on current traffic and/or weather conditions. Posted speed limits are then dynamically updated to reflect the conditions that motorists are actually experiencing. Presenting drivers with speed limits that are appropriate for current conditions may reduce speed variance, a concept sometimes called speed harmonization. If properly designed, VSL systems have been shown to reduce crash occurrence and can also reduce system travel time and vehicle emissions through increased uniformity in traffic speeds.

Table 3-2: Selected Benefits of Variable Speed Limit Systems on Freeways.

Selected Findings
Field data collected over the last two decades show variable speed limit (VSL) systems can reduce crash potential by 8 to 30 percent. (2012-00806)
Variable Speed Limit System shows promise; crashes reduced to lowest level in a decade. (2011-00733)
A variable speed limit system used to regulate traffic flow through work zones on a 7.5 mile section of I-495 saved motorists approximately 267 vehicle-hours of delay each day. (2011-00765)

Collisions on I-5 in Washington State have been reduced by 65-75 percent in a 7.5 mile corridor where an active traffic management system was deployed. (2012-00803)
A Variable Speed Limit (VSL) system on the I-270/I-255 loop around St. Louis reduced the crash rate by 4.5 to 8 percent, due to more homogenous traffic speed in congested areas and slower traffic speed upstream. (2011-00735)
Implementing variable mandatory speed limits on four lanes with the optional use of the hard shoulder as a running lane resulted in a 55.7 percent decrease in the number of personal injury accidents on a major motorway in England. (2011-00724)
17 percent reduction in NOx on "Ozone Action Days" with Variable Speed Limits. (2014-00909)

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, websites and in-vehicle systems, or specialized information transmitted to individual vehicles.

Organizations operating ITS can share information collected by sensors or probe vehicles with road users through technologies within the freeway network, such as DMS or HAR. ITS operators may also send information to in-vehicle devices capable of displaying traveler information. Coordination with regional or multimodal traveler information efforts, as well as arterial and incident management programs, can increase the availability of information on freeway travel conditions.


Photo Source: USDOT

Surveillance

Traffic surveillance systems use detectors and video equipment to support the most advanced freeway management systems. Surveillance technology, either in-ground or overhead, is used to provide real-time traffic data that is communicated to TMCs to assist agencies with decision making support to improve freeway operations. Table 3-3 includes selected benefits for freeway systems related to surveillance and information dissemination applications.

Table 3-3: Selected Benefits of Freeway Management.

	Selected Findings
Information Dissemination - DMS	When link travel times posted on DMS are twice as long as typical travel times, drivers begin to favor alternate routes. (2013-00846)

Information Dissemination - DMS	Ninety-four percent of travelers took the action indicated by the DMSs in rural Missouri and drivers were very satisfied by the accuracy of the information provided. (2013-00828)
Information Dissemination - In-Vehicle	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. (2010-00646)
Surveillance	NY State DOT TMC operators and NY State Thruway Authority staff were able to reduce traffic queues by 50 percent using vehicle probe data available through the I-95 Corridor Coalition. (2010-00653)

3.1.4 **Costs**

The purpose of the I-70 Corridor Intelligent Transportation Systems (ITS) and Technology Applications Study was to evaluate and plan for innovative technologies that could enhance the safety and mobility within the I-70 Corridor between Kansas City and St. Louis, Missouri. This report discussed the following ITS applications currently implemented or planned for deployment by the Missouri Department of Transportation (MoDOT).

Table 3-4 provides general cost estimates for data sharing components for I-70 Corridor ITS Project.

Table 3-4: I-70 Corridor ITS Project - Estimated Costs (2013-00287).

Application	Description/Units	Cost Estimates*
Road Weather Information Systems (RWIS)	Number of Electronic Sensor Stations/ <25	$10,000 each
	Number of Electronic Sensor Stations/ >25	$12,500
Fog Warning Systems	Cost of New Infrastructure	$125,000
	Cost of Modifying an Existing Road Weather Information System (RWIS)	$75,000
Dynamic Message Signs (DMS)	Relocate Existing Signs	$30,000 to $40,000 each
	New DMS Installed	$100,000 to $120,000
Lane Control Signal System	Per Ramp	$80,000 to 90,000
Closed Circuit Television (CCTV)	Cost per camera site	$50,000

Traffic Flow Monitoring	Transponder based systems – one direction of traffic	$15,000
	Transponder based systems – both directions of traffic	$30,000
Emergency Response System	Web-based system	$50,000
Virtual Weigh Stations		$300,000 to $1.4 million
Enhanced Work Zone Systems		$785,000
Tolling Systems	Toll Gantry/Per Gantry	$300,000
	Toll Lane Equipment/Per Lane	$200,000
	Toll Vehicle Enforcement System (VES) Data Host/Per Toll System	$1.0 million to $1.5 million
	Host Servers and Functions/Per Toll System	$300,000
	TMC/Video Control/Per TMC	$500,000
	Transponders/each	$10 to $40
Communications/Fiber Optic Backbone	Per Mile	$70,000 to $200,000

*Estimates come from several sources including FHWA or based on national averages

3.1.5 **Lessons Learned**

Ensure proper placement of variable speed limit (VSL) signs in a work zone and operate the VSL system consistently on a long term basis.

In July 2008, a VSL system was installed along a segment of heavily traveled urban interstate in Northern Virginia (I-495) that will undergo several years of continuous construction. This was the first deployment of a traffic-responsive VSL system in Virginia. The following on lessons learned from this deployment:

- **Ensure proper placement of VSL signs in a work zone.** VSL signs are to be located in such a way that they facilitate driver understanding and smooth operations. Signs should be placed so that they are not at risk of being obstructed and are not generally difficult to see under normal circumstances.

- **Operate the VSL system consistently on a long term basis.** A concept of operations for future VSL systems should be developed and followed to ensure consistent application of VSL.
- **Design VSL control algorithm to facilitate rapid response to changing traffic patterns in a work zone.** Agency operations staff has to ensure that the VSL control algorithm is designed to facilitate rapid response to changing traffic in a work zone.
- **Consider operational and safety tradeoffs prior to installing VSL systems on roads where demand far exceeds capacity.** Agencies should carefully consider operational and safety tradeoffs prior to installing VSL systems on roads where demand far exceeds capacity. VSLs do not appear to provide significant operational benefits where there is a sudden onset of severe congestion.

Virginia's experience suggests that a well-configured VSL system can provide operational benefits and improvements in safety surrogate measures provided that demand does not exceed capacity by too large a margin. Prior to deploying future VSL systems, it is suggested that departments of transportation perform site specific simulations to determine likely operational impacts (2011-00599).

3.1.6 **Case Study - Kansas City Ramp Metering Implementation** (2013-00852)

In April, 2010, KC SCOUT, the joint Kansas and Missouri traffic management agency for the Kansas City region, deployed the first regional application of ramp metering on seven interchanges along a 5-mile corridor of the I-435 corridor. This project was implemented because the corridor often experienced congestion during the peak commute periods, largely caused by friction and incidents due to merging at on-ramp locations. Increasing capacity or adding lanes would have been expensive and difficult given limited right of way.


Photo Source: Missouri and Kansas DOT

KC SCOUT identified the following five objectives for the ramp metering system:

- Reduce rear end and side swipe accidents.
- Maintain or reduce travel time along the corridor even with greater traffic volume.
- Avoid ramp meter back up onto arterial streets.
- Limit motorist wait time at ramp to 1 minute or less.
- Reduce incident clearance time.

The activation of the system was supported by an intense public education campaign designed to educate drivers on the intended purpose of the system, how to safely navigate the newly implemented traffic control devices, and the enforcement activities that would accompany non-compliance. Several evaluations of the system were performed. In 2011 the initial evaluation was performed by the Kansas and Missouri Departments of Transportation six months following the activation of the meters, with a follow-up evaluation completed at the 12-month interval. Another evaluation study was performed in

2011-2012 using archived data to assess whether the initial impacts reported in the original year continue over time.

Results

Results of the initial 2011 evaluation include:

- Accidents were reduced by 64 percent along the I-435 ramp-metered corridor.
- Travel times decreased or stayed the same while increasing corridor throughput by as much as 20 percent.
- No ramp meter backed up on to city streets due to queue flushing policies.
- Motorist wait times were limited to less than 1 minute on all ramps.
- Incidents were cleared 16 to 22 minutes faster.

Results of the 2011-2012 Long Term Impacts Evaluation:

- The change in the average volume in the corridor for the longer-term evaluation period was observed to decrease by less than 4 percent in the morning peak and less than 3 percent in the afternoon peak compared with volumes observed in the initial evaluation. These results were not statistically significant and are within the range of normal fluctuation in traffic levels on the corridor for each peak period, suggesting that travelers have not significantly changed their use of this corridor during peak periods as compared to after the initial deployment of the ramp meters.
- Since the time of the initial evaluation, incident clearance times also proved stable overall. Incident clearance times during the morning peak period from April 2011 through March 2012 were on average four minutes shorter than in the extended term following the first year activation of the metering system.

The analysis of the longer-term evaluation period from April 2011 through March 2012 concluded that peak period average speed, volume, and incident clearance time remain consistent in the period subsequent to the initial deployment and evaluation of the I-435 Corridor.

3.3 Integrated Corridor Management

3.3.1 **Introduction**

As ITS technologies continue to evolve, new strategies for operating our roadways continue to be researched and deployed. By focusing on ITS strategies that include freeways, arterials, transit, and transportation management centers, agencies can look beyond individual networks and explore regional corridors that may offer an opportunity to operate and optimize the entire system. The U.S. DOT has introduced the concept of Integrated Corridor Management (ICM), the purpose of which 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. ICM Deployment demonstrations in Dallas and San Diego have been implemented and evaluations are currently ongoing. Additional information on this initiative is available at the ITS JPO's Web site: www.its.dot.gov/icms.

ICM is defined as a collection of operational strategies and advanced technologies that allow transportation subsystems, managed by one or more transportation agencies, to operate in a coordinated and integrated manner [7]. With ICM, transportation professionals can manage the transportation corridor as a multimodal system rather than a fragmented network of individual assets.

Using a wide variety of operating scenarios, operating agencies can manage demand and capacity across multiple travel modes in real-time to improve mobility, reduce fuel consumption and emissions, and increase travel time reliability and predictability. Initial guidance and lessons learned have been made available on the ICM Website.

ICM Implementation Guide and Lessons Learned

ICM Analysis, Modeling and Simulation (AMS) Guide

3.3.2 **Benefits**

Transportation researchers have used Analysis, Modeling, and Simulation (AMS) methodologies to estimate the impacts of proposed ICM solutions. Projected benefit-cost ratios range from 10:1 to 25:1 over a 10 year period.

Table 3-5: Benefits of ICM.

Evaluation Measures	San Diego (2011-00736)	Dallas (2011-00757)	Minneapolis (2012-00804)	San Francisco (2009-00614)
Annual Travel Time Savings (Person-Hours)	246,000	740,000	132,000	1.2 million to 4.6 million
Improvement in Travel Time Reliability	10.6%	3%	4.4%	-
Gallons of Fuel Saved Annually	323,000	981,000	17,600	3.1 million to 4.6 million
Tons of Mobile Emissions Saved Annually	3,100	9,400	175	20,400 to 20,800
10-Year Net Benefit*	$104 million	$264 million	$82 million	$570 million
10-Year Cost	$12 million	$14 million	$4 million	$75 million
Benefit-cost Ratio	10:1	20:1	22:1	7:1 to 25:1

*The values of safety benefits were not included in the San Diego, Dallas, and Minneapolis estimates.

3.3.3 Costs

While the 10 year project cost estimate for a corridor-wide ICM solution can range from $4 million to $75 million, the cost of a traditional improvement such as lengthening commuter trains, expanding bus rapid transit (BRT), or building a new highway lane can be much higher ranging from $400 million to $1 billion over the same period [8]. ICM solutions are a better value over time compared to traditional improvements [9]. Cost estimates for ICM implementation are represented in Table 3-6.

The 10 year project cost estimate for a corridor-wide ICM solution can range from $4 million to $75 million.

Table 3-6: Cost Estimates for ICM Implementations.

Planned ICM Deployments	Estimated Costs
ICM Strategies deployed on U.S. 75 in Dallas, Texas (2011-00236)	$13.6 million with annualized costs of $1.62 million per year for 10 years.
ICM strategies implemented on the I-15 Corridor in San Diego, California (2011-00219)	$12 million with annualized costs of $1.42 million per year for 10 years.
ICM Strategies deployed in Minneapolis, Minnesota (2012-00270)	$3.96 million
ICM Strategies deployed on the I-880 Corridor in San Francisco, California (2009-00194)	$7.5 Million Average Annual Capital and O&M Costs

Consistent with the ITS National Architecture cost estimates can be derived from ITS costs data housed in the U.S. DOT ITS Knowledge Resources.Table 3-7 provides an example of a planning-level cost estimate developed for the I-880 corridor. Additional data sets are available in the ITS Costs Database.

Table 3-7: Combined ICM Strategies, I-880 Corridor Estimate (2009-00194).

ICM System Components (2008)	Life (Years)	Capital Cost	Annual O&M Cost	Annualized Lifecycle Costs	Amount	Total Annual Cost
Common Infrastructure						
Basic TMC and Facilities				$633,333		$633,333
TMC Hardware and Software for Surveillance	20	$150,000	$7,500	$15,000		$15,000
Loop Detectors Double Set (each 0.5 mile)				$3,350	120	$402,000
Systems Integration	5-20	$1,435,000	$14,000	$155,750		$155,750
Communications						
DS3 Communications (Surveillance)	20			$2,700	120	$324,000
DS3 Communications (Transit and Traveler Info)	20	$8,000	$96,000	$96,400		$96,400
DS1 Communications (ETC and Signals)	20	$750	$6,000	$6,638	280	$1,858,500
Arterial Signal Control						
TMC Hardware for Signal Control	5	$22,500	$2,000	$6,500		$6,500
Linked Signal System LAN	20	$55,000	$1,100	$3,850		$3,850
Signal Controller Upgrade (per intersection)		$6,250	$350	$663	160	$106,000
Labor for Arterial Management			$540,000	$540,000		$540,000
Ramp Metering						
Ramp Meter (Signal, Controller)	5	$40,000	$2,000	$10,000	90	$900,000
Loop Detectors (2)	5	$11,000	$4,500	$6,700	90	$603,000
Transit and Traveler Information						
TMC Hardware and Software for Info	5	$27,500	$1,375	$6,875		$6,875

ICM System Components (2008)	Life (Years)	Capital Cost	Annual O&M Cost	Annualized Lifecycle Costs	Amount	Total Annual Cost
Dissemination						
Labor for Traffic Information Dissemination			$100,000	$100,000		$100,000
Info Service Center Hardware and Software	20	$457,000	$21,525	$44,375		$44,375
Map Database Software	2	$22,500		$11,250		$11,250
Labor for Information Service Center			$225,000	$225,000		$225,000
Transit Center Hardware	10	$22,500		$2,250		$2,250
Labor for Transit Center			$150,000	$150,000		$150,000
Electronic Toll Collection (ETC)						
Electronic Toll Collection Structure	20	$30,000		$1,500		$1,500
Electronic Toll Collection Software	10	$20,000		$2,000		$2,000
Software for Dynamic Electronic Tolls	5	$55,000	$2,700	$13,700		$13,700
Electronic Toll Reader (each 0.5 mile)	10	$10,000	$1,000	$2,000	120	$240,000
High-Speed Camera (each 0.5 mile)	10			$4,000	120	$480,000
Labor for HOT Lanes Management			$540,000	$540,000		$540,000
					TOTAL	**$7,461,283**

3.3.4 **Lessons Learned**

The U.S. DOT continues to encourage regions to become early adopters of Integrated Corridor Management System (ICMS). To assist with successful planning and implementation, a series of lessons learned have been collected from the Pioneer Sites to help others successfully apply the concepts to their region [10].

Foster Champions and Organize Stakeholders when initiating an effort to consider ICM for a regional corridor (2014-00666)**.**

As a corridor is being considered for ICM, it is important that all agencies affecting the operation and maintenance of all networks are invited and participate in the planning of the ICM. The roles and level of involvement may differ, but to be most effective, the ICM Team should consider all transportation resources (those affecting supply and demand). This broad stakeholder list should include all of the agencies that are involved in transportation planning, operations, and management as well as groups that use the transportation system (e.g., fleet operators) or impact its operation (e.g., special event venue owner/operators).

The following are key lessons learned when initiating an effort to consider ICM for a regional corridor:

- **Include all potential stakeholders.** When initiating an effort to consider ICM for a regional corridor, look to include all potential stakeholders early in the process. Some agencies and organizations may choose not to participate, but all should be invited.
- **Encourage broad participation of stakeholders.** Let potential stakeholders decide what their involvement will be as the process moves forward, but encourage as broad participation as possible. Even if agencies or organizations choose not to participate at the start, keep them informed about the decisions being made. Initially reluctant partners can prove to be strong participants later on.
- **Involve executive leaders.** Involve executive leaders in facilitating the multi-agency partnerships vital to the long-term success of ICM. Their support is essential and it is particularly valuable if one (or more) of those executive leaders becomes a champion for ICM.
- **Obtain planner and modeler input early in the process.** Involve transportation planners and modelers, along with the transportation operations personnel, early in the process. Transportation planners and modelers can provide input into the performance measures selected and can help the team understand how best to track system performance against the established goals.

Plan for success of an ICM project by developing a knowledgeable and committed project team that can provide oversight, direction, and necessary reviews (2014-00667).

Developing and deploying an ICMS is not a trivial exercise. When establishing goals and objectives for developing a successful ICM project and planning for success, it is vital that the project team be knowledgeable and committed and that the managing agency be able to successfully assemble the team. Lessons to managing the team successfully include:

- **Confirm project responsibility, commitment and expertise.** ICM project teams need to be committed to the process, provide the correct project expertise (e.g., systems engineering, software and hardware design and integration, communications, etc.) take ownership of the work products, and see the work products through to successful completion. It is imperative that all stakeholders take responsibility for their part in the project and play an active role in providing successful outcomes. Key activities that can seem time-consuming but provide significant benefit later in the project include: the definition of the current corridor and system assets (both physical and data), identification of corridor needs, and the development of a common vocabulary among partners to describe existing systems and proposed capabilities.

- **Obtain buy-in from all stakeholders.** Before proceeding with the development of an ICMS, it is essential that the stakeholders be able to describe why the proposed system is needed and what the goals of the ICMS are.
- **Manage project procurements, costs, schedules, and risk to reduce the impact that multiple tasks have on a large project.** Multiple procurements from multiple agencies are a challenging endeavor. If, as a part of the ICM project, one of the stakeholder agencies slips schedule or misses requirements in selection and procurement, this can affect the project as a whole. Procuring systems prematurely (prior to defining the requirements) could significantly impact the cost and schedule of the project.
- **Develop an acronym and terminology list that includes common definitions.** When working with multiple agencies, it was found that terminology and acronyms can differ in definition. Developing an acronym and terminology list that includes common definitions improves coordination and communication.
- **Provide concrete project guidance.** Make sure project guidance is concrete so the contractor is not confused or getting mixed messages. There should be a unified message when providing guidance. Developing a Project Management Plan and documenting all stakeholder roles and responsibilities is essential for project success.

The remaining lessons from the ICM Implementation Guide are provided below:

- Develop a Systems Engineering Management Plan (SEMP) to achieve quality in project development and ultimately produce a successful ICMS (2014-00668).
- Develop a Concept of Operations to define the system that will be built (2014-00669).
- Develop a logical architecture as one key resource for describing what the Integrated Corridor Management System (ICMS) will do (2014-00670).
- Write well-formed requirements from the perspective of the system and not the system user that are concise and include data elements that are uniquely identifiable (2014-00671).
- Analyze individual design possibilities to determine which are feasible, which provide the best performance, and which would be the most cost effective methods of system implementation (2014-00672).
- Coordinate among stakeholders and schedule periodic team meetings to make sure that the correct and necessary information is provided for all development and implementation activities (2014-00673).

- Adequately train all operations and maintenance (O&M) personnel and conduct regularly scheduled team meetings to continually improve processes and procedures as the ICM system operations matures (2014-00674).
- Develop a list of factors and metrics to analyze system performance to determine when system replacement or retirement may become necessary (2014-00675).

3.3.5 **Case Study - Dallas North Tollway** (2013-00868)

In Dallas, Texas the concept of a real-time traffic network estimation and prediction tool with built-in decision support capabilities was tested as a potential solution to increasing congestion on the Dallas North Tollway. The system was designed to integrate a wide range of traffic control and traveler information strategies and provide traffic network managers with capabilities to estimate current network conditions, predict congestion dynamics, and generate efficient traffic management schemes to address recurrent and non-recurrent congestion.

As part of a feasibility assessment researchers used a large-scale dynamic traffic assignment (DTA) model with 400 links and 150 junctions to simulate traffic conditions on the Tollway and surrounding areas. A genetic algorithm was used to identify efficient traffic management schemes that could be incorporated into response plans and accepted by partnering agencies, and then several model runs were analyzed to estimate impacts across the network.

The following scenarios were modeled during evening rush periods with varied levels of congestion. Travelers were assumed to follow the most typical historical routes and no pre-trip or in-vehicle information was provided.

- Normal operation conditions (no incident).
- Travelers following historical routes experience incident delay on the freeway while the traffic management system is inactive.
- The traffic management system activated to manage the incident.

In all scenarios, response plans activated a dynamic message sign (DMS) located upstream from an incident on the Tollway, and signal timing changes were implemented at up to 30 intersections on parallel alternate routes. Calculated diversion rates ranged from 10 to 70 percent.

Findings

Simulation results indicated that network performance improved when response plans were implemented.

- Average travel time on the network decreased nine percent when the system was implemented and signal timing was adjusted at all 30 intersections.
- In scenarios where signal timing changes were limited to frontage roads, average travel time over the network decreased by only 3 percent.
- More spatial coverage for signal timing plans increased diversion route capacity and improved average network travel times.

Overall, the DTA model proved to be a valuable tool for modeling congestion dynamics on a large-scale urban transportation network. Evaluation work continues as researchers examine additional applications for real-time traffic management.

4 Roadway Operations and Maintenance

4.1 Work Zone Management

4.1.1 **Introduction**

ITS applications for operations and maintenance can improve planning for roadway maintenance, enhance safety, and facilitate traffic movement through and around construction work zones. Smart work zones, automated enforcement, traveler information systems, and operations planning tools are a few of the most widely deployed solutions. Evaluation data clearly show these technologies can improve performance; however, with limited budgets and growing demand that exceeds capacity in most metropolitan areas, transportation agencies have adopted new more practical measures to increase benefits and justify costs. Mitigation strategies have shifted from a capacity-oriented approach that relies on increasing capacity to reduce travel times, to a reliability-oriented approach focused on maintaining existing capacity while minimizing disruptions to improve travel time reliability. Using work zone ITS, agencies can better plan and actively manage work zones, increase driver awareness, and improve quality of service.

Both portable and permanent work zone ITS solutions are in use today. Portable Traffic Management Systems (PTMS) can be rapidly deployed to improve safety and mobility regardless of work zone location. Using queue sensors, dynamic message signs (DMS), video cameras, communication equipment, and other hardware and software components, these systems can automatically monitor traffic conditions and communicate with vehicles and drivers to improve situational awareness, harmonize traffic flow, and lessen the impacts of reduced capacity at work zones. More permanent solutions can be implemented for longer term projects or where ITS can be integrated into initial construction. Permanent work zone solutions are generally used as freeway or arterial management systems during time periods without construction activities. These systems often provide broader coverage and use traveler information networks such as 511 services, DMS systems, traffic detection networks, and agency websites to improve system operations, trip-planning and traveler behavior.

4.1.2 **Benefits**

Work zone ITS can have a wide range of benefits and costs. Benefit-cost ratios can exceed 2:1 depending on the work zone design and technologies used. Specific benefits include construction schedule compression; reductions in traffic volumes, vehicle speeds, queue lengths, and crashes; and fewer and shorter periods of congestion and unexpected delay. Additional benefits related to travel time reliability should become available as guidance on these measures is released through the Second Strategic Highway Research Program (SHRP 2) in 2014.

Figure 4-1 below highlights benefit ranges for several ITS work zone technologies based on entries in the ITS Knowledge Resource database at: http://www.itsknowledgeresources.its.dot.gov/. Benefits can be seen with many different measures across multiple goal areas including mobility, safety, and the environment. Dynamic Lane Merge Systems have demonstrated their ability to reduce the number of stops per vehicle, as well as the number of dangerous driving maneuvers at work zones. Variable speed limits and queue warning systems have shown promise in crash reduction. Automated enforcement systems have reduced speeding, and automated work zone information systems have reduced delays for trips that travel through work zones.

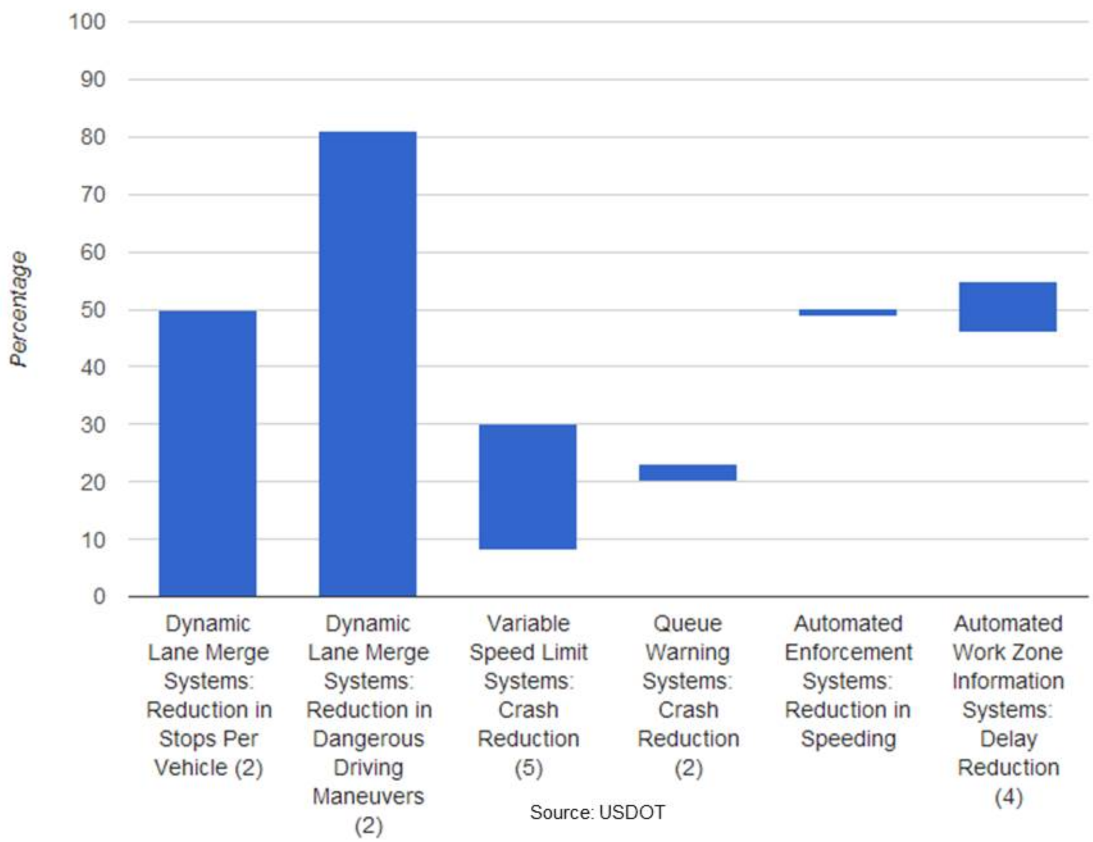


Figure 4-1: Work Zone ITS Benefits (Source: ITS Knowledge Resources).

Agencies under pressure to improve operations and reduce lifecycle maintenance costs can use ITS tools in conjunction with sound planning and asset management strategies to improve the efficiency of maintenance operations. In areas where work zones are required, modeling and analysis tools can be used to coordinate multiple work zone schedules, and design and test alternate work zone plans and mitigation strategies, including ITS applications where appropriate, before and during construction. In Detroit, for example, a large transportation network micro-simulation model was used to estimate the impacts of changing traffic patterns, coordinate work zone activities, and implement efficient work zone management plans during major freeway closures on I-75 during the Ambassador Bridge Gateway Project. Improved traffic management saved freeway users more than $1.63 million per day during reconstruction of the I-75/I-96 interchange (2013-00862).

4.1.3 **Costs**

Costs for ITS at work zones represent one to six percent of total construction costs depending on the size and duration of the project, temporary and permanent functions required, and if ITS components such as DMS units, traffic sensors, and portable cameras are purchased or leased. Overall, estimates vary widely ranging from $100,000 to $2.5 million, with the majority of systems costing $150,000 to $500,000 over the first year (2006-00109).

Table 4-1: System Costs for Smart Work Zones.

Smart Work Zone Location	Project Duration	System Cost	Percentage of Total Project Costs
In North Carolina, NCDOT leased a smart work zone system for a construction project on I-95 near Fayetteville. (2006-00106)	10 months (2002–2003)	$235,000	-
In Illinois, IDOT implemented work zone ITS on a 7.7 miles section of I-64. (2007-00126)	30 months (2005–2007)	$435,000	1%
In Illinois, IDOT leased a real-time work zone traffic control system for a major bridge and highway reconstruction project along a 40-mile section of I-55. (2006-00107)	16 months (2001–2002)	$785,000	2%
In Arkansas, contract bid estimates were provided for an automated work zone information system on a 6.3 mile section of I-40 in Lonoke County. (2004-00068)	12 months (2000–2001)	$322,500	-
In Arkansas, contract bid estimates were provided for an automated work zone information system on an 8.6 mile section of I-40 in Pulaski County. (2004-00068)	33 months (2001–2003)	$490,000	-
In Arkansas, the Arkansas State Highway and Transportation Department leased an automated work zone information system for a 3-mile section of I-40 in West Memphis. (2004-00072)	<18 months (2000-2002)	$495,000	<4%

4.1.4 **Lessons Learned**

Realize that ITS solutions are just one part of a successful work zone management plan.

ITS components can be instrumental in improving the safety of a work zone; however, it is not a cure all for eliminating travelers' exposure to hazards at work zones.

- Allow for sufficient start-up time when deploying an ITS application. Unanticipated issues may arise that will take time to address (2005-00061).
- Follow accepted guidelines to create concise, effective DMS messages to notify motorists of slow traffic and queuing ahead (2007-00336).
- Conduct outreach and permit drivers to become comfortable with new work zones by allowing an adjustment period (2005-00041).

4.1.5 **Case Study - SafeTrip 21 Initiative**

Through the SafeTrip-21 initiative, federal and state agencies collaborated to test and evaluate a variety of technologies designed to reduce congestion, improve efficiency, and enhance safety on the nation's roadways. Findings from two case studies that evaluated work zone applications are highlighted below.

I-95 Corridor Coalition Test Bed, Final Evaluation Report: North Carolina Deployment of Portable Traffic-Monitoring Devices

The North Carolina DOT tested the use of portable traffic-monitoring devices (PTMDs) and the U.S. DOT conducted interviews with agency staff to evaluate their experience (2013-00860). The following benefits were cited:

- **Accurate speed counts.** PTMDs resembled traditional work zone drums to mitigate data skewing that can occur when traffic-monitoring devices are more visible to drivers. The data reported were confirmed by on-site.
- **Ease of installation and operation.** Devices were battery powered, equipped with wireless communications, and designed to easily replace traditional work zone drums. Data were accessible using a web-based interface.
- **Data warehousing capability.** In addition to providing real-time data, the web-based system was designed to archive data for up to five years, giving NCDOT staff the flexibility to analyze historical data.
- **Safety benefits.** PTMDs allowed personnel to collect traffic volume data without requiring them to work in the travel lane, reducing the potential for injuries.
- **Staff Productivity.** Staff could monitor sites remotely and limit site visits, saving staff time.

Experience with Prototype Testing on San Francisco Freeways

In San Francisco, recent studies suggest that vehicle-infrastructure (V2I) applications can further improve benefits achieved through work zone ITS. A field study of 24 vehicles equipped with in-vehicle traveler information systems designed to provide auditory alerts of "slow traffic ahead" effectively smoothed the driving profiles of drivers approaching end-of-queue traffic on a congested freeway (2013-00823). These data agree with previous research in Minneapolis where portable traffic management systems were found to reduce speed variability by 70 percent and slow speeds of approaching vehicles by 9 mph (2007-00411). Considering evidence that suggests an 8.4 percent increase in crash risk for each 1 mph increase in the standard deviation in speed, variable speed limit (VSL) systems that produce smoother driving profiles may have significant safety benefits [11]. The information provided to drivers, however, must be accurate, reliable, and delivered at the right time. Studies show that when drivers are directed to change speeds at 2-minute intervals, crash potential increases; however, when recommendations are made at 5- or 10-minute intervals, crash potential is reduced [12].

5 Crash Prevention and Safety

5.1 Introduction

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. After six consecutive years of declining motor vehicle crashes and fatalities on the Nation's roadways, 2012 showed an increase in fatality and injury rates of 3.6 percent and 6.7 percent respectively [13]. Additionally, in 2012 there were 4,743 pedestrian fatalities and 726 pedal cyclists fatalities accounting for over 16 percent of all traffic fatalities and an increase of approximately 6.5 percent over 2011 [13].


Source: U.S.DOT

Crash prevention and safety systems detect unsafe conditions and provide warnings to travelers to take action to avoid crashes. These systems provide alerts for traffic approaching dangerous curves, off ramps, restricted overpasses, highway-rail crossings, high-volume intersections, work zones, adverse weather conditions, and also provide warnings of the presence of pedestrians, bicyclists, and even animals on the roadway. Crash prevention and safety systems typically employ sensors to monitor the speed and characteristics of approaching vehicles and frequently also include environmental sensors to monitor roadway conditions and visibility. These systems may be either permanent or temporary. Some systems provide a general warning of the recommended speed for prevailing roadway conditions. Other systems provide a specific warning by taking into account the particular vehicles characteristics (truck or car) and a calculation of the recommended speed for the particular vehicle based on conditions. In some cases, manual systems are employed, where pedestrians or bicyclists manually set the system to provide warnings of their presence to travelers; however these systems are being replaced with automated systems with the increasing implementation of connected vehicle technologies. With the introduction of connected vehicle safety applications, crash prevention and safety systems are also moving from passive driver warning systems, to active driver assistance systems where the vehicle can automatically react to other vehicles or road sensors during hazardous conditions.

Intersection Collision Warning Systems: Intersection collision warning systems use sensors to monitor traffic approaching dangerous intersections and warn vehicles of approaching cross traffic, using roadside infrastructure, in-vehicle systems, or some combination of the two. The newer approaches to intersection collision warning systems provide information to drivers on proper maneuvers (gap acceptance assistance) and warn drivers of right-of-way violations at intersections. The warnings may include the driver's vehicle violating traffic control signs or signals or of another vehicle violating, or about to violate, the subject vehicle's right-of-way. Specific examples are provided below:

- Left Turn Assist: Warnings given to driver via an in-vehicle system when trying to make a left turn that may be visually blocked by another car or object. Warnings can alert the driver that a left turn should not be attempted.

- Traffic Control Violation Warning: Warnings given to drivers via in-vehicle systems if it is determined the driver may violate a red light or other traffic control device.
- Stop Sign Gap Assist: Information provided to drivers while stopped at a stop sign where only the minor road has stop signs. The driver receives information of any danger to the vehicle proceeding through the intersection from vehicles approaching on the cross street.

Collision Avoidance Systems: To improve the ability of drivers to avoid accidents, vehicle-mounted collision warning systems (CWS) continue to be tested and deployed. These applications use a variety of sensors to monitor the vehicles surroundings and alert the driver of conditions that could lead to a collision. Examples include forward collision warning, obstacle detection systems, rear impact collision warning, “do not pass” warnings, and road departure warning systems.

Collision Notification: In an effort to improve response times and save lives, collision notification systems have been designed to 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 with automatic collision notification (ACN), and advanced systems may transmit information on the type of crash, number of passengers, and the likelihood of injuries.

5.2 Benefits

Crash Prevention and Safety strategies include collision avoidance systems and systems that warn drivers of potential road hazards. These systems have demonstrated success in detecting potential conflicts and warning motorists of crash potential. Evaluations of these systems find reduction in road crashes, injuries and fatalities as summarized in Table 5-1.

Table 5-1: Selected Benefits for Crash Prevention and Safety Strategies.

Categories	Selected Findings
Collision Avoidance	A Korean study finds that Automatic Crash Information Notification Systems would reduce freeway fatalities by 11.8 to 18.1 percent. (2013-00864)
Collision Avoidance	Electronic Stability Control (ESC) systems can reduce the risk of fatal crashes by 33 percent. (2013-00861)
Collision Avoidance for Trucks	Forward collision warning systems have potential to prevent 23.8 percent of crashes involving large trucks. (2012-00811)
Collision Avoidance for Transit Vehicles	The camera-based system with a regular angle lens reduced 43 percent of blind zones, and wide-angle camera systems were able to entirely eliminate blind zones. (2013-00853)
Pedestrian Safety	In Tucson, Arizona, installation of High-Intensity Activated Crosswalk (HAWK) pedestrian beacons showed 69 percent reduction in crashes involving pedestrians. (2013-00848)

Animal Detection System	In Montana, an animal detection system with the warning lights activated resulted in 1.52 mi/h lower vehicle speeds (compared to warning lights off) for passenger cars and pick-ups. (2012-00752)

In-vehicle active and passive safety technologies have also shown to provide significant benefits to road users. The most significant findings are that in-vehicle technologies, including automated braking systems, have the ability to significantly reduce the injury and fatalities due to collisions. Table 5-2 highlights some of these findings.

Table 5-2: Selected Benefits for In-vehicle Safety Technologies.

Categories	Selected Findings
Automated Braking System	In 2011, NHTSA evaluated an Advanced Collision Mitigation Braking System (A-CMBS) designed with forward sensing radar, an on-board electronic control unit, and sensors to monitor vehicle speed, brake pressure, steering angle, and yaw to predict and warn drivers of impending collisions, and automatically implement countermeasures to avoid or mitigate collisions. The report found that light vehicles that automatically activate in-vehicle alerts, seat belt tensioners, and braking systems can reduce fatalities by 3.7 percent. (2013-00833)
Automated Braking System	In-vehicle technologies that use automated braking to prevent rear-end collisions can reduce drivers injured by 19 to 57 percent. (2013-00832)
Automated Braking System	Advanced emergency braking systems in passenger vehicles have potential benefit-cost ratios ranging from 0.07 to 2.78. (2012-00815)
In-vehicle Safety System	A literature review of in-vehicle safety systems in the United States and New South Wales, Australia found that active and passive in-vehicle safety technologies are expected to decrease fatalities up to 16 percent. (2013-00827)

Figure 5-1 shows ranges of benefits for select entries in the ITS Knowledge Resource database at: http://www.itsknowledgeresources.its.dot.gov/. Benefits of collision notification and avoidance system include reduction in fatalities and injury to drivers.

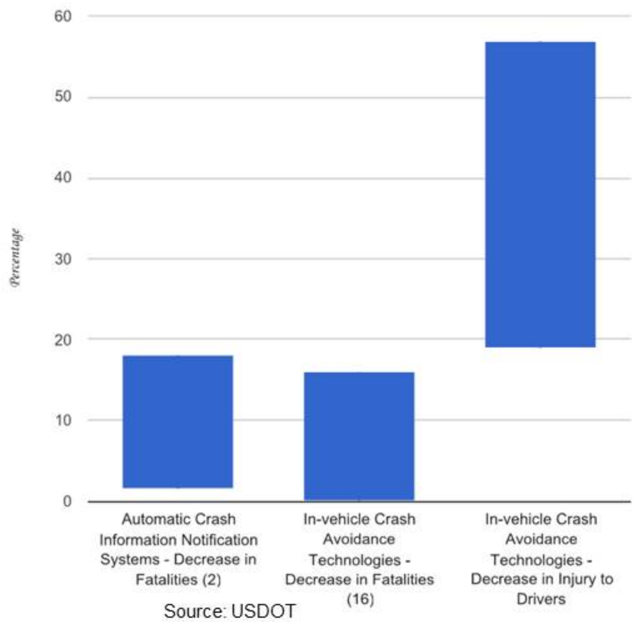


Figure 5-1: Range of Benefits for Crash Avoidance Technologies (Source: ITS Knowledge Resources).

Several crash warning systems have also shown significant benefits in reducing overall number of crashes**.** Figure 5-2 shows the ranges of these benefits.

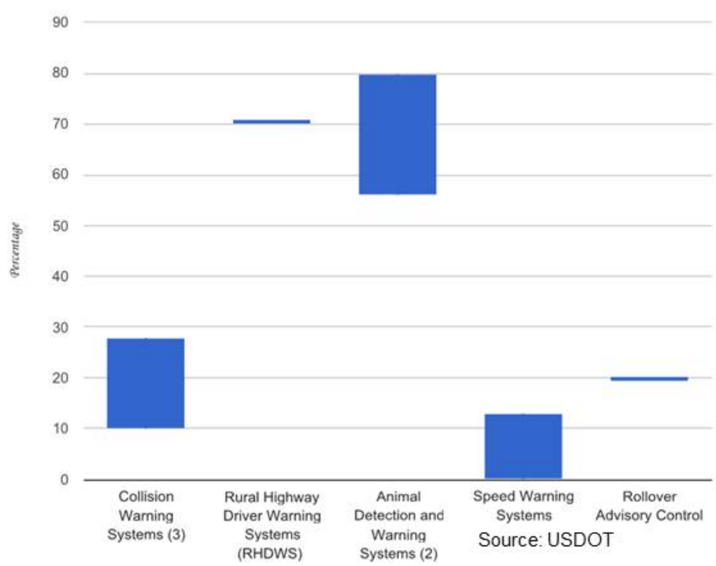


Figure 5-2: Range of Crash Reduction Benefits from Collision Warning Systems (Source: ITS Knowledge Resources).

As connected vehicle technologies are just now being developed and tested, few evaluations are available. However, driver acceptance clinics were conducted at six different cities in the United States to assess how motorists respond to connected vehicle technologies and benefit from in-vehicle alerts and warnings. The preliminary findings showed that 91 percent of volunteer drivers that tested vehicle-to-vehicle (V2V) communications safety features indicated they would like to have these technologies on their personal vehicle (2012-00785).

Additionally, a European study evaluated the potential benefits and costs of V2V and vehicle-to-infrastructure (V2I) technologies. This study concluded that V2V applications can have positive benefit-cost ratios at fleet penetration rates above 6.1 percent, whereas V2I technologies require a greater market share (2013-00842).

5.3 Costs

The ITS Knowledge Resources database provides a variety of system costs for crash prevention and safety strategies that range from individual in-vehicle collision avoidance systems to estimates of nationwide implementations of connected vehicle environments.

The database includes several recent cost estimates for in-vehicle collision avoidance systems shown in Table 5-3. Delphi study techniques, using independent estimates from multiple industry experts and multiple rounds to achieve consensus, were used to forecast the estimated costs for future years.

Table 5-3: System Costs for Crash Prevention Systems.

In-vehicle collision avoidance systems	Year	System Costs
Advanced Emergency Brake System in the UK (2012-00275)	2011	$334 - $1,337
Side collision warning system (Blind Spot Warning) (2013-00287)	2010	$760 to $2,000
Advanced Emergency Brake Systems with pedestrian detection in the UK (2012-00275)	2009	$1,499 - $2,249
Lane Departure Warning Systems in the UK (2012-00275)	2009	$457 - $750
Cost to Vehicle Manufacturers for Embedded On-board DSRC equipment (2013-00288)	2017	$175
Cost to Vehicle Manufacturers for Embedded On-board DSRC equipment (2013-00288)	2022	$75
Cost Added to Base Vehicle Price for DSRC equipment (2013-00288)	2017	$350
Cost Added to Base Vehicle Price for DSRC equipment (2013-00288)	2022	$300
Aftermarket DSRC equipment (2013-00288)	2017	$200
Aftermarket DSRC equipment (2013-00288)	2022	$75

5.4 Lessons Learned

The ITS Knowledge Resources database identifies several lessons learned from crash prevention strategies. A national evaluation of ITS applications presents new approaches to address distracted driving when designing and developing ITS applications (2013-00651).

- **Communicate alerts designed to orient drivers to general traffic conditions ahead, and therefore, make them more attentive to the driving environment to help reduce driver distraction.**
- **Use "geofencing" as an approach to limiting driver distraction.** The geofencing technique attempts to determine which mode the traveler is using in order to allow transit users to continue to receive updates while on the move while preventing them from using the information while driving. It was demonstrated that it is feasible to determine whether a smart phone user is traveling on a transit vehicle versus in a vehicle on a road. Therefore it is possible to provide travel information to smart phone users while minimizing the risk of causing distracted driving.
- **Continue to explore avenues for advancements in technology to prevent driver distraction as well as instilling a safety culture mindset to support the goal of a change in driver behavior.** As in-vehicle technology continues to develop, supporting safe driving habits will continue to be a challenge.

5.5 Case Study - Wisconsin DOT's Rural Intersection Collision Avoidance System (RICAS)

Rural environments often present very specific challenges and priorities from a transportation safety perspective. The Rural Safety Innovation Program (RSIP) was created as a procurement opportunity in 2008 with the goal of improving rural road safety by providing rural communities the opportunity to compete for grant funding to address pressing highway safety problems using innovative approaches and through application of ITS technologies. The program allowed rural communities to develop data driven, creative, locally crafted solutions to their roadway safety problems, document their efforts and outcomes, and share the results with other communities across the country.

One of the 21 projects selected for RSIP funding was a Wisconsin project with a high crash rate and safety problem at a rural thru-stop intersection. The primary project goal in Wisconsin was to demonstrate technology that improves the safety of rural thru-stop intersections by providing drivers information that promotes safer gap selection (i.e., intersection crossing). Improper gap selection is the primary factor in rural thru-stop intersection crashes.

This project implemented and demonstrated a Rural Intersection Collision Avoidance System (RICAS) at the intersection of U.S. 53 and State Trunk Highway (STH) 77 just west of Minong, WI. This novel intersection collision avoidance system used emerging sensing, computation and display technology to provide real-time warnings to drivers before the conditions which lead to a serious crash can develop. Real-time information regarding mainline traffic was provided to side street drivers through the use of large display boards that graphically indicate vehicle locations. In total, there were four display boards. For each of the side street approaches, one is positioned for drivers at the first stop bar and the other is positioned for drivers at the median (internal) stop bar.

The RICAS system was developed during 2009 and 2010 and was deployed in the field in April 2010. Data collection started immediately following testing and continued through April 2011. This data collection included gap selection data through recruitment of 50 drivers to have their vehicles instrumented with RFID (radio-frequency identification) tags. RFID readers at the intersection monitored the drivers' gap selection behavior before the system went live (approximately 1-month worth of data) to obtain some baseline data as well as after deployment data [14].

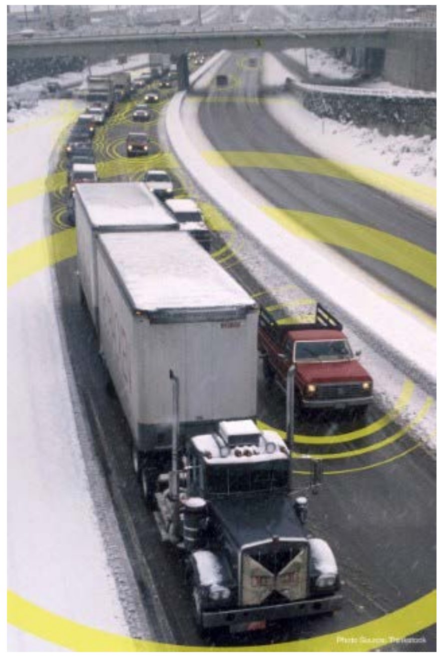
The project evaluator gathered feedback about the system performance and driver perception of the RICAS through user surveys (two sets), interviews, focus groups, crash report analysis, review of traffic video, and RFID tracking of residents traveling through the intersection.

The evaluation findings were mixed. Survey results indicated that over 55 percent of respondents believed the signs to be "very accurate and very reliable" and over 30 percent believed the signs to be "accurate and usually reliable." In addition, most respondents believed the signs were effective at reducing accidents. Signs appear to be more beneficial during the night and adverse weather conditions, when visibility affects a driver's ability to see oncoming traffic. However, several concerns were surfaced through the evaluation effort. For example, the technology and sign placement seemed to cause confusion with many motorists, and no detectable change in gap acceptance behavior was indicated. Given the other conditions the intersection, evaluators reported that too much information was presented to motorists for them to effectively process and make decisions. Some technical issues also caused confusion, such as turning vehicles not triggering the sign. Although several crashes could potentially have been prevented through proper application of the information presented in the signs, analysis of the data indicates that crashes were not reduced following installation of equipment [15].

In the future, connected vehicle technologies may be able to augment or replace the reliance on an infrastructure-based physical sign solution. From a technical perspective, the use of DSRC and in-vehicle displays or other audible or tactile cues should be able to address many of the issues that were raised by respondents. Research continues in this area.

6 Road Weather Management

6.1 Introduction



An investigation of vehicle crashes from 1995 through 2008 shows that 24 percent of all crashes occur under adverse weather conditions, resulting in more than 673,000 people injured and 7,100 fatalities [16]. 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 [17], [18]. 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 [19]. 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 [18].

In spite of these statistics, there is a perception that transportation managers can do little about weather. However, three types of mitigation measures may be employed in response to environmental threats: advisory, control, and treatment strategies. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity.

Treatment strategies supply resources to roadways to minimize or eliminate weather impacts. Many treatment strategies involve coordination of traffic, maintenance, and emergency management agencies. These road weather management strategies are employed in response to various weather threats including fog, high winds, snow, rain, ice, flooding, tornadoes, hurricanes, and avalanches.

The ITS Knowledge Resources is a great place to find information about the state of the art and the adoption of effective technologies by the Road Weather Management (RWM) industry and its customers. This information includes private, public, and network-based benefits, costs and lessons learned to help those considering implementation of advanced RWM systems. The following information provides a sampling of the road weather management evaluation data available in the ITS Knowledge Resources.

6.3 Benefits

Rear-end conflicts are projected to be the most eliminated conflict type by a weather-responsive traffic signal systems with a potential average reduction of approximately 22 percent for moderate volume levels and 43 percent for high volume levels.

High-quality road weather information benefits travelers, commercial vehicle operators, emergency responders, and agencies. Road Weather Information Systems (RWIS) are now a critical component of many agencies' winter maintenance programs. Information dissemination such as automated wind warnings have proven successful. Traffic control technologies that enable agencies to reduce speed limits with variable speed limit (VSL) signs and modify traffic signal timing based on pavement conditions are starting to show results. For example, a Speed Management System for winter maintenance resulted in zero (100 percent reduction) winter weather related accidents in one section of highway in Snowmass Canyon, Colorado (2014-00894). 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. Winter maintenance vehicles can be equipped with automatic vehicle location (AVL) systems and mobile sensors to monitor pavement conditions and optimize treatment application rates. A sampling of the benefit cost ratios reported from these strategies is shown in Table 6-1 below.

Table 6-1: Benefit-cost Ratios of Road Weather Management Strategies.

Benefit-cost Ratio	Description	Application
4.13 to 22.80	In Oregon, the benefit-cost ratios for two automated wind warning systems were 4.13:1 and 22.80:1. (2008-00529)	Automated Wind Warning System (AWWS)
2.6 to 24.0	A survey of state and local transportation agencies found that AVL applications for highway maintenance can have benefit-cost ratios ranging from 2.6:1 to 24:1 or higher. (2008-00536)	Automatic Vehicle Locator
1.33 to 8.87	Maintenance Decision Support System (MDSS) use shows benefit-cost ratios ranging from 1.33 to 8.67. (2011-00668)	Maintenance Decision Support System (MDSS)
1.34	A Maintenance Decision Support System (MDSS) in Denver Colorado helped reduce maintenance operations labor hours, and had a benefit-cost ratio of 1.34. (2010-00654)	MDSS
2.8 to 7.0	Rural Road Weather Information System deployments show estimated benefit-cost ratios of 2.8 to 7.0. (2011-00685)	Road Weather Information System (RWIS)

1.8 to 36.7	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. (2011-00693)	RWIS
11.0	Utah DOT's Weather Operations/RWIS program provides a benefit-cost ratio of 11:1 from reduction in winter maintenance costs. (2011-00691)	RWIS
1.1 to 1.9	In Finland, a benefit-cost analysis supported the deployment of weather information controlled variable speed limits on highly trafficked road segments. (2008-00528)	Weather controlled Variable Speed Limit (VSL)

Integrating Clarus Data in Traffic Signal System Operation

An example of using weather data to improve traffic operations is the survivable weather-responsive traffic signal system developed as part of a project to integrate Clarus data into traffic signal system operations. The potential crash reduction benefits, expressed as the percent reduction in total, rear-end, and crossing conflicts, were shown to be highest during snowy and icy weather conditions. The potential crash reduction benefits were shown to continue to increase as the traffic volume level increases. Rear-end conflicts are the conflict type projected to be most eliminated by a weather-responsive traffic signal system with a potential average reduction of approximately 22 percent for moderate volume levels and 43 percent for high volume levels. The weather-responsive signal timing plans also show considerable potential in reducing traffic delays and stops. Again, the percent reduction increases as the traffic volume level increases. The potential reduction in delays and stops seems consistent with what has been reported in the literature.

Several studies have investigated the effect of inclement weather on various signal timing traffic parameters. Studies have shown that weather-responsive signal timing plans can improve both the safety and efficiency of the traffic signal system operations. Simulation studies revealed benefits of approximately 7 percent to 23 percent reduction in average delay, 4 percent to 9 percent reduction in vehicle stops, and 3 percent to 12 percent increase in average speeds (2013-00889).

6.4 Costs

An October 2012 report published by U.S. DOT's Office of Operations provided results of research conducted to better understand the use of mobile data for Weather-Responsive Traffic Management (WRTM) Models and information needed to support those models. The study found that vehicle trajectory data serves best for the purpose of improving WRTM models.

Weather events have a significant role in traffic operations, road safety and in travel time reliability. This research demonstrates how mobile data can enhance the flexibility and performance of traffic models that are used to evaluate WRTM strategies. A lot of research has already been completed in this area, so the goal of this project was not to add to that research, but rather to evaluate the available mobile data and its applicability to existing WRTM models.

As part of this research a compilation of costs and associated parameters of mobile data used for WRTM by various public agencies was presented, see Table 6-2. These costs provide public agencies with some perspective on procuring the types of private sector data they need for WRTM systems (2013-00294).

Table 6-2: Public Agency Consumers of Private Sector Data.

	Wisconsin DOT	Houston-Galveston Area Council	Michigan DOT	Texas DOT (d)	Phoenix MPO (MAG)
Status	Request for Information	Purchased	Purchased	Purchased	Purchased
Service Purchased (a)	H	H	H	H	H
Aggregation Level	Hourly day-of-week averages	15 min	5 min	Hourly day-of-week averages	Weekday
Data Purchased (b)	S/TT, PM	S/TT	S/TT	S/TT, PM	PM
Applications (c)	PM, TM	PM, TM, OD	PM	PM	PM
Coverage	All arterials	Houston region	MI Freeways	Statewide TMC network	Region
Timeframe	1-2 years	1 year	5 years	2009	1 year
Validation Criteria (d)	Not yet established	Not yet established	Avail. >99.5% Acc. less than +/- 10mph	None	Not yet established
Validation Techniques	N/A	N/A	Probe, fixed point, re-id	None	Probe, fixed point
Pricing (in thousands)	$80,000(Est.)	$77,000	$200,000 per year	$28,000	negotiating
Licensing	Multiple Use	Multiple Use	Single Use	Single Use	Multiple Use
Multi-Agency	Yes				Yes

NOTES:
(a) Service Purchased: “H”=Historical, “RT”=Real-time
(b) Data Purchased: “S/TT”=Speed or Travel Time”, “PM”=Performance Measures

(c) Applications: “PM”-Performance or Congestion Monitoring, “TM”=Traffic Model Validation or Calibration, “OD”=Origin-Destination Studies
(d) Validation Criteria: "Avail." - Availability, "Acc." - Accuracy
(d) See http://apps.dot.state.tx.us/apps/rider56/list.htm for published study results

6.5 Lessons Learned

Weather Information Integration in Transportation Management Center (TMC) Operations (2011-00586)

A January 2011 U.S. DOT report titled, *Weather Information Integration in Transportation Management Center (TMC) Operations*, captured the experience from four Transportation Management Centers' (Colorado Springs; Colorado; Cheyenne; Wyoming; Kansas City; Missouri; Shreveport; Louisiana) efforts to identify and implement strategies to meet their weather integration needs. The weather integration plans that were prepared served to guide each TMC's future integration plans but also offer clear examples for the benefit of weather integration for other TMCs. Each TMC established new partnerships, both internal and external, to their agency that served to enhance their overall operations, provide benefit to the traveling public, and chart a pathway to improved relationships in the future. In particular, stronger relationships were established with maintenance counterparts to encourage active sharing of weather information. Awareness was raised at all levels of the DOT organizations involved to understand the potential value of weather information to enhance the quality and content of traffic operations information.

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

- **Use the self-evaluation and integration planning process to increase awareness of the value of weather integration**, while understanding that TMC managers and staff may require considerable assistance in moving forward to incorporate new ways to integrate 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 more 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.

The experience of the evaluators shows that integrating weather information into TMC operations can positively impact the U.S. DOT's goals of productivity and improved mobility. However, TMC staff must be proactive in promoting the value of weather integration, recognizing that new policies and procedures must be put in place to effectively use weather information and when engaging their operations and maintenance counterparts in the initiative to achieve these goals.

7 Transit Management

7.1 Operations and Fleet Management

7.1.1 Introduction

In 2011, the public transportation industry in the United States provided 4.8 billion revenue miles of service, including 3.7 billion traveled on roadways. The roadway services carried 5.6 billion passenger trips and collected $6.1 billion in fares. Rail systems carried 4.6 billion passenger trips and collected $7.3 billion in fares [20].

By 2010, over half of the fixed-route buses in the United States had Automatic Vehicle Location (AVL) systems installed.

The utilization of ITS for improving operations and fleet management in the transit industry has become widespread. Automated vehicle location (AVL), computer-aided dispatching (CAD), and transit signal priority (TSP) are all mature technologies. By 2010, over half of the fixed-route buses in the United States had AVL systems installed [21]. AVL data now provides the input into real-time traveler information systems and archived AVL data are inputs into the service planning and scheduling processes. The use of CAD and scheduling software have improved efficiency and reliability for both fixed-route and paratransit service. These tools have also improved the ability for transit agencies to coordinate their services. TSP is gaining in popularity as cities begin to recognize that improved bus service can encourage mode shift away from personal vehicles to transit, without large negative impacts to traffic traveling in the cross direction of bus routes with TSP.

Deploying ITS technologies for transit operations and fleet management can help improve service reliability; decrease running time; reduce bus delays at intersections, missed trips, and emissions; and allow for increased service without additional staff or vehicles.

7.1.2 Benefits

A comprehensive Transit Cooperative Research Program (TCRP) report from 2010 on TSP provides a set of benefit ranges that may be experienced by an agency deploying TSP based on case studies from a few dozen cities. Transit travel time savings experienced were between 2 and 18 percent, with Los Angeles and Chicago seeing 7.5 and 15 percent decreases, respectively. Decrease in bus delay is heavily dependent on the priority guidelines set by the agencies, and thus has a wider range experienced by the cities examined for the report. Overall, agencies indicated that bus delay was reduced between 15 and 80 percent. Los Angeles had a 35 percent decrease in bus delay at intersections, while Oakland had a decrease of 5 seconds per intersection (2013-00847).

Similar results in transit travel time savings were also experienced on Staten Island in New York, where signal priority along a 2.3 mile corridor led to 17 percent transit travel time savings (2013-00856). As part of a pilot test in Minneapolis, Minnesota, the University of Minnesota demonstrated a new TSP algorithm that lead to travel time savings of between 2.6 and 6.4 percent (2012-00814). Figure 7-1 shows ranges of benefits for select entries in the ITS Knowledge Resource database.

Benefits of TSP systems include travel time savings, reduced delay for buses at intersections, and reduced emissions.

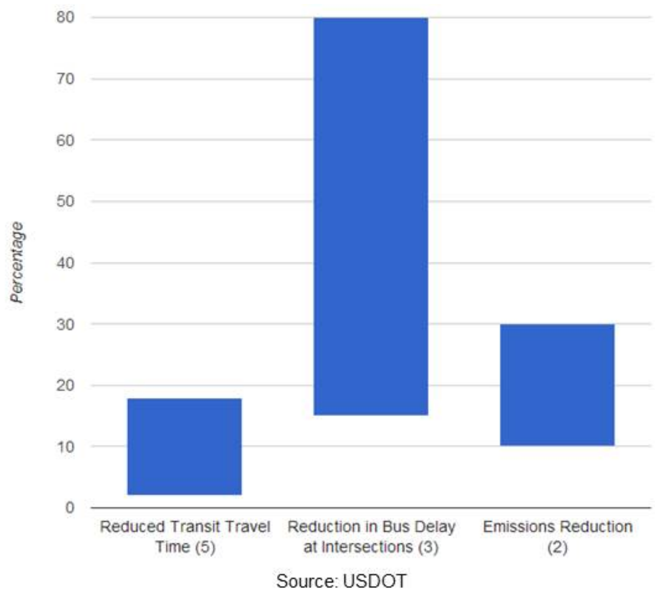


Figure 7-1: Benefits of Transit Signal Priority Systems (Source: ITS Knowledge Resources).

The use of scheduling software to support transit operations can save multiple weeks' worth of labor for service planners. In Chattanooga, the switch from manual run-cutting to using software to generate multiple run-cutting scenarios that are compared by the service planners saves two weeks of labor for each of their semi-annual service revisions. The software can also generate the new materials needed for passenger information, such as schedule leaflets, saving even more staff time (2011-00713).

Switching from manual run-cutting to using scheduling software that provides multiple run-cutting options can save up to 4 weeks of staff labor per year.

The maintenance department of a north central Pennsylvania demand-response service provider attributes a 69 percent decrease in in-service breakdowns to using mobile data terminals (MDTs) for pre-trip inspections by drivers that are uploaded daily, instead of a two-week lag with paper inspection logs (2011-00710). Washoe County Transportation experienced a 50 percent reduction in missed trips due to mechanical problems.

7.1.3 **Costs**

The cost of deploying an AVL system for a vehicle fleet ranges from $10,000 to $20,000 per vehicle (2009-00190). Cellular or radio communications costs also need to be considered when deploying AVL systems because it is used for location "polling". TSP emitter costs can range from $50 to $2,500 per vehicle, with TSP detectors ranging from $2,500 to $40,000 depending on whether or not the existing signal controller is new enough to have TSP added or if new signal controllers need to be installed (2013-00286, 2008-00155).

Costs for scheduling and run cutting software vary widely by vendor, system size and types of transit services the agency provides.

7.1.4 **Lessons Learned**

The transit industry tends to deploy customized solutions to meet each specific agency's needs. However, there are many lessons learned from other projects that can be generally applicable to the development and deployment of transit information dissemination systems. Below is a sample of lessons learned:

- **Allow one agency to be in charge of the procurement process when implementing ITS technologies designed to coordinate services between urban and rural transit systems.** Having a lead agency in the procurement process can ensure consistency in purchases and delivery of products and services (2012-00637).
- **Specify in the procurement solicitation that the AVL supplier use the transit operator's preferred base maps.** Accurate and complete base maps are critical. An AVL supplier must demonstrate that an AVL system can accept frequent map updates easily (2012-00637).

7.1.5 **Case Study - Mobility Services for All-Americans (MSAA) Coordination Simulation Study**

The concept that coordinating demand-response services across agencies and funding sources results in better and more efficient services is widely accepted. However, quantitative analysis on the benefits of coordination was lacking. This study simulated three levels of coordination using actual trip data from two rural demand-response transit agencies in North Carolina and South Carolina (2013-00888). The authors utilized the funding sources to categorize trips into three groups: Medicaid, aging-related (Aging), and other.

The simulation tested three coordination scenarios: Some Coordination, More Coordination and Full Coordination. Some Coordination only coordinates trips within each of the three funding categories. Passengers with trips classified as "Aging" can only ride on vehicles assigned to the Aging group and with other Aging passengers. Passengers in the Medicaid and Other groups are assigned with similar restrictions. More Coordination simulates the effect of a Medicaid brokerage model, where Medicaid trips are scheduled separately from all other trips (Aging and Other trips and vehicles are combined). Full Coordination allows any trip from any funding category to be scheduled on any available vehicle.

The analysis used scheduling software to automatically optimize scheduling of trips. The results show a reduction in both total revenue distance and total revenue hours ranging from 7 to 13 percent when comparing the Some Coordination scenario to the Full Coordination scenario. Additionally, the average number of passengers served per revenue hour increased by approximately 10 percent. These efficiencies gained from greater coordination of trips would allow the agencies to serve a greater number of passengers without needing to increase their staff or number of vehicles.

7.3 Information Dissemination

The cost to implement a multimodal trip planner can range from $138,000 to more than $4 million, depending on the need to develop custom software and consolidate data feeds.

7.3.1 Introduction

In 2011, the public transportation industry in the United States provided 4.8 billion revenue miles of service, including 3.7 billion traveled on roadways. The roadway services carried 5.6 billion passenger trips and collected $6.1 billion in fares. Rail systems carried 4.6 billion passenger trips and collected $7.3 billion in fares [20].

The proliferation of mobile devices and real-time information have led to a shift over the past several years in the way transit agencies disseminate traveler information to their existing (and potential) passengers. Increased adoption of the General Transit Feed Specification (GTFS) by transit agencies has led to the development of transit traveler information mobile applications by third party developers in many cities, not just by the transit agencies themselves. Transit agencies continue to develop their own trip planning tools that are hosted on their agency webpages, but these trip planners only typically cover walking and transit directions. Map tools, such as Bing Maps and Google Maps, allow for a comparison between walking, transit and driving modes, but are still largely single-modal in nature.

Initiatives such as the U.S. DOT's Integrated Corridor Management (ICM) program seek to remove the modal silos and provide multimodal traveler information en-route in addition to pre-trip information as travel conditions change.

7.3.2 Benefits

Increasing the pool of potential customers can be seen as a major benefit of improved information dissemination by the transit industry. The use of mobile trip information allows both visitors and infrequent system users to feel more confident in their ability to navigate that city's transit systems, as well as expose individuals to transit options they may not have previously been aware of.

In the Chicago metro area, a Multimodal Trip Planning System (MMTPS) was developed by the Regional Transit Authority (RTA) and made available to the public. Surveys found that the MMTPS increased user knowledge of the transit system. Nearly 40 percent of all respondents and 50 percent of suburban respondents reported using at least one transit service that they did not normally use (2012-00794).

As can be seen in Figure 7-2, the use of traveler information tools such as trip planners and station parking information encourages individuals who have never tried transit options to take them at least once and encourages existing riders to use the transit system more frequently.

Providing passengers with real-time arrival information has also improved customer satisfaction with system performance. A survey of users of London's Countdown system (wayside real-time arrival information for buses) demonstrated that despite a decrease in on-time arrivals, 64 percent of customers perceived that on-time performance had improved after the installation of the system. Perceived waiting times also decreased from nearly 12 minutes to less than 9 minutes. This customer satisfaction is largely attributed to high system availability, as well as more than 75 percent of posted arrival times being accurate within two minutes of actual arrivals (2011-00737).

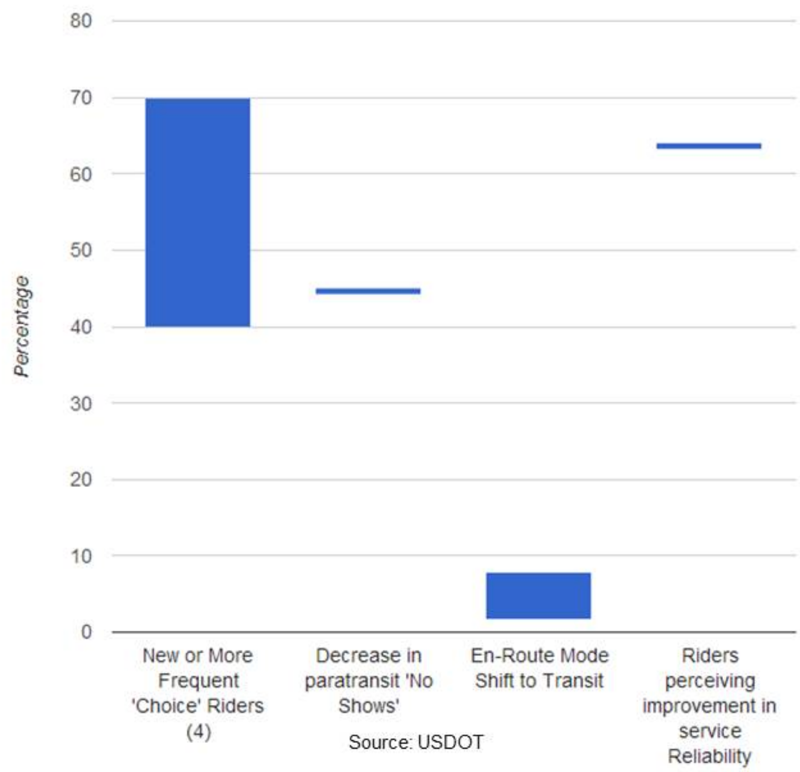


Figure 7-2: Benefits of Providing Transit Traveler Information (Source: ITS Knowledge Resources).

As can be seen in Figure 7-2, providing real-time traveler information about transit arrival times allowed agencies to attract new "choice" riders or have existing choice riders opt to take transit more frequently, resulting in 40-70 percent increases in trips taken by choice riders. Washoe County Transportation attributed a 45 percent decrease in paratransit "No Shows" in part, to having real-time vehicle information obtainable by passengers over the phone. A pilot test showed that providing en-route transit information on highways in the San Francisco Bay area provided a 1.6 to 7.9 percent mode shift to transit, depending on the displayed minutes of travel time that could be saved by switching modes.

7.3.3 Costs

The costs for transit information dissemination vary widely based on the amount and type of existing equipment that can be utilized for the system. Real-time arrival systems are dependent on the vehicle fleet being AVL equipped and the methods of disseminating that information (DMS, mobile applications, websites, etc.) varies by agency. As mentioned earlier, with the development of the GTFS, there is minimal work needed by the agency to have transit information available through an application programming interface (API) for mobile and web application developers. This provides benefits to the agency through easier dissemination of traveler information without the development costs.

Transit traveler information dissemination systems that include websites range between $700,000 and $1.5 million in capital costs. Annual operations and maintenance costs range from $93,000 to $225,000 per year (2009-00194, 2008-00152, 2008-00151). Individual signs at stations can be approximately $6,000, while on-board message signs can be $4,000 per vehicle (2008-00148). A parking management guidance system in Chicago cost approximately $1 million to implement (2009-00183).

7.3.4 **Lessons Learned**

The transit industry tends to deploy customized solutions to meet each specific agency's needs. However, there are many lessons learned from other projects that can be generally applicable to the development and deployment of transit information dissemination systems. Below is a sample of lessons learned:

- **Prepare agency staff for implementation of new ITS technologies and involve maintenance and information technology (IT) staff in the installation process**. By preparing staff and making them aware that the system is likely to have some issues at startup, it will help to encourage staff acceptance. Building in-house capability with maintenance staff during the installation process, by having them alongside the contractor, allows staff to be more familiar with the technology when they need to remove, diagnose and replace equipment (2011-00612).
- **Develop requirements using widely accepted standards, preferably the open source compatible ones if available, and review those requirements immediately before requesting proposals from contractors.** Successful and rapid adoption of open standards can sometimes render proprietary systems obsolete. Proprietary systems can make it difficult to procure technical support or replacement hardware (2011-00608).
- **Expect agency's information technology (IT) operations and maintenance budget to increase in order to train qualified IT staff to maintain a new suite of hardware and software.** Because managing the transit ITS technologies requires additional or advanced skills, such as database and network management, implementation of transit ITS requires staff with advanced expertise. This causes agencies to make a stronger effort to retain experienced staff resulting in salary increases for IT staff (2012-00627).

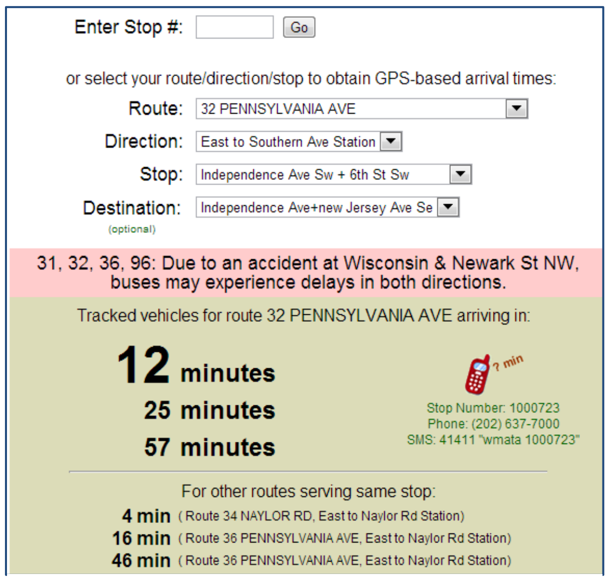


Figure 7-3: Bus arrival prediction website for WMATA in Washington, D.C. (Source: www.nextbus.com)

- **Commit to testing the new systems thoroughly, develop an acceptance matrix to document status of testing, and perform verification and validation before introducing them to support agency's transportation operations.** Having a mechanism for testing is not sufficient without a commitment to conducting thorough testing. An agency should be willing to change plans if it becomes clear during the testing phase that the planned system is not going to provide the expected benefits (2010-00559).

8 Transportation Management Center

8.1 Introduction

Transportation or traffic management centers (TMCs) or transportation operations centers (TOCs) are an integral part of a transportation system. TMCs are responsible for operating the latest Intelligent Transportation System (ITS) technology including data collection, command and control of ITS devices, incident response, and communication for transportation networks. As deployments of ITS have increased over the last decade, state DOTs are continuing to implement TMCs to focus on the operations of their systems. TMCs are the focal point for agencies as they look to operate their transportation systems as efficiently as possible with the existing ITS infrastructure. New concepts are leading to the more effective use of the conventional ITS devices in the field.

Implementing Integrated Corridor Management (ICM) strategies on the U.S. 75 corridor in Dallas, Texas produced an estimated benefit-cost ratio of 20.4:1.

Recent initiatives and concepts such as Integrated Corridor Management (ICM) and Active Traffic and Demand Management (ATDM) integrate more functionality into a single center for more responsive or even predictive traffic operation strategies. TMCs will be at the center of operating and maintaining these new systems. At the heart of ICM is a decision support system which consists of the set of procedures, processes, data, information systems, and people that support transportation system managers in making coordinated decisions to improve the collective performance of all transportation networks within a corridor. ICM seeks to integrate freeway, arterial, and transit systems together to make the entire transportation network more efficient.

ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Through the use of available tools and assets, traffic flow is managed and traveler behavior is influenced in real-time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, reducing emissions, or maximizing system efficiency.

Under an ATDM approach, the transportation system is continuously monitored. Using archived data and/or predictive methods, actions are performed in real-time to achieve or maintain system performance. Both ATDM and ICM are being deployed across the country. Two U.S. DOT ICM Pioneer Demonstration sites (Dallas and San Diego) went live with systems in early 2013.

Other technology trends that are impacting TMCs are big data, social media and crowdsourcing, and the continual growth of mobile and wireless communications. TMCs are collecting more and more data every day with the potential for data directly from vehicles in the near future. Social media is being used more and more for traveler information, while crowdsourced data is being used to gather data from drivers to obtain travel times, incidents, and other roadway information from driver reports [22].

Smartphone applications are beginning to provide real-time individualized traveler information to users through crowdsourced data. These applications could be greatly enhanced with involment from TMCs by simply collecting and providing data to the applications and eventually the individual users. For example, data that in real-time can track the status of incidents on the roadway would be of great value to application developers and their end users [23].

8.2 Benefits

Benefits enabled by TMCs vary depending on the purpose and functionality of the TMC. Many TMCs are currently focused on freeway, arterial, or transit operations. Figure 8-1 shows ranges of benefits for select entries in the ITS Knowledge Resource database. Benefits can be seen with many different measures across multiple goal areas including mobility, safety, and the environment. In this case, TMC benefits include incident clearance time, delay reduction, queue reduction, crash reduction, and travel time.

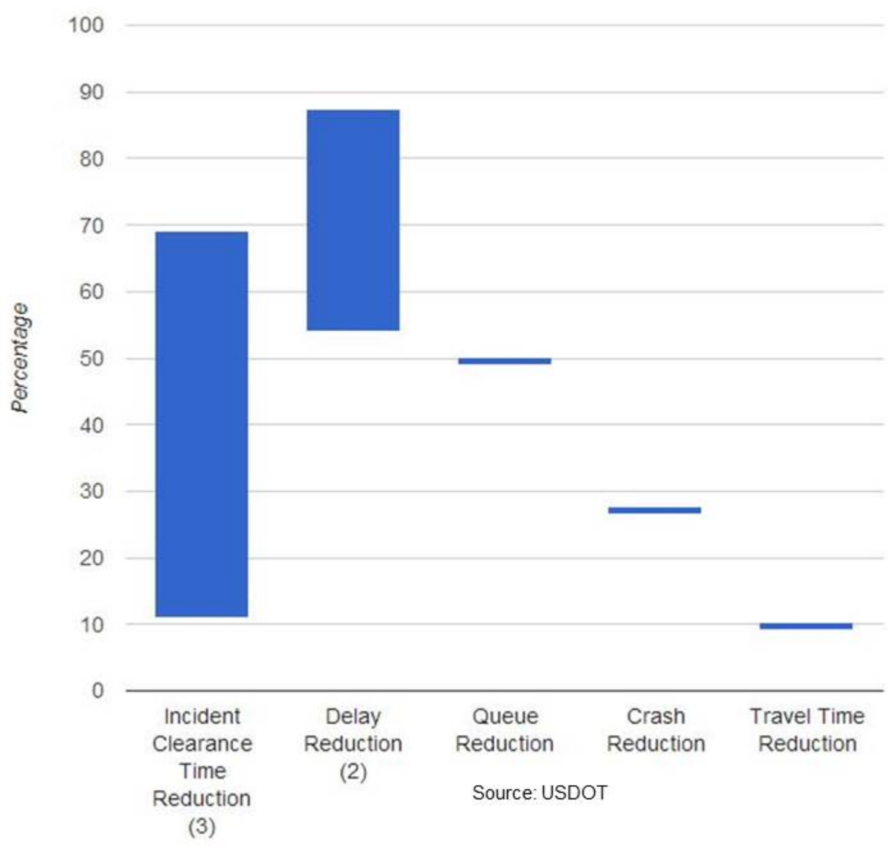


Figure 8-1: Range of Benefits for Transportation Management Centers (Source: ITS Knowledge Resources).

The travel time reduction benefits in Figure 8-1 are based on an advanced traffic signal system in New York City. The key to this project was the adaptive decision support system that resided at a TMC facility for NYC. The system uses historic data as well as real-time conditions to determine the optimal operation of the signals. If a new plan is needed, it is presented to an operator for visual verification of conditions using the CCTV cameras before it is initiated. With this real-time congestion management system in place, NYC DOT was able to achieve 10 percent reductions in travel times through the initial corridor (2012-00810).

8.3 Costs

TMCs are a critical component of the shift in emphasis of state DOTs from building infrastructure to managing and operating the existing systems. Operations and Maintenance (O&M) is one of the largest portions of a TMC cost, as shown in Figure 8-2. This column represents annual O&M costs as reported by seven agencies. The large range can be explained by size of the agency (statewide or local) as well as the TMC housing a single agency or integrating multiple agencies into a single TMC. Personnel costs are generally the greatest percentage of O&M costs. The construction costs in Figure 8-2 cover planning and building a TMC, and the equipment costs include general hardware such as computers, servers, and video walls.

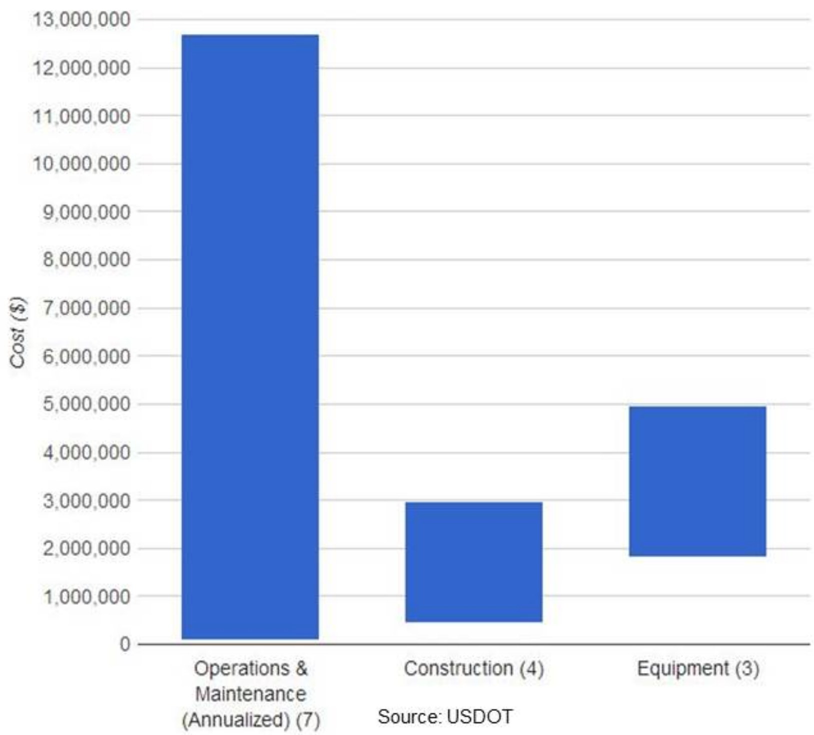
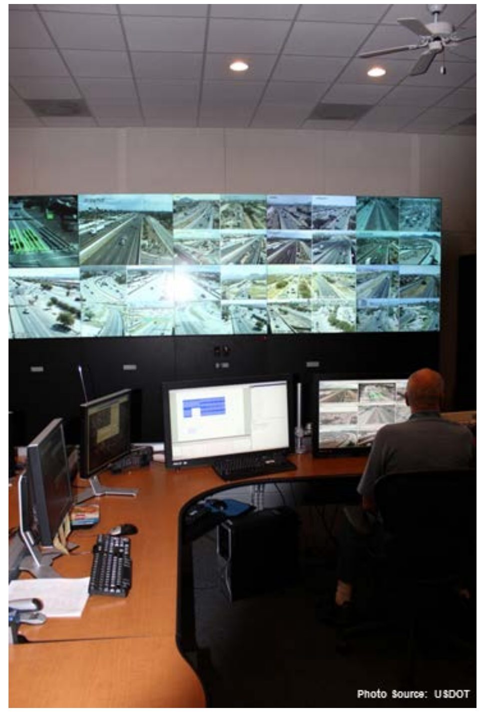


Figure 8-2: Range of Costs for Transportation Management Centers (Source: ITS Knowledge Resources).

Costs for TMCs vary dramatically depending on the functionality of the TMC, if it is a multi-agency or multi-jurisdictional TMC, level of ITS deployment required, and the communication costs. Regardless of the specific functionality, the highest portion of the cost of a TMC over its useful life will likely be in the Operations and Maintenance of the centers and its systems.

8.4 Lessons Learned



The report titled *Impacts of Technology Advancements on Transportation Management Center Operations* identifies many of the trends discussed in this fact sheet in TMC operations. The report lists several lessons to help TMCs move forward with new technologies and tools (2013-00642):

- **Develop a data fusion engine to merge data from multiple sources, such as travel time information coming from toll tag readers, Bluetooth sensors, and/or third party providers.** An automated data fusion engine is designed to integrate multiple forms of raw data from different types of sensors, process and arrange the data into subsets, and present them in a way that provides a clear, more accurate picture for the operator to draw conclusions from, creating situational awareness.
- **Develop procedures and protocols for use of social media.** Develop a uniform policy for DOT use of social media, such as Facebook, Twitter, and video distribution platforms such as YouTube, among others. Social media can provide an important connection to users to disseminate travel warnings and alerts, as well as promote projects or public interest campaigns.
- **Support two-way information exchange via social media.** Social media can provide a valuable tool to reach out to travelers and residents, but also can provide an important source of data for the TMC.
- **Utilize crowdsourcing for traffic information, incident information, and feedback on department performance, pavement roughness, etc.** Crowdsourcing would enable real-time feedback from users on a variety of transportation issues and impacts, with an emphasis on crowdsourced information.

8.5 Case Study - Idaho Statewide Communications Center

While TMCs can be a critical part of a regions transportation network, they are also costly to the transportation departments that must build, operate, and maintain them. Across the country, more and more TMCs are being used to co-locate transportation operations staff and other agencies, such as public safety and emergency departments. This allows for resource sharing and more efficient transportation networks.

The Idaho Statewide Communications Center is under the Idaho Department of Health and Welfare with a customer base in emergency medical services and hospitals [24]. The Statewide Communications Center serves the entire state of Idaho. It is a 24 hour, 7 days-a-week dispatch for the Idaho Transportation Department (ITD) that includes dispatching maintenance vehicles and snow plows. It also dispatches 15 rural Emergency Medical Service (EMS) units (county and community

Photo Source: USDOT

based) and provides communications to public health departments for the state and the seven districts. In addition, the communications center provides public health emergency notification, and is the point of contact for the Idaho Bureau of Homeland Security for Weapons of Mass Destruction and Hazardous Materials. The Statewide Communications Center also works with the Department of Environmental Quality, FBI, EPA and other local state agencies.

This unique partnership has allowed for the development of applications that other standalone TMCs may not be able to handle. For example, the (CARS) MAYDAY project brings OnStar data from a crash vehicle and uses an urgency algorithm to provide a real-world real-time data feed that predicts injury. The urgency algorithm (developed by the University of Florida) gathers the change in velocity, air bag deployment information, and other on-board data to estimate the probability of injury to occupants. The information comes into the Statewide Communications Center screens and places an icon on the screen representing the vehicle with direction of travel before the crash, and automatically displays the appropriate dispatching organization to contact. It also triggers dispatcher reminder boxes (early notification to hospital, need for helicopter on standby etc.). They are presently in the evaluation stage and validating the probability of injury scores.

The information provided by the system is not currently being acted upon until the system is validated; a larger number of incidents are needed to validate the system. Because Idaho is rural, it may take 1 to 2 years to validate. Once validated, the Statewide Communications Center supervisor plans to approach other systems similar to OnStar to expand the system. This unique center that operates 24/7 with operators that are all EMS trained can handle this type of information easily. And with the same operators responsible for handling the Idaho DOT message signs and other ITS, the transportation system will be able to respond quickly and appropriately to the situation.

9 Alternative Fuels

9.1 Introduction

Alternative fuels offer significant benefits over more conventional petroleum fuels, producing lower emissions and fewer toxic contaminants than gasoline and diesel vehicles, helping to reduce impacts on air quality, global warming, the environment and public health. According to the U.S. Department of Energy (DOE), more than a dozen alternative fuels are in production or already in use in alternative fuel vehicles (AFVs). The six predominant alternative fuels used in the United States are biodiesel, electricity, ethanol, hydrogen, natural gas, and propane. Of these fuels, electricity is the most widely used – primarily in hybrid electric vehicles (HEVs) or all electric vehicles.

To date, government and private-sector vehicle fleets have been the primary users of these fuels and vehicles, but recently consumers are becoming increasingly interested in them as well. Fleet operators including long-haul trucking, taxi services, law enforcement, public transit, and school transportation services have seen environmental benefits from AFVs. In addition to reducing the organization's carbon footprint, AFVs have helped to reduce operating costs for many of these organizations. Over the last decade, the City of Sacramento successfully transitioned its entire diesel refuse-hauler fleet to clean-burning liquefied natural gas (LNG). The fleet operator worked with Sacramento Clean Cities, the local air district, and other fleets in the area to systematically roll out 113 side- and rear-loader LNG refuse trucks, as well as the fueling stations and maintenance facilities to support them. This effort contributed to millions of dollars saved and more than 1,900 tons of annual greenhouse gas (GHG) emissions averted [25].

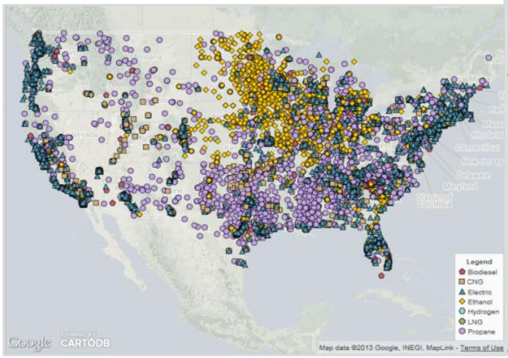
The popularity of AFVs with consumers has increased over the past 20 years. This increase in popularity can be attributed to many factors including more environmentally conscious consumers, rising gasoline prices, as well as stricter federal fuel efficiency standards (which will rise from 2011's fleet average of 27.3 mpg to 54.5 mpg by 2025). The automotive industry has responded to these trends by enhancing the fuel efficiency of conventionally fueled light passenger vehicles, as well as introducing new AFV models into the market. In 1991, there were only two models of AFVs offered by automobile original equipment manufacturers (OEMs). In 2013, thirty OEMs offered 162 models of AFVs.

HEVs, powered by both electricity and gasoline, which get upward of 50 miles per gallon, are by far the most common type of AFV. OEMs are also beginning to offer battery electric vehicles (BEVs) that rely completely on an electric battery to power its electric motor.

While AFVs provide several environmental, economic, and societal benefits over internal combustion engine vehicles, there are also some limitations to these vehicles. The most obvious limitation is that these vehicles usually cannot be refueled at the corner gas service station. The fueling infrastructure for many alternative fuels is only now being developed. According to the U.S. DOE there are 12,541 alternative fuel stations in the United States, excluding private stations. Table 9-1 depicts the number of alternative fueling stations in the United States. In comparison, a report published by ITS America stated that there are approximately 30,000 gas service stations to support approximately 200 million vehicles in the United States, or about 6,000 vehicles per station [26]. In the long-term, the market for

AFV charging stations will likely grow. In the meantime, the lack of infrastructure serves as a major hurdle for mass adoption of AFVs by consumers.

Table 9-1: Alternative Fueling Stations in the United States (Source: U.S. DOE Alternative Fuels Data Center [27]).



Fuel Type	Number of Stations in the U.S.
Biodiesel (B20 and above)	324
Compressed Natural Gas	605
Electric	6,601
Ethanol (E85)	2,338
Hydrogen	10
Liquefied Natural Gas	35
Liquefied Petroleum Gas	2,638
All Fuel Types	12,541

With AFVs, a lack of information provided to the driver can be a contributing factor to range anxiety, the fear that a vehicle has insufficient range to reach its destination and would thus strand the vehicle's occupants. Intelligent Transportation Systems (ITS) offer potential to support AFVs. Navigation systems equipped with knowledge of the vehicle's battery capacity, remaining distance, and the locations of charging/fueling stations can help minimize driver fear.

Charging/Fueling Information applications located on in-vehicle systems or on nomadic devices can inform travelers of locations and the availability of AFV charging and fueling stations. These applications may also allow drivers to make reservations to use charging stations before they start their trip or while en-route. Electronic payment cards—or applications on smart phones—may also be used to support the payment at charging and fueling stations.

Charging /Fueling Payment applications may be integrated with other transportation payment systems such as transit fares, parking, and electronic toll collection systems.

Inductive or Resonance Charging is another promising technology that has the potential to support AFVs. Inductive or resonance charging includes infrastructure deployed under the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables electric vehicles to charge their batteries once positioned over the charging station. Inductive or resonance charging may support static charging capable of transferring electric power to a vehicle parked in a garage or on the street and

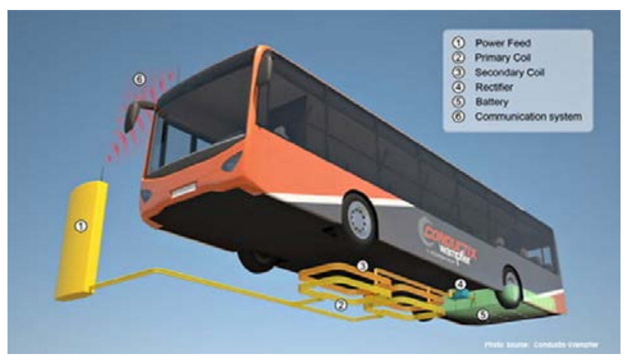


Figure 9-1: Inductive Charging. Position marking for a wireless charging system with coils integrated in the road surface (Source: Conductix-Wampfler).

vehicles stopped at a traffic signal. The technology may also support charging vehicle batteries while the vehicle is moving at highway speeds; the capability known as dynamic wireless charging is currently being researched.

Catenary Systems that use overhead wires to provide electricity for heavy duty vehicles have been in use for well over 100 years. Today, catenary systems can be found on urban light rail vehicles, city buses, and mining equipment. A recent demonstration shows how these systems may be used along truck corridors as part of a catenary based system for zero-emission trucks. While catenary system technology is very mature, it is only recently that hybrid/electric drive technology has matured to the point that a cost-effective hybrid system could be developed that allows for zero-emission operation on and off the catenary line. In the proposed system, a diesel or natural gas hybrid truck is envisioned that can operate solely on electrical power from the catenary lines. Additionally, an onboard battery will allow the truck to operate in electric mode for a limited distance after disconnecting from the catenary system [28].

9.2 Benefits

Transportation is the "fastest-growing source of U.S. GHG emissions, accounting for 47 percent of the net increase in total U.S. emissions since 1990, and is the largest end-use source of CO_2, which is the most prevalent GHG" [29]. Transportation activities accounted for 27 percent of all GHG emissions in the United States, with on-road vehicles contributing 84 percent to that total. Nearly "97 percent of transportation GHG emissions came through direct combustion of fossil fuels." Over 43 percent of surface transportation emissions are the result of passenger vehicles, 19 percent from light-duty trucks, and freight trucks account for another 22 percent. AFVs have the potential to reduce these numbers significantly and ITS is an enabling technology to make these vehicles more attractive to the traveling public.

To date, ITS technologies to support AFVs have not been widely deployed. As a result, there is limited data documenting the benefits of Charging/Fueling Information, Charging/Fueling Payment, Inductive or Resonance Charging, or Catenary Systems that support HEVs. While documentation of benefits is limited, ITS technologies relating to AFVs seem promising. Charging/Fueling information may help to reduce range anxiety which may result in more purchases or use of AFVs. Additionally, Inductive or Resonance Charging applications will allow drivers to charge their electric vehicles in small amounts fairly often. As a result, electric batteries could be smaller with the resulting reduction in electric vehicle cost and weight. These technologies will also make electric vehicles more attractive to consumers. Finally, the potential benefits of a catenary-accessible hybrid truck platform may be significant. Trucks, when connected to the catenary system, will have zero-emissions which can significantly reduce emissions along a corridor.

As these technologies mature and the number of AFVs on the roadway increase, it is expected that private and public agencies will begin deploying technologies to support the operations of these vehicles and more benefit data will become available.

9.3 Costs

A limited number of ITS applications have been deployed to support alternative fuels. At this time, there is not cost data available for these applications.

9.4 Lessons Learned

The following lessons learned are gathered from the U.S. DOE's Office of Energy Efficiency and Renewable Energy:

- **Receive significant cost savings by driving AFVs instead of vehicles powered by internal combustion engines (ICEs).** The U.S. DOE's "Find a Car" tool allows consumers to compare fuel efficiency, costs, carbon footprints, and emissions of different vehicle makes and models (http://www.afdc.energy.gov/tools).
- **Convert petroleum-based fleet vehicles to AFVs to save operating costs and avert greenhouse gas (GHG) emissions.** The U.S. DOE's "Green Fleet Footprint Calculator" is a tool that can be used to estimate the potential savings for fleet operators (http://www.afdc.energy.gov/tools).
- **Minimize range anxiety with in-vehicle navigation systems equipped with knowledge of battery capacity, remaining distance, and the locations of charging/fueling stations.** As a result, consumers may be more likely to purchase and use AFVs.

9.5 Case Study - London's Wireless Inductive Charging Trial

In November 2011, London, England announced it was embarking on the first large-scale pre-commercial trial of inductive charging in the world. The trial involves a combination of passenger cars and light good vehicles and is based partially in Tech City in the East of London. The objective of the trial is to better understand how inductive charging can be deployed in a mega city environment like London and to gain feedback from inductive charging drivers on their experience of wireless charging.

According to a press release from Qualcomm, the pre-commercial trial is expected to start in early 2012 and will involve as many as 50 electric vehicles. The trial will use Qualcomm wireless inductive power transfer technology that enables high-efficiency power transfer across a large air gap. With the technology, the driver simply parks the vehicle in the usual way and the system automatically aligns for power transfer, making parking easier and charging hassle free. Addison Lee, the UK's largest minicab company, and Chargemaster Plc, the leading European operator of advanced electric vehicle charging infrastructure, are partners on the project. Cost and benefit data will be available at the end of the trial period [30].

9.6 Case Study – The I-710 Corridor Project: Zero Emissions Corridor

The California Department of Transportation (Caltrans), in cooperation with the Los Angeles County Metropolitan Transportation Authority (Metro), the Gateway Cities Council of Governments, the Southern California Association of Governments, the Ports of Los Angeles and Long Beach recently proposed improvements to Interstate 710. Interstate 710 is a major north-south interstate freeway connecting the city of Long Beach to central Los Angeles. The corridor serves as the principal transportation connection for goods movement between the Port of Los Angeles and the Port of Long

Beach, located at the southern terminus of I-710 and the Burlington Northern Santa Fe (BNSF)/Union Pacific (UP) Railroad rail yards in the cities of Commerce and Vernon. The existing I-710 Corridor has elevated levels of health risks related to high levels of diesel particulate emissions, traffic congestion, high truck volumes, high accident rates, and contains many design features in need of modernization. The U.S. Environmental Protection Agency (EPA) has designated the South Coast Air Basin (Basin), which includes the Study Area, as an extreme ozone non-attainment area and a non-attainment area for small airborne particulate matter less than 10 and 2.5 microns (PM10 and PM2.5).

The proposed project recommends several alternatives to improve the corridor, including widening the corridor, providing improvements to the arterials, deploying ITS, and implementation of zero-emission electric truck technology. This proposed zero-emission truck technology is assumed to consist of trucks powered by electric motors and producing zero tailpipe emissions while traveling on the freight corridor. The zero-emission electric trucks would receive electric power while traveling along the freight corridor via an overhead catenary electric power distribution system (road-connected power) as depicted in Figure 9-2.

Figure 9-2: Proposed Catenary System for I-710 Zero-Emissions Corridor (Source: Siemens Mobility).

According to a presentation by the South Coast Air Quality Management District (SCAQMD), a demonstration project is being proposed to prove the catenary truck concept in real-world drayage operations. The catenary system would be one mile long with pole spacing similar to street lights and a DC power substation with remote monitoring. Four demonstration trucks - a diesel hybrid, CNG hybrid, battery electric, and another vehicle platform to be determined at a later date - would be used in the demonstration. The demonstration would begin in 2016 and last for one year. Estimated project costs to plan, design, build, and conduct the demonstration of the catenary system are $16,682,795. If the system were implemented on the corridor, the potential benefit includes reducing emissions of 75,000 diesel heavy duty trucks in the basin and 12,120 trucks used in drayage that produce 17.7 tons on NOx per day and 0.2 tons of PM2.5 per day [31].

10 Traffic Incident Management

10.1 Introduction

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 [32]. 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 strategies have shown significant safety, mobility, efficiency, productivity, environmental, and customer satisfaction benefits.

The estimate for the total expected risk-adjusted cost of implementing and operating a nationwide NG9-1-1 system ranges from $82 billion to $86.3 billion over the next 20 years.

Traffic incident management 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 (TMCs), the police, emergency medical services and other emergency services.

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. 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 are now frequently incorporated into traffic incident management programs. The patrol vehicles and staff supported by an array of other ITS components, such as mobile field reporting, enable significant reductions in the time to respond to and clear incidents.

With the new mandates for performance reporting requirements through MAP-21, incident tracking has become a very important part of traffic incident management programs. Many ITS technologies can be used for both traffic measures as well as emergency response services, creating additional benefits to the traffic incident programs. For example, installing CCTV cameras for traffic monitoring also helps the police achieve more efficient incident response operations.

10.2 Benefits

Traffic incident management programs have demonstrated success and shown high value through benefit-cost ratio analysis. Some sample benefit-cost ratios from incident management programs around the country are shown in Table 10-1.

Table 10-1: Benefit-Cost Ratios for Incident Management Systems.

Program	Benefits-Cost Ratio
Expansion of the St. Louis Motorist Assist (MA) program (2011-00666)	**38.25:1**
Safety Service Patrol in Hampton Roads, Virginia (2011-00670)	**4.71:1**
Northern Virginia's freeway safety service patrol (2011-00669)	**5.4:1**
Georgia's HERO motorist assistance patrol program and NaviGAtor incident management activities (2007-00466)	**4.4:1**
Arterial Service Patrol deployed during the re-construction of I-64 in St. Louis (2011-00667)	**8.3:1**
A multi-jurisdictional emergency response crew in the Phoenix metropolitan area providing services to six cities (2012-00792)	**6.4:1**

Traffic incident management programs have shown significant benefits under several goal areas of ITS, as summarized in Table 10-2. The most significant findings are that incident management programs have the ability to significantly reduce the duration and clearance time of traffic incidents.

Table 10-2: Selected Benefits for Incident Management Strategies.

ITS Goal	Selected Findings
Safety and Mobility	In 2008, WSDOT implemented a new Incident Response program that provides roving patrols during peak periods, as well as being on call 24 hours a day, 7 days a week. The Incident Response Team was able to clear 98 percent of incidents in under an hour and nearly three quarters in less than 15 minutes. (2012-00801)
Productivity	In Portland, Oregon, an incident response program, known as COMET has reduced 30 seconds per incident, resulting in a reduction of $711,300 costs of delay, which is equivalent to the cost of operating the incident response program for a year. (2013-00869)
Productivity	A multi-jurisdictional emergency response crew in the Phoenix metropolitan area provides services to six cities with a benefit-cost ratio of 6.4:1 by increasing responder safety and reducing the number of patrol officers necessary at each crash scene. (2012-00792)

Productivity	A value analysis of a Next Generation 9-1-1 (NG9-1-1) system found that over a 20-year lifecycle, NG9-1-1 would likely cost about the same as maintaining the status quo of the current 9-1-1 system, but deliver 80 percent additional value (2011-00755)

Figure 10-1 shows ranges of benefits for select entries in the ITS Knowledge Resource database at: http://www.itsknowledgeresources.its.dot.gov/. Benefits include reduction in incident duration time, reduction in incident clearance time as well as collision and secondary crash reduction.

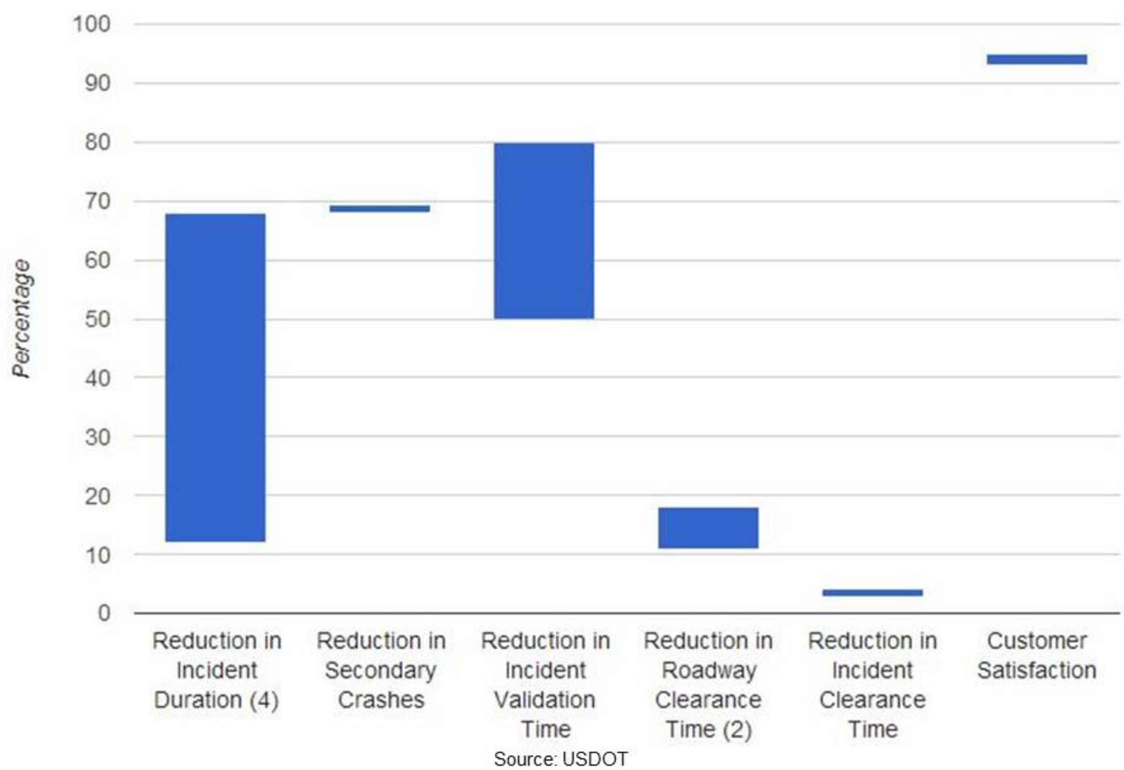


Figure 10-1: Range of Benefits of Traffic Incident Management (Source: ITS Knowledge Resources).

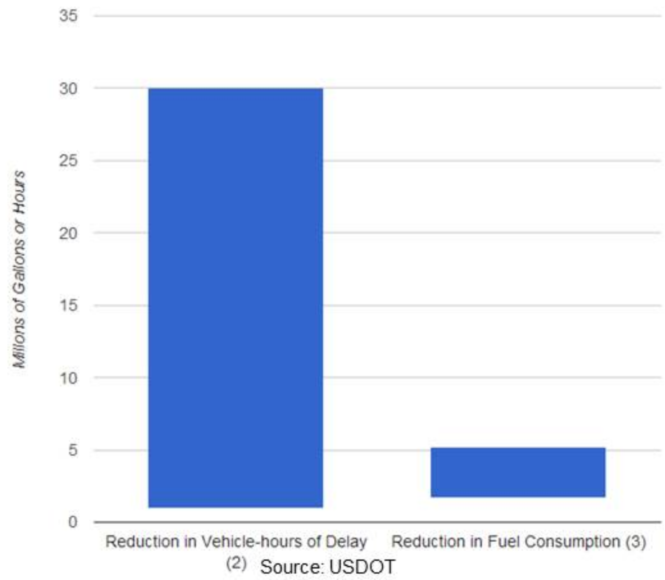


Figure 10-2: Range of Vehicle Delay and Fuel Consumption Benefits (Source: ITS Knowledge Resources).

Traffic Incident Management strategies have also shown significant benefits in reducing vehicle delay and fuel consumption. Figure 10-2 shows the ranges of these benefits.

10.3 Costs

ITS Knowledge Resource database provides a variety of system costs for incident management strategies that range from small scale local programs to estimates of full nationwide implementations.

The database includes several cases of annual operating costs for motorist assist and highway service patrol programs around the country. Since 2004, annual operating costs for these programs range from less than half a million dollars to over $20 million, depending on location, type of program and number of vehicles. Table 10-3 shows selected system annual operating costs.

Table 10-3: Annual Operating Costs for Incident Management Systems.

Incident Management Systems	Annual Operating Costs
Motorist Assistance and Safety Services in Arizona (2013-00289)	$389,000
Northern Virginia (NOVA) Safety Service Patrol (2011-00208)	$1,193,511
The Safety Service Patrol (SSP) in Hampton Roads, Virginia (2011-00207)	$2,353,238
The St. Louis, Missouri Motorist Assist Program in 2008 (2011-00206)	$2,015,378
The St. Louis, Missouri Motorist Assist Program in 2009 (2011-00206)	$2,075,839
Tennessee DOT's HELP Program FY 2005-2006 (2007-00119)	$6.5 million

Tennessee DOT's HELP Program for FY 2004-2005 (2006-00096)	$5.6 million
A Southeast Michigan freeway service patrol program in 2005 (2006-00105)	$2.4 million
A Southeast Michigan freeway service patrol program in 2004 (2006-00104)	$2.5 million
Florida DOT Road Ranger program (2006-00103)	$1,133,085
Los Angeles County Metro service patrol program (2006-00102)	$20.5 million

10.4 Lessons Learned

The ITS Knowledge Resource database identifies several lessons learned from deployed traffic incident management strategies. Many of these lessons apply not only to incident management programs, but are also useful in other areas such as road weather operations and freeway operations management.

A report on the experience of the Utah DOT's integration of their Road Weather Information Systems (RWIS) Program with Traffic Operations discussed several lessons learned including:

- **Use weather information from sensors and forecasts to improve incident response times and only having crews on call when weather events are looming.** The availability of up to 10 forecast updates during a storm allows the Incident Management Team (IMT) to place crews in areas where they will most likely be needed before the weather worsens. Flexible staffing has been made possible through the use of forecasts to increase staff only when necessary. Additionally, because the RWIS program staff provides weather reports to Traffic Operations Center (TOC) staff at least twice daily (and more frequent updates during weather events), the IMT no longer needs to spend staff time looking for weather updates (2012-00634).

The I-95 Corridor Coalition developed a white paper on the benefits of using vehicle probes to monitor traffic cost-effectively, manage incidents and queues proactively, reduce delays, and increase traveler satisfaction along a multi-state transportation corridor.

Lessons learned from the experience of several State departments of transportation (DOT) are discussed in the white paper, including an experience from New Jersey's DOT (NJDOT) on using vehicle probe data for incident management:

- **Enhance incident management efficiency by using vehicle probe data** (New Jersey). During a surprise snowstorm in October 2008, NJDOT TOC was reviewing an accident on I-80 via a closed circuit television (CCTV) camera. The Vehicle Probe Project (VPP) monitoring site identified a second incident where CCTV coverage was not available that involved multiple jack-knifed tractor-trailers along I-80. The knowledge gained from the VPP about the second incident enabled responders to attend to the second incident nearly an hour sooner than would have been possible without the VPP. A NJDOT executive stated at the 2008 ITS World Congress and ITS America Annual Joint Meeting that the expedited response to the second incident translated into an estimated $100,000 savings in user delay costs (2010-00557).

10.5 Case Study - Mobile Field Reporting/Arizona Public Safety

One of the biggest challenges facing traffic incident management strategies is to reduce the incident response and clearance times to prevent secondary crashes and alleviate congestion. First responders are required to collect information from drivers involved in a collision and develop an incident report.

In the past, the Arizona Department of Public Safety (DPS) would collect incident and driver information and prepare manual paper reports that included information on the drivers and incident. In addition to the incident report, the officer would also give a citation to the driver at fault, which contained much of the same information that the officer had to manually copy. If the vehicles involved needed towing, the officer on the scene would also have to copy that same information one more time for the towing report.

With the recent downturn in the economy, Arizona lost 25 percent of their personnel overall and up to 60 percent in some districts. At the same time, new mandates for the police were creating more paperwork and increasing administrative responsibilities for officers, thus taking away from response times and preventative activities.

To combat these trends, the Arizona DPS started implementing mobile field reporting activities. In 2008 the Arizona DPS started using electronic crash reports so that the crash data can more efficiently and accurately be moved from the field officer standing on the road to the DOT. By 2009, mobile field reporting was being used by approximately 700 road officers. The officer uses bar code scanners to scan information from registrations and drivers licenses. This information auto-populates into the crash form, citation and tow sheets. The benefits of mobile field reporting have proven to be significant, decreasing the incident reporting and clearance from 1.5 hours to approximately 15 to 30 minutes. The automated field reporting also improved time at traffic stops, which decreased from 20 minutes to between 5 and 10 minutes.

Besides time savings on the field, mobile field reporting in Arizona has also improved the quality of incident reports and reduced processing time. Previously, a supervising officer had to review most of these reports for accuracy but the new software includes validation rules that are built in the software to prevent mistakes. The supervisor reads the electronic data on the screen and accepts it. Daily crash reports are now sent to DOT and, if needed, these reports could be submitted on demand. The crash reports are used for crash analysis, planning purposes, Fatality Analysis Reporting System (FARS) and other databases. The process for a crash report to be included in the DOT's database decreased from several months to eight days.

11 Emergency Management

11.1 Introduction

> **In Washington D.C., allowing transit vehicles priority during a no-notice emergency evacuation resulted in a 26 percent time saving for transit buses without impacting personal vehicle travel time.**

In the United States every year, there are hundreds of events requiring emergency services including evacuations from tropical storms, hurricanes, tornadoes, and hazardous materials (HAZMAT) incidents. 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. In addition, good data analytics are important for performing analyses and understanding emergency management trends so that additional problems can be solved.

The ITS Knowledge Resources provide benefits, costs, and lessons learned information about the state of the art and the adoption of effective technologies by the emergency management community and its customers. This information includes private, public, and network-based benefits that can assist deployers with a greater understanding of resources available and implementation of useful technologies. The following information provides a sampling of the emergency management evaluation data that is included in the ITS Knowledge Resources.

11.2 Benefits

A 2011 report provided results from research that tested the effects of transit signal priority on emergency evacuation clearance times and the results showed significant time savings.

The study area was a 14-intersection corridor located in the Southeast corner of Central Washington, DC (NW 7th Street from SW E Street (South) to NW Pennsylvania Ave, West to NW 12 Street). The corridor encompasses a major metro station in the city (L'Enfant Plaza), and is one of the 19 major corridors designated as a primary evacuation route to assist in the evacuation process. The scenario was the detonation of a dirty bomb at L'Enfant Plaza, setting in motion the city's emergency evacuation response.

The methodology used a microscopic traffic simulation of an evacuation environment merged with a transit operations and signal priority component. The evacuation environment consisted of socio-economic data, census data and regional evacuation data, and the transit operations and signal priority component was built from data on street geometry, signal timing data, traffic counts and transit information (schedule, stop location, dwell time, etc.). These models generated an evacuation origin destination (O-D) matrix to create a realistic emergency evacuation traffic model with measures of effectiveness (MOEs) including travel time, evacuation clearance time, and delay time. The simulation network included 17 of the 34 bus lines within the borders of the study area. The bus lines not included were those that do not require priority (right hand turns only) or do not use more than one intersection within the study corridor.

Allowing transit signal priority during the evacuation resulted in a 26 percent time savings for transit buses, meaning that three prioritized vehicles accomplish the same as four would without priority. The 26 percent time savings enables more transit units to make additional trips, resulting in shorter evacuation times. The results also found that the time saving is achieved without having an impact on evacuation clearance times or evacuee travel times for non-transit vehicles. Moreover, when transit signal priority is restricted to operate only on evacuation routes, evacuee travel and delay time decreases (in contrast to previous studies that found transit priority results in delays to vehicular traffic during high roadway demand) (2012-00784).

11.3 Costs

The I-95 Corridor Coalition of states in the northeastern U.S. work together on initiatives to improve highway travel. The Coalition published a report in 2010 documenting one initiative to improve the collection and accuracy of crash data because of the importance of this data to many agencies including departments of transportation, law enforcement, and emergency services for both planning and operations based decision making. The Crash Data Reporting Methods (Final Report) provides data on crash reporting practices for the 17 states in the coalition. One of many examples provided in the report is the implementation of a crash data system in Virginia with results shown below in Table 11-1 (2013-00280).

Table 11-1: Virginia Crash Data System Costs.

Component	Cost
Fees for a consulting team to plan, design, develop and implement a new Traffic Records Electronic Data System (TREDS) (estimated 2006-2009)	$2 million
TREDS software, system maintenance, and training to begin the design of comprehensive traffic records automated system	$116,462
Cost to reduce the backlog of crash reports in the TREDS crash database and subsequently, its roadway database	$66,000
Cost to change, reprint, and distribute the Model Minimum Uniform Crash Criteria (MMUCC) compliant, scannable police crash form	$37,000
Provide statewide train-the-trainer training on the new FR300 Police Crash Report to over 400 local and state law enforcement trainers	$20,000
Staff to perform database programming modifications in the State's crash database and Centralized Accident Processing System (CAP) to enable collection of new fields and attributes from the new FR300P	$26,737
TOTAL	**$2.27 million**

11.4 Lessons Learned

Utilize transportation tools in communications, traffic control, and monitoring and prediction to maximize the ability of the highway network to support evacuation operations.

There are a multitude of transportation tools that can support evacuation operations in emergencies with advance notice. As the agency responsible for emergency management develops emergency response plans, it is useful to review the array of transportation tools available for support in emergencies. For example, transportation tools for communicating with the public can support emergency management's effort in communicating evacuation orders to the public. Similarly, tools that help manage traffic operations can be used in emergency operations for the purpose of increasing traffic capacity on evacuation routes and responding to traffic incidents that can harm the evacuation effort by blocking traffic. As the evacuation is ongoing, emergency management can use monitoring/predicting tools for monitoring conditions and predicting outcomes. These tools can improve the response team's situational awareness of the progress of the evacuation, help identify potential problem areas and determine optimal evacuation routes. Perhaps the most important message is that governments need a variety of tools at their disposal and the ability to choose which to use in an evacuation. The transportation tools listed below are identified by the FHWA as having potential to support emergency evacuations with advanced notices.

- **Communication Tools.** A critical element in emergency evacuations is the ability of emergency response officials to communicate to all segments of the population in the evacuation zone.
- **Traffic Control Tools.** The efficient and safe management of the highway network is a critical component of successful emergency evacuations. Traffic control tools can be used to manage highway operations in controlling traffic, assessing levels of congestion, responding and clearing incidents and optimizing traffic flow.
- **Assessment Monitoring and Prediction Tools.** The transportation community has generated advanced computerized modeling tools that can be used in evacuation planning and operations to predict weather, estimate losses and damages from weather events, evaluate evacuation plans and model traffic scenarios.

These tools can improve evacuation operations in communications, traffic control, and assessment and monitoring. They can be used in the readiness, activation and operations phase of the evacuation. To be used as effectively as possible, evacuation plans should identify which tools are available in the jurisdiction and how they can be used most effectively. By planning ahead, emergency management can use transportation tools to improve the safety, mobility, and efficiency of emergency evacuations with advance notice (2008-00461).

12 Traveler Information

12.1 Introduction

A major goal of departments of transportation and transit agencies is to provide the best service possible to their users. One of the ways to provide improved service to road and transit users is through providing accurate and timely traveler information. Traveler information is important when traffic conditions are worse than normal, in weather conditions that affect service or road conditions, special events that may require detours or cause traffic volumes far above normal, and for work zones and road closures.

The cost to implement a multimodal trip planner can range from $138,000 to more than $4 million, depending on the need to develop custom software and consolidate data feeds.

Providing the public with accurate and timely information on travel conditions is important because it may affect their choice of mode, route, and departure time. Road conditions due to weather may affect vehicle choice, while parking information at a transit station may lead someone to use a feeder bus or get dropped off at the station in order to avoid driving to an already full parking lot.

Traveler information can be provided both pre-trip and en-route through information dissemination via radio, television, Highway Advisory Radio (HAR), 511 websites and phone systems, other traveler information websites, mobile applications, and dynamic message signs (DMS). Each of the technologies has different benefits and costs, as well as different audiences (i.e., commuters, tourists, commercial vehicles, etc.). The next generation of en-route traveler information is in-vehicle traveler information through connected vehicle technologies and other "infotainment" applications. Some of these technologies are covered more specifically in the factsheets that focus on arterial, freeway, and transit management. This factsheet serves largely as an overview of traveler information.

12.2 Benefits

Benefits of traveler information systems differ widely depending on the type of information provided, the medium through which the information is provided and the type of event that the public needs notification of (e.g. work zone, crash, inclement weather, etc.). Benefits presented below are a sample of benefits that can be found in the ITS Knowledge Resources Database.

A six-month test of in-vehicle systems in Washington State determined that users changed their travel routine once out of every 4.2 times they used the device. When diverting, the surveyed users indicated that they saved approximately 30 minutes in travel time (2012-00812).

Multimodal trip planners can be instrumental in encouraging individuals to use existing transit services. By incorporating information such as gas prices and transit fares, in addition to travel times, a multi-modal trip planning tool in northeastern Illinois helped newer residents establish efficient transportation habits. As knowledge of local transportation options increased, residents were more likely to use transit for some trips. Nearly 40 percent of all respondents and 50 percent of suburban respondents reported using at least one transit service that they did not usually use as a result of using the trip planning tool (2012-00794).

12.3 Costs

Costs for Traveler Information systems vary widely based on the technologies used, as well as the quantity of each component used. The costs presented here are a sample of the system and unit costs available through the ITS Knowledge Resources Costs Database.

Alaska developed NewGen 511 to replace a previous pooled fund 511 system they had been using. The public website uses a web-based interactive map interface that enables the user to zoom and pan to see symbolized alerts for construction, accidents, and weather advisories. The Alaska 511 system also has a mobile-version of the website with reduced features for use by mobile device and low bandwidth Internet users. It also utilizes RSS feeds to send alerts; a Facebook page; a Twitter account; an iPhone app; GovDelivery; and the traditional phone system. The system was designed to be multi-modal and includes information on Alaska's Marine Highways. The phone system has nearly doubled in call traffic since 2003. The system cost $440,000 to develop and $140,000 annually to operate (2012-00263).

Multi-modal trip planners can cost upwards of $4 million to develop for a metropolitan area. However, if systems are already in consolidated standardized databases and have feed access, there will be significantly reduced costs for development. In Oregon, TriMet used OpenTripPlanner and open source software to minimize costs and were able to develop their system for less than $150,000 (2011-00228).

12.4 Lessons Learned

Delivering traveler information to the public requires different solutions that depend on the types of alerts that need to be disseminated and the ways in which the public can access it. However, there are many lessons learned from other projects that can be generally applicable to the development and deployment of traveler information systems. Below is a sample of lessons learned:

- **Monitoring traffic with vehicle probe data and coordinating traffic redirection in adjacent states can help motorists change routes prior to reaching congestion.** Vehicle probe data help manage traffic within a state, but also across state boundaries, accruing regional benefits along a multi-state corridor. North Carolina used probe data to identify building congestion on I-85 in Virginia and coordinated with Virginia to coordinate redirection onto less congested, parallel routes (2010-00558).

- **Design a trip planning website to capture and convey real-world factors such as gas prices and congestion information.** Market research reviewed during the project indicated that travel time information was important to travelers, but it was not the sole reason for mode choice. Researchers indicated that a well-designed trip planning website should be more than just an itinerary-trip planner; it should be able to effectively capture and convey real-world factors that make transit an increasingly attractive option. Researchers noted there was an increased desire for real-time vehicle location information, predictions, and disruption notification information, particularly when travelers were en-route and using mobile devices (2012-00638).

> **Over 75 percent of survey respondents said TV news was the best way to provide planned closure project information.**

- **Develop a robust electronic interface for obtaining comprehensive incident information data from the highway patrol police organizations.** Obtaining information from local police can help to provide more complete incident information to the public. The Florida Highway Patrol CAD data served as a valuable source of information for the iFlorida's statewide traveler information service (2010-00541).

12.5 Case Study - I-64 Full Closure – St. Louis County, Missouri

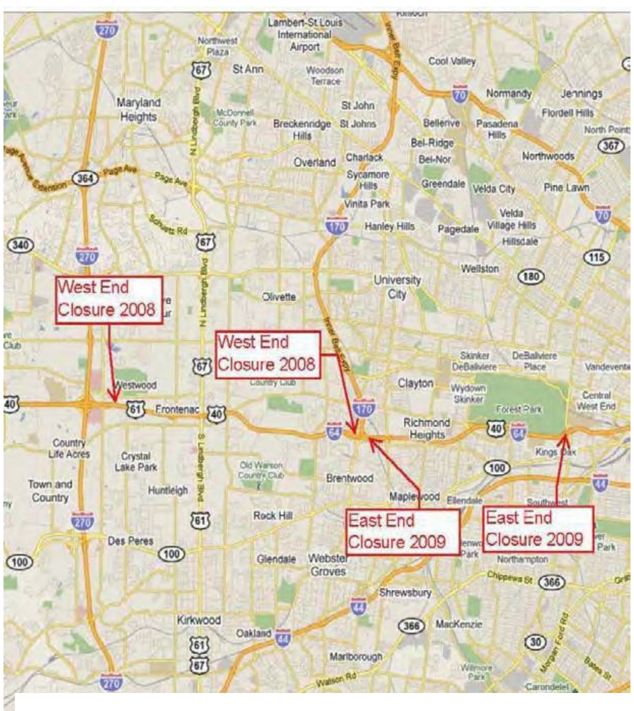


Figure 12-1: I-64 Full Closure General Information.

The Missouri Department of Transportation (MoDOT) decided to use an accelerated construction plan to rebuild a 10 mile section of I-64 in St. Louis County. This construction plan required full closure of two large portions of I-64 for two years (2008 to 2009), rather than partial closures for six to eight years (as shown in Figure 12-1). In order to successfully meet the public's expectations for the project, MoDOT undertook an extensive traveler information campaign prior to the closure to make travelers aware of where the closure would be and suggested alternate routes (2012-00816).

MoDOT surveyed drivers in order to gauge the effectiveness of various forms of public communication used regarding the I-64 closure. MoDOT learned that television news was the best method to communicate project information, according to 78 percent of respondents. Road signs near the highway, radio news, and newspapers were also considered effective by more than half of the respondents. Only about 40 percent of the respondents felt that the internet was an effective way for MoDOT to communicate with them. Overall, 95 percent of residents surveyed were satisfied or very satisfied with how the I-64 closure was handled.

Prior to the closure of I-64, the alternative routes added capacity through restriping on the interstates and through upgraded signals and improved signal timing on arterial roads. While the alternative routes saw increases in volume, the efforts undertaken to increase capacity kept travel times along those routes similar to pre-closure levels. It is estimated that by diverting 98,000 to 120,000 vehicles daily to alternative routes for two years, the cost was $101.5 million more than the normal operational state. However, a partial closure for six to eight years would have cost between $147 million and $188.3 million. Assuming construction materials remained constant with inflation, the accelerated construction saved between $93 million and $187 million.

13 Driver Assistance

13.1 Connected Eco Driving, Intelligent Speed Control, Adaptive Cruise Control, Platooning

13.1.1 Introduction

Controlling the speed of traffic flow either on freeways or arterials can have large impacts on the performance of the roadway in terms of mobility and environment. The basic implementation of this is an intelligent speed control system that limits the maximum speed of a vehicle by sending a message from the roadside infrastructure. Going a step further would involve interactions with other vehicles on the roadway to allow them to all follow a similar speed and smooth traffic flow. Adaptive cruise control systems set specific speeds to automatically follow; if there is a lead vehicle, a gap can be set for the vehicle to automatically keep. In the future, new communication technologies and connected vehicles will make vehicle platooning a realistic option. Platooning consists of vehicle platoons where two or more vehicles travel with small gaps/headways, reducing aerodynamic drag. Platooning relies on vehicle-to-vehicle (V2V) communication that allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction of drag results in reduced fuel consumption, greater fuel efficiency, less pollution for vehicles, and increased traffic flow.

Cooperative Adaptive Cruise Control Systems have the potential to be in every vehicle in the future, are very easy for drivers to use, and have the potential of up to a 37% reduction in fuel consumption in some scenarios [33].

Connected vehicle technologies and V2V communications allow things like Cooperative Adaptive Cruise Control (CACC) and vehicle platooning to be possible. Vehicles with these technologies can greatly increase mobility, decrease environmental impacts, and with the continuing development of better autonomous vehicle controls, increase safety.

Today many high end luxury cars are already equipped with some form of an ACC system. As the technology improves and becomes more economical, it will be seen more often in less expensive vehicle models.

All of these in-vehicle technologies are advanced aspects of eco-driving. Eco-driving is simply changing driver patterns and styles to reduce fuel consumption and emissions. When used in combination with in-vehicle communications, customized real-time driving advice can be given to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles based on prevailing traffic conditions and interactions with nearby vehicles. Feedback may be provided to drivers on their driving behavior to encourage driving in a more environmentally efficient manner. Vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy such as ACC and platooning are a great way to make eco-driving easier for the driver.

13.1.2 **Benefits**

Figure 13-1 shows safety, mobility, and environmental benefits of these technologies. The ACC and platooning with automated control of the vehicles provides the safety benefits of crash reductions. All of the technologies lead to environmental benefits including emissions reduction (usually of Carbon Dioxide) and fuel consumption reduction.

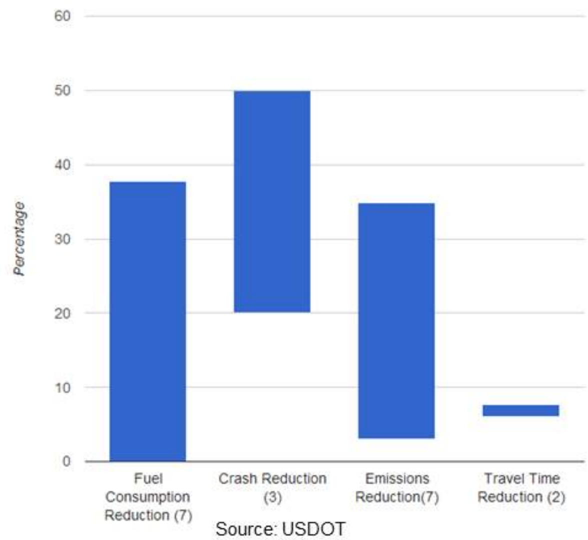


Figure 13-1: Range of Benefits for Connected Eco-Driving, Intelligent Speed Control, Adaptive Cruise Control, and Platooning (Source: ITS Knowledge Resources).

Recent eco-driving research shows significant fuel savings and emissions reductions. The eco-driving benefits in Figure 13-1 vary from simply providing eco-driving training to drivers or fleet companies to providing real-time driving feedback to the driver while in the vehicle. Both show great potential for fuel and emissions reduction. One study that included simulation and a field study was able to show that eco-driving also reduced travel times between six and eight percent (2010-00646).

13.1.3 **Costs**

Costs for these in-vehicle systems change rapidly as the technology is changing and improving. For example in 2006 it was estimated that on luxury vehicles ACC systems cost an additional $3,000 (2008-00175). Today for the most advanced ACC system in one luxury vehicle the cost is estimated at $2,000. This system would include features like automatically slowing the vehicle down if an issue ahead is detected and giving audio or visual warning to the driver to retake control of the speed of the vehicle. The system also works at any speed. The same auto manufacturer also offers a $500 ACC system with basic features that works at speeds 25 mph and higher [34]. That is over an 80 percent decrease in price in 7 years.

13.1.4 **Case Study - Safe Road Trains for the Environment (SARTRE)**

The overall concept of Safe Road Trains for the Environment (SARTRE) is to have a group of vehicles driving together with a lead vehicle, driven normally by a trained professional driver, and several following vehicles driven fully automatically by the system with small longitudinal gaps between them. Driving in this way, in a platoon, brings benefits in fuel consumption, safety and driver convenience. In addition to investigating the concept, a demonstrator system has been developed consisting of five vehicles: a lead truck, a following truck, and three following cars. An offboard system has also been developed to allow a potential SARTRE driver to find, and navigate to, a suitable platoon, although this has not been fully integrated into the vehicle system.

The project investigated the human factors aspects of platooning from the point of view of the lead driver, the following drivers, and the other road users. The demonstration system has been successfully tested on test tracks and public motorways, and demonstrated to industry stakeholders as well as members of the press. Using these vehicles, the fuel consumption benefits of platooning have been measured. The SARTRE project measured the fuel consumption individually for each vehicle in order to compare it with the fuel consumption while platooning. The distances tested for the full platoon system were 5, 6, 7, 8, 9, 10, 12, and 15 meters. A two-truck platoon was also tested at 20 and 25 meter gaps. Measurements of the fuel consumption are not available for cars in the full platoon system at gap sizes of 7 meters and below.

The results show that there is an important decrease in fuel consumption when platooning at shorter distances. For example, the following truck saw the highest fuel savings of 16 percent at a gap of 5 meters. When the gap was increased to 15 meters, the following truck still showed fuel savings of just over 8 percent. The following vehicles fuel savings ranged from 15 percent at a 7-meter gap to just over 4 percent at a 15-meter gap. This behavior follows a similar trend to what has been previously researched and also similar to that of the simulation results. Figure 13-2 shows all of the results by gap distance and vehicle location.

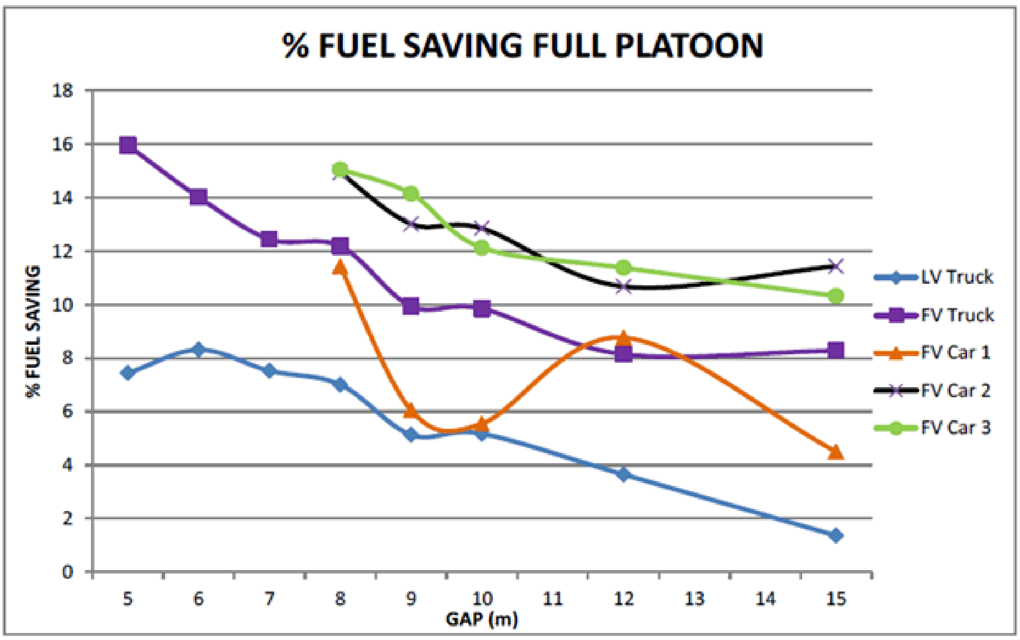


Figure 13-2: Percentage of fuel savings of each vehicle in the platoon at varying gaps (Source: SARTRE Final Report).

13.3 Navigation / Route Guidance, Driver Communications, and In-Vehicle Monitoring

13.3.1 Introduction

Driver assistance refers to a collection of capabilities and associated technologies to help augment key driving tasks, such as navigation, speed control, and parking. This fact sheet focuses on in-vehicle mobility assistance:

- 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.

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.

Eighty-three percent of the audible alerts received by drivers were rated as either good or neutral, and only 13 percent were rated as bad. The alerts enhanced drivers' situational awareness and improved safety on freeways.

13.3.2 Benefits

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 and predicted 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.

The tables below show the benefits of these technologies in reducing fuel consumption and vehicle emissions.

Table 13-1: Benefits of Navigation/Route Guidance.

ITS Goal	Selected Findings
Energy & Environment	In the Buffalo-Niagara region of New York, a green routing system for passenger vehicles showed: An average Carbon Monoxide (CO) emissions reduction of 16.77 percent, with only a 3.33 percent increase in the average travel time when the route was based on CO reduction. When the route was based on reducing Nitrogen Oxides (NOx), a 19.47 percent decrease was seen, with an 11.04 percent increase in travel time. When the route was based on reduced fuel consumption there was an average decrease of 5.55 percent gallons of gasoline used with a 12.7 percent increase in travel time (2013-00866). (For a long haul truck case: An 18.65 percent reduction in CO was seen with a 2.46 percent increase in travel time (2013-00866).
Energy & Environment	Eco-routing features that assist drivers with navigation can improve fuel economy by 15 percent by identifying more fuel efficient routes and save them up to 30 percent in mileage when searching for a parking space when appropriate information is provided. Overall, combining multiple eco-driving applications was projected to reduce fuel consumption by 20 percent. AVL systems can help commercial motor vehicles find more efficient routes which in effect can reduce VMT. An AVL/OBD technology solution identified eliminated 44,000 pounds of greenhouse gas emissions annually from the City of Napa's vehicle fleet (2012-00791).

Table 13-2: Benefits of Driver Communication.

ITS Goal	Selected Findings
Energy & Environment	A modeling study found that alerting drivers to the status of upcoming traffic signals led to smoother decelerations to the intersection. Results showed that the drivers alerted to the red signal 360 m (1200 ft) ahead of the intersection reduced fuel consumption and CO_2 emissions by up to 40 percent for passenger vehicles and 38 percent for pick-ups and SUVs at the posted speed limit of 65 km/h (40 mph) (**2011-00751**).
Safety Customer Satisfaction	Audible "slow traffic ahead" alerts can improve drivers' situational awareness and increase safety on freeways. The metric measuring variability in speed as drivers approached a queue supported the test hypothesis and confirmed that during the alert week, drivers experiencing the alerts exhibited smoother driving profiles. When the system worked as intended, 83 percent of the alerts received by drivers were rated as either good or neutral, and only 13 percent were rated as bad (2013-00823).

Energy & Environment	Commercial motor vehicles (CMV) can use Access Management applications such as Pre-Pass to improve motor carrier safety and efficiency. These systems allow participating transponder-equipped commercial vehicles to bypass designated inspection stations and continue to move freight and reduce shipment times. In 2009, Pre-Pass saved an estimated 21 million gallons of fuel for commercial vehicles (2012-00791).

Table 13-3: Benefits of In-Vehicle Monitoring.

ITS Goal	Selected Findings
Safety	Participating drivers from two motor carriers (identified as Carrier A and Carrier B) drove a vehicle equipped with a Driving Behavior Management System (DBMS) for 17 consecutive weeks while they made their normal, revenue-producing deliveries. For severe safety-related events, a 59.1 percent reduction in mean rate of severe safety-related events per VMT was observed at Carrier A and a 44.4 percent reduction was observed at Carrier B. (2011-00698)
Productivity Customer Satisfaction	By using an In-Vehicle Data Recorder (IVDR) to enable pay as you drive (PAYD) car insurance, drivers can save up to 60 percent on their car insurance premiums. A Brookings Institution study estimates that 63.5 percent of all households would experience savings with PAYD insurance, and such savings would amount to an average of $270 per vehicle and $496 per household, among households that do save. (2011-00717)
Productivity Energy & Environment	Idle-off stop-start systems integrated into vehicle designs can also be monitored by fleet management systems to reduce truck emissions up to 83 percent at truck rest stops. (2012-00791)

13.3.3 **Costs**

Costs and Outlook of On-Board Equipment for Connected Vehicles (2013-00288)

Respondents of the Connected Vehicle (CV) Technology Industry Delphi study overwhelmingly reaffirmed the consensus that Dedicated Short Range Communication (DSRC) is needed for cooperative, active safety systems, while third generation (3G) and fourth generation (4G) cellular communications tend to be thought of as appropriate for other applications.

DSRC was commonly viewed as being standard equipment by 2017. The majority think the applications will be built-in by that point. Below are consensus unit costs to include on-board DSRC equipment in vehicles:

- Cost to Vehicle Manufacturers of Embedded DSRC - In both rounds of the study, when asked how much it will cost vehicle manufacturers (in US$) to add a DSRC radio as embedded equipment, respondents gave a median response of $148 to $175 for 2017 and $73 to $75 for 2022. The second round means were $148 for 2017 and $73 for 2022.

- Cost Added to Base Vehicle Price for Connected Vehicle Technology - Regarding what connected vehicle technology will add to the base cost (in US$) of a new vehicle for the consumer, the median in both rounds was $350 for 2017 and $300 for 2022. The second round means were $335 for 2017 and $260 for 2022.
- Consumer Cost to Add DSRC as Aftermarket Equipment - The cost to the consumer (in US$) to add DSRC as aftermarket equipment had a median estimate of $200 for 2017 and $75 for 2022 in both rounds. The second round means were $233 in 2017 and $113 in 2022.

13.3.4 **Lessons Learned**

Consider New Approaches to Address Distracted Driving when Designing and Developing ITS Applications (2013-00651)

The SafeTrip-21 Initiative advanced knowledge and technological solutions to reduce distracted driving. The U.S. DOT tested a variety of technologies in a number of locations in California as well as along the I-95 corridor on the east coast. Below are some of the lessons learned during the evaluation of the SafeTrip-21 Initiative that focused on improving safety with the deployment of these applications:

- Assess vehicle location, speed and direction along with the ability to predict potential driving path conflicts and transmit alerts to the driver to provide needed capability to minimize driver distraction.
- Communicate alerts designed to orient drivers to general traffic conditions ahead, and therefore, make them more attentive to the driving environment to help reduce driver distraction.
- Use "Geofencing" as an approach to limiting driver distraction.
- Continue to explore avenues for advancements in technology to prevent driver distraction as well as instilling a safety culture mindset to support the goal of a change in driver behavior.

13.3.5 **Case Study - Crash Avoidance Metrics Partnership (CAMP) Driver Acceptance Clinics [35]**

From August 2011 through January 2012, the Crash Avoidance Metrics Partnership (CAMP) held driver acceptance clinics to introduce drivers to vehicle-to-vehicle communications aimed at reducing traffic accidents and saving lives.

Source: U.S.DOT

The clinics were held in six different locations around the country: the Michigan International Speedway, Brainerd International Raceway in Minnesota, Walt Disney World Speedway in Orlando, FL, the Virginia Tech Smart Road, the Texas Motor Speedway and Alameda Naval Air Station.

The clinics used 24 vehicles from eight participating automakers, each with its own system to provide safety information to drivers. The systems used sounds, lights, displays, and seat vibrations to alert drivers of various threats. A total of 688 drivers tested several scenarios that involved applications of connected vehicle technology including:

- Emergency electronic brake lights
- Forward collision warning
- Blind spot warning/ lane change warning
- Do not pass warning
- Intersection movement assist
- Left turn assist

Results

- More than four out of five participants, or 82 percent, strongly agreed that they would like to have vehicle-to-vehicle safety features on their personal vehicle.
- In addition, more than 90 percent of the participants believed that a number of specific features of the connected vehicle technology would improve driving in the real world, including features alerting drivers about cars approaching an intersection, warning of possible forward collisions, and notifying drivers of cars changing lanes or moving into the driver's blind spot.
- In 12 focus groups held with 96 participants, the most common reaction to the technology was that saving a life or many lives far outweighs the potential drawbacks of dependency, complacency or over-reliance on the technology.

14 Information Management

14.1 Introduction

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.

The 2012 transportation reauthorization law Moving Ahead for Progress in the 21st Century (MAP-21) has set up new requirements for performance-based transportation decision making, including establishing performance measures and targets in seven national goal areas such as congestion reduction and system reliability. Public agencies are seeking real time and archived data to provide metrics and measurements of system performance.

Example uses of archived ITS data include:

- 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.
- 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.

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.

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 transportation management centers (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.

14.2 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 not easily quantified. 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. Methodologies for computing the benefits of information management must be developed.

Table 14-1: Benefits of Information Management.

ITS Goal	Selected Findings
Customer Satisfaction	In Virginia, a web-based archived data management system (ADMS) was deployed to provide decision makers and other transportation professionals with traffic, incident, and weather data needed for planning and traffic analyses. An assessment of website activity indicated that 80 percent of the website usage was devoted to downloading data files needed to create simple maps and graphics. Overall, users were pleased with the ability of the system to provide a variety of data, but wanted more information on traffic counts, turning movements, and work zones, as well as broader coverage. (2008-00560)
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. (2008-00587)
Productivity	The Iowa Department of Transportation (DOT) found that a project to make data reporting and analysis tools available to local law enforcement organizations resulted in an increase in officer-generated crash reports received electronically from 68 percent from 47 percent, allowing the agency to provide statewide crash data on a quarterly basis. At the beginning of the project, the available data was 1.5 to 3 years old. (2013-00882)
Productivity	A study using archived data at five study locations with a variety of seasonal traffic patterns found that in some situations, up to 75 percent of all days can be missing data at urban locations when calculating annual average daily traffic statistics with archived ITS data. This finding challenges conventional procedures for the calculation of annual average planning statistics. (2013-00873)

14.3 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.

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, D.C. 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.

A study of the feasibility and implementation options for establishing a regional data archiving system to help monitor and manage traffic operations in Northeast Illinois estimated the cost for developing software to integrate data from multiple agencies in a region and produce both historical and real-time reports as ranging from $700,000 (low) to $1,000,000 (high) (2011-00221).

Table 14-2: System Costs of Archived Data Management Systems.

Cost Category	Source	Min	Max	Cost ID
ADMS	Washington State TRAC System and Caltrans PeMS	$85,000 (initial R&D)	$8,000,000	2008-00173
Statewide Electronic Crash Data Collection System	Vermont, Virginia	$1,105,000	$2,272,209	2013-00280
Regional Data Archive	Northeast Illinois Regional Data Archive (estimate)	$700,000	$1,046,000	2011-00221

Table 14-3: Selected Archived Data Management Costs.

Cost Category	Source	Min	Max	Cost ID
Hardware Costs	Illinois Regional Data Archive (estimate)	$42,400	$46,400	2011-00221
Operations and Maintenance	Virginia ADMS University of Maryland RITIS	$150,000 $400,000	$350,000 $400,000	2008-00174 2011-00220
Software Development	Illinois Regional Data Archive (estimate)	$700,000	$1,000,000	2011-00221
Training	Caltrans PeMS	$350,000	$350,000	2013-00291

14.4 Lessons Learned

The SafeTrip-21 Initiative demonstrated the feasibility of alternative approaches to collecting and using traffic data. In some cases, applications demonstrated new sources of traffic condition data. In other cases, applications made use of traditional data in new ways. The SafeTrip-21 Initiative highlighted, for example, how the mass-market availability of GPS-enabled smart phones complements traditional fixed sensors as a new data source, as well as offers the potential to deliver personalized travel information (2013-00649). Among the lessons learned are:

- **Use new and traditional data sources to enhance traffic models and to help solve problems related to mode shift and travel demand.** Traffic model development can benefit from integrating traffic probe data with other data sources for both freeways and arterials. Several SafeTrip-21 tests showed that ITS technology is capable of collecting the data needed by traffic and transit operations agencies to collaborate and better understand mode shift and travel demands across modes.
- **Consider procuring traffic data and information, rather than building in-house data collection systems, to reduce costs.** Agencies have traditionally procured hardware, software, and systems that allowed them to collect, analyze, and produce traffic data, which likely proved to be a laborious effort. An emerging alternative is to procure data and/or information services as a more cost-effective, resource-efficient alternative to developing the data and/or end product internally.
- **Explore the potential of new consumer devices, applications and services for collecting new traffic data and combining it with traditional traffic data to be used in new and innovative ways.** For example, cell phone GPS systems can alter the way traffic data is collected by leveraging the existing cell phone infrastructure to collect traffic data and transmit traffic information directly back to drivers.
- **Assess traffic data and information services carefully to ensure the quality and quantity of data and information needed**. The ability to deploy a traveler information concept is only as successful as the availability, timeliness, and accuracy of its data sources. Also, practical concerns of transportation professionals should govern their acceptance of new traffic data services and devices.

14.5 Case Study – Regional Integrated Transportation Information System (RITIS)

A major traffic accident on the Washington, D.C. Capital Beltway can cause traffic backups and delays, as well as secondary incidents for hours. There are four major transportation agencies and countless emergency management groups that can respond to traffic incidents, but in early 2003 there was only limited automated data sharing. Maryland, Virginia and D.C. transportation agencies and the Metro transit system approached the University of Maryland's Center for Advanced Transportation Technology Laboratory (CATT Lab) for help coordinating traffic around the Beltway.

"It turns out the agencies were collecting more data than we thought they did, but they weren't doing a good job managing their data," said Michael Pack, CATT Lab Director [36]. Each DOT had a different system from a different vendor, so the data came in a variety of formats.

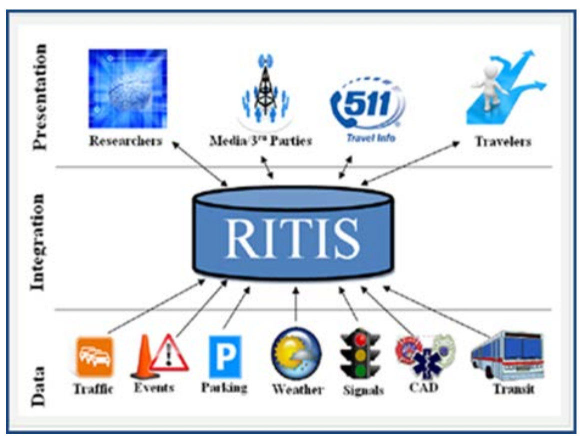


Figure 14-1: RITIS System Overview (Source: Maryland CATT Lab).

The Regional Integrated Transportation Information System (RITIS) is an automated data sharing, dissemination, and archiving system that includes many performance measure, dashboard, and visual analytics tools that help agencies to gain situational awareness, measure performance, and communicate information between agencies and to the public. RITIS automatically fuses, translates, and standardizes data obtained from multiple agencies in order to provide an enhanced overall view of the transportation network.

Participating agencies are able to view transportation and related emergency management information through innovative visualizations and use it to improve their operations and emergency preparedness. RITIS also uses regional standardized data to provide information to third parties, the media, and other traveler information resources including web sites, paging systems, and 511. There are three main RITIS components including, real-time data feeds, real-time situational awareness tools, and archived data analysis tools.

CATT Director Michael Pack explains the success of the RITIS system:

- 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 a more complete picture of the transportation system than they would have just using their own resources or archives of individual systems.
- Provide easy, free access to all of the data (or as much as you 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 benefits the transportation system and responds to real time events (2011-00583).

15 Commercial Vehicle Operations

15.1 Introduction

ITS applications for commercial vehicle operations (CVO) enhance communications between motor carriers and regulatory agencies, reduce administrative costs for public and private sector operations, and assure safe reliable movement of goods and services on the Nation's roadways. As part of the Motor Carrier Safety Improvement Act of 1999 the U.S. DOT commissioned the Federal Motor Carrier Safety Administration (FMCSA) to advance these goals and implement the Commercial Vehicle Information Systems and Networks (CVISN) program to fund state participation. CVISN consists of both Core and Expanded functions where Core functions have priority for nationwide deployment.

Core CVISN

- **Electronic credentialing** – Automates the application, processing, and issuance of motor carrier operating credentials.
- **Safety information exchange** – Facilitates the collection, distribution, and retrieval of motor carrier safety information at the roadside.
- **Electronic screening** – Enables commercial vehicles with good safety and legal status to bypass roadside inspections and weigh stations.

Expanded CVISN

- **Expanded electronic credentialing** – Enables authorized stakeholders to access current and accurate credentials information.
- **Smart roadside** – Connects remote inspection sites and virtual weigh stations to CVISN networks.
- **Enhanced safety information sharing and data quality** – Provides motor carrier access to Federal and state safety data and CVISN updates.
- **Driver information sharing** – Enables enforcement personnel to access driver records and safety data.

As of July 2013, all states and the District of Columbia have deployed at least one Core CVISN element. Eleven (11) states, however, have not yet achieved Core CVISN compliance because of transponder requirements needed for electronic screening.

Recent changes in Federal Policy address these issues and enable States to use alternate types of communication devices including smartphones, tablets, fleet management systems, GPS navigational units, and onboard telematics devices to transmit data as required to meet CVISN requirements [37].

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. Although commercial vehicle operators have demonstrated a willingness to participate in these programs, participation rates nationwide have been relatively low and included only about 20 percent of all commercial motor vehicles [38]. There is now wide consensus that regulatory agencies should no longer only focus on increasing the number of inspections carried out, but use available resources to increase the percentage of non-compliant vehicles stopped for inspection. With core CVISN capabilities expected in all states by 2015, agencies have identified alternative solutions through the Expanded CVISN program. The Smart Roadside Initiative, for example, will create efficient data handling between private and public sector motor carrier systems while maintaining current operational systems. Inspections and measurements traditionally conducted at weigh stations will be provided at strategic points along commercial vehicle routes to increase the effectiveness of available resources. Currently, four ITS application areas are the focus of this initiative [39].

1. E-screening vehicles in motion to automatically detect safety issues.
2. Improving truck size and weight enforcement with virtual weigh stations, and enhancing safety and credentials assessment with e-credentialing.
3. Transmitting driver, vehicle, and carrier safety data directly from commercial vehicles to the roadside and from carrier systems to government systems.
4. Providing commercial vehicle parking information so commercial drivers can make advanced route planning decisions based on hour-of-service constraints, location and supply of parking, travel conditions, and loading/unloading.

15.2 Benefits

Core CVISN

Electronic credentialing allows carriers to register with state agencies online to improve turn-around times and lower labor costs associated with permit processing and approval.

- Ninety-four (94) percent of motor carrier companies surveyed say that electronic credentialing is more convenient, 80 percent saw savings in staff labor time, and 58 percent achieved costs savings over manual methods (2011-00738).
- With more rapid processing and reduced overhead and labor costs, carrier savings can be as high as $360,500 per year depending on fleet size (2009-00609).
- A national evaluation of the CVISN deployment program indicated electronic credentialing has a benefit-cost ratio of 2.6 (2012-00787).

The safety information exchange (SIE) portion of the CVISN program integrates national and state databases enabling a coordinated review of registration and safety data. Enforcement personnel can access national database clearinghouses to review carrier regulatory compliance data and crosscheck safety assurance information. Electronic screening systems allow transponder equipped commercial vehicles to:

- Provide expedited information to inspection stations
- Improve inspection efficiency
- Allow safe and legal carriers to bypass roadside inspections and weigh stations.

An evaluation of the national CVISN program found that electronic screening has a benefit-cost ratio of 1.9 to 7.5. Results varied depending on the system configuration, level of deployment, and the benefits of crash avoidance gained through increased compliance (2012-00787).

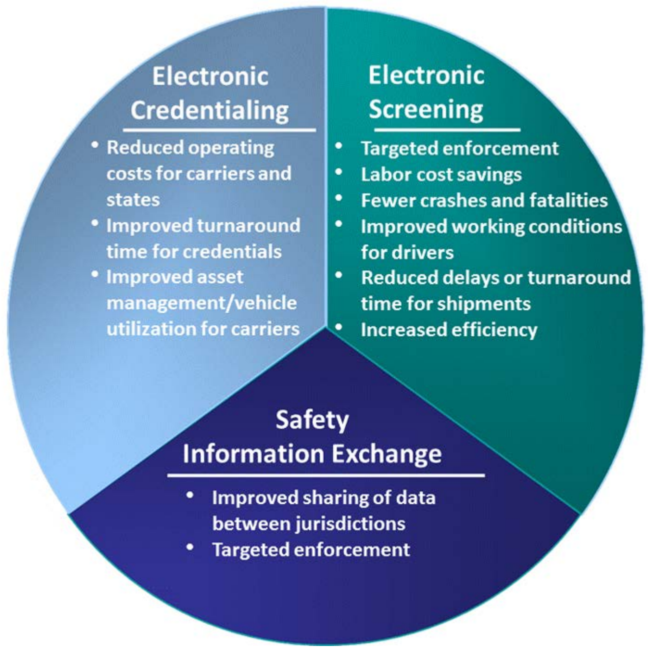


Figure 15-1: Summary of Benefits for Core CVISN Functions (Source: U.S. DOT, 2008 [40]).

Expanded CVISN

Initial results from limited scale field operational tests show that ITS applications for Expanded CVISN functions support Core CVISN functions and improve mobility, safety, and productivity for commercial vehicle operations. The Smart Roadside Initiative continues to develop, design, build, and test prototype applications designed to share data seamlessly between commercial vehicles, motor carriers, enforcement resources, highway facilities, intermodal facilities, toll facilities, and other nodes on the transportation system. Initial feasibility analysis conducted by the U.S. DOT suggest that with sufficient economies-of-scale, a network wide deployment of smart roadside applications can yield benefit-cost ratios ranging from 3.51:1 to 6.17:1 over 10 years [41].

Table 15-1: Wireless Roadside Inspection (WRI) Benefit-Cost Ratios, Nationwide (Source: U.S. DOT).

Annual Benefits	
Lives Saved	253
Injuries Prevented	6,192
Total Cost Savings	$1.7B

Annualized Costs	
Government—Facility, Equipment, IT, Communications Capital Costs (Amortized over 10 years)	$22M – $34M
Government—Facility, Equipment, IT, Communications O&M Costs	$23M – $42M
Industry—Annual Incremental Commercial Motor Vehicle (CMV) Costs. Based on 420,000 units/year ($533 - $940 per CMV)	$224M – $395M
Total Annualized Cost	$269M – $471M
Benefit-Cost Ratio	
Low-High	3.51:1 – 6.17:1
Average	4.84:1

Additional field studies in the United States and Canada show that vehicle-to-infrastructure (V2I) technologies can make surface transportation safer, smarter, and greener.


Photo Source: USDOT

- Dynamic mobility applications that improve data sharing among commercial vehicle drivers can improve freight travel times up to 20 percent (2013-00845).
- In British Columbia, a study of the Green Light Transportation System (GLTS) found that adding an automated license plate reader (ALPR) to an electronic screening system effectively focused inspections on high-risk carriers, reduced commercial vehicle travel times, and decreased fuel consumption and emissions resulting in a benefit-cost ratio of 26.2:1 (2013-00836).

15.3 Costs

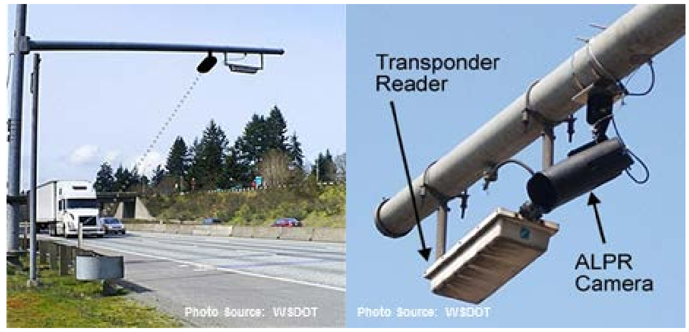
Core CVISN

Data collected from four states (Montana, New Jersey, New York, and South Dakota) show Core CVISN costs vary widely depending on the size of the state, and the level and type of systems deployed.

- The average start-up cost for electronic credentialing was estimated at $1.35 million per state (with a range of $28,037 to $8.57 million) with annual operating and maintenance costs estimated at $250,000 per year ($22,645 to $1.09 million) (2011-00229).
- The average per state start-up costs for safety information exchange systems were estimated at roughly $680,000 ($31,828 to $2.68 million) with operating costs estimated at $74,000 per year (2011-00230).
- The average per state start-up cost for electronic screening systems varied from $1 million to $2.8 million (2011-00231).

Expanded CVISN

Virtual weigh stations can monitor traffic in truck-only lanes without having to purchase extensive right of ways located adjacent to the mainline for weigh station construction. CVISN funding requests suggest that virtual weigh station system costs range from $300,000 to $1.4 million (2013-00287).



Automated license plate reading systems (ALPR) can supplement Core CVISN functions. The cost of an ALPR system used to supplement existing inspection systems at eight inspection sites was estimated at $1.06 million (CAN).

- Total hardware costs for sensors, cameras, and overview image capture equipment were estimated at $484,000.
- Total software costs including an enterprise software module, and customized optical character recognition (OCR) and electronic screening software at eight inspection sites were estimated at $382,000 (2013-00279).

15.4 Case Study - Wireless Roadside Inspection Field Operational Test

In Schodack, New York a field operational test was conducted to evaluate the performance of a smart roadside inspection station (SRIS) installed on I-90. The system was designed with a weigh-in-motion (WIM) system in the mainline, dedicated short range radio communications (DSRC), an ALPR system, and enhanced imaging that enabled the system to detect overheight vehicles, read U.S. DOT Numbers, and identify HAZMAT placard symbols posted on commercial vehicles. The on-site equipment and e-screening software were connected to the New York State Commercial Vehicle Information Exchange Window (CVIEW) and New York State Commercial Vehicle Infrastructure Integration (CVII) network which enabled the system to query several databases and collect and share compliance data on high-risk carriers. The databases queried by the system included:

- FMCSA SAFER (Safety and Fitness Electronic Records) system
- FMCSA PRISM (Performance and Registration Information Systems) program
- NYS Tax and Finance HUT (Highway Use Tax) credentials database
- NYSDOT OS/OW (Oversize/Overweight) permits database.

Evaluators monitored SRIS activity for the last 10 minutes of every hour between December 6 and December 7, 2012 and a total of 240 commercial vehicles were detected and processed.

Findings

Compared to traditional commercial vehicle inspection methodologies SRIS reduced the number of Level 1 Commercial Vehicle Safety Alliance inspections required to maintain target enforcement levels (number of non-compliant carriers expected to be placed out-of-service each day). With an inspection station that performs 20 inspections per day the system was estimated to save 14 compliant carriers from 14 needless one-hour inspections and improve the out-of-service rate by 70 percent (2013-00859).

Fuel Consumption and Emissions

- Fuel savings for compliant carriers were estimated at $89,425 per year.
- Total annual emissions savings were estimated at 6.57 metric tons.

Carrier Mobility and Productivity

- Time savings for trucks at $75 per hour would save $383,250 per year.

Inspector Productivity and Efficiency

- Time savings for agency personnel at $45 per hour would save approximately $1.15 million per year with enforcement levels maintained.

16 Intermodal Freight

16.1 Introduction

While the United States economy has been affected by an economic downturn in recent years, it is expected to recover and continue to grow. Long-term economic growth should result in even greater demand for freight transportation.

The freight industry and its customers are increasingly turning to information technologies and telecommunications to improve freight system efficiency and productivity, increase global connectivity, and enhance freight system security against common threats and terrorism. In short, these technologies help freight operators use the transportation system more intelligently. Most importantly, they do so in ways that improve safety, whether related to hazardous materials transport, heavy truck operation and maintenance, or load limit compliance.

Analyses in the HAZMAT FOT Final Synthesis show that using wireless communications and GPS tracking can save from $80 to $309 per month by reducing empty freight miles.

Intelligent freight technologies are currently deployed in several areas including the following:

- Asset tracking: Mobile communications and global positioning systems, bar codes, and radio frequency identification (RFID) tags track the location of trucks, containers, and cargo to improve efficiency and to ensure the safety and security of shipments.
- On-board status monitoring: Sensors record vehicle operating conditions, check the condition of cargo, and detect tampering or intrusion.
- Gateway facilitation: Non-intrusive inspection technologies, such as scanners and RFID tags, are used at terminals, inspection stations, and border crossings to search for contraband and enhance national security.
- Freight status information: Web-based technologies facilitate the exchange of information on freight shipments and improve data flows.
- Network status information: Cameras, road-sensors, and display technologies monitor congestion, weather conditions, and incidents.

The ITS Knowledge Resources provides information about the state of the art and the adoption of effective technologies by the freight industry and its customers. This information includes private, public, and network-based benefits, costs and lessons learned.

16.2 Benefits

Efficiency Benefits Assessment

A U.S. DOT HAZMAT Field Operational Test (FOT) was conducted to test methods for leveraging technology and operations to improve HAZMAT transport security and operational efficiency. The evaluation of this FOT quantified benefits resulting from technology deployments that improve the security and operational efficiency of HAZMAT shipments from origin to destination.

Regardless of technology configuration in the FOT, two technologies created the enabling platform on which the other test technologies operated – wireless communications and asset positioning/tracking. Through discussions with the participating motor carriers, these two capabilities provided the majority of measurable operational benefits. Without these two capabilities, potential operational, as well as safety and security benefits of the other test technologies could not be realized.

The inputs used in calculating per truck monthly benefits of Wireless Communications with GPS tracking are presented in *HAZMAT FOT Volume III* report, Section 2 [42]. The return-on-investment (ROI) model essentially equates downtime savings associated with eliminated driver call-in stops and unscheduled en-route maintenance/repairs with increased asset capacity. The ability to know where assets are, the state of conditions vis-à-vis maintaining schedule, and knowing driver availability for hours of service allows dispatchers/load planners to assess the feasibility for picking up potential backhaul loads (applicable to the operation). The model also estimates the value of freed up phone call time for dispatchers talking with drivers, thus allowing them to focus on other duties, or have the time to manage more drivers if necessary. Other benefits include lower communications costs, less idling time (associated with driver call-in stops), resulting in reduced fuel and engine wear costs. These benefits are displayed below in Table 16-1 (2013-00880).

Table 16-1: Estimated and Minimum Estimated Monthly Per Truck Benefits Derived Using Wireless Communications with GPS Vehicle Positioning System.

Benefits	LTL* High Hazard	Bulk Chemicals	Truckload Explosives
Improved vehicle utilization by reducing empty miles (Estimated)	$309	$199	$270
Improved vehicle utilization by reducing empty miles (Minimum)	$124	$80	$108

* Less than Truckload (LTL) shipping

It is recognized that all operations are not able to realize many of the estimated benefits as modeled for the FOT participants. The proportion and degree to which carriers realize benefits of technologies has been examined in numerous case studies and industry benefit-cost analyses. To explore low-end benefits of the Wireless Communications with GPS vehicle positioning system, this effort draws upon the results of a 1999 American Trucking Association (ATA) Foundation study that examined the benefits and costs of technology systems across a wide-range of carrier operations for over 900 surveyed motor carriers. Among the findings, carriers using Wireless Communications and vehicle tracking technologies, 33 to 47 percent increased loads; 22 to 35 percent reduced non-revenue miles; and 12 percent lowered driver to dispatcher ratios. By focusing only on these three areas of operational efficiency improvements (using the midpoint values) and ignoring the other modeled benefits, the results of a "minimum" benefit analysis are presented in Table 16-1 as well.

16.3 Costs

The benefits presented in Section 6 of the HAZMAT FOT Volume II synthesis report were compared to the generally, more high-end costs of the satellite and terrestrial-based product/service offerings to estimate benefit-cost ratios and expected payback periods. Per the synthesis report, Table 2 presents the costs by industry segment (capital costs are amortized over three years). Using the costs from Table 16-2 and benefits developed in the synthesis document, benefit-cost ratios were calculated, with the results shown per segment/fleet size in Table 16-3 (2013-00290).

Table 16-2: Per Truck-Specific Technology Costs (Wireless Communications with GPS Tracking Capabilities).

Item	Purchase Cost Truck Terrestrial/Satellite	Annual Cost Truck Terrestrial/Satellite
Mobile Communications with GPS Tracking Units (Hardware Costs)	$1,000 / $2,000	$336 / $672
Installation	$200	$72
Basic Monthly Service (per truck)		$600
Monthly Maintenance Agreement		$180
Total Per Truck Costs	$1,200 / $2,200	$1,188 / $1,524

Table 16-3: Costs, Benefits, Benefit-Cost Ratios, and Payback Periods by Industry Segment (Wireless Communications with GPS Tracking Capabilities).

Segment/Fleet Size	Annual Cost/Truck	Annual Benefit/Truck	Benefit-Cost Ratio	Payback on Purchase in Months
Bulk Fuel (Terrestrial)	$1,188	$5,832	4.9:1	3
LTL-High Hazard (Satellite)	$1,524	$2,352 to $9,840	1.5:1 to 6.5:1	3 to 17
LTL Non-Bulk (Terrestrial)	$1,188	$1,920	1.6:1	13
Bulk Chemicals (Satellite)	$1,524	$1,560 to $7,116	1.0:1 to 4.7:1	5 to 34
Truckload Explosives (Satellite)	$1,524	$1,824 to $11,004	1.2:1 to 7.2:1	3 to 25

16.4 Lessons Learned

Implementing a National Freight Data Architecture

In practice, the value of a national freight data architecture is a function of the costs associated with its implementation. Quantifiable data about expected benefits and costs are currently not available and were not part of the Guidance for Developing a Freight Transportation Data Architecture survey. However, it is clear from the documentation and information gathered during the research that the "do-nothing" alternative (i.e., not implementing the national freight data architecture) is costly, ineffective, and unsustainable. Therefore, the research teams recommended to pursue the national freight data architecture following a scalable implementation path in which the national freight data architecture starts with one application at one or two levels of decision making and then adds applications and levels of decision making as needed or according to a predetermined implementation plan until, eventually, reaching the maximum net value.

The research team for this guidance conducted a planner and analyst survey, a shipper survey, and a motor carrier survey (as well as follow-up interviews) to gather information about freight data uses and needs. The research team also conducted interviews with subject matter experts to address specific items of interest to the research. The purpose of the planner and analyst survey was to gather information from government planners, analysts, and other similar freight-related stakeholders. Respondents were involved in all modes of transportation, including air, rail, truck, pipelines, and water. Respondents indicated that they use freight data to support the production of a wide range of public-sector transportation planning documents, adding weight to the notion that the national freight data architecture should support a variety of freight-related processes. Respondents reported using and/or needing data at various levels of geographic coverage and resolution. The feedback on unmet data needs complement similar findings in the literature.

Below are lessons learned through surveys conducted during the preparation of Guidance for Developing a Freight Transportation Data Architecture (2013-00655).

- Understand the different business processes that affect freight transportation at different levels of coverage and resolution.
- Understand the supply chain, which should help transportation planners to identify strategies for improving freight transportation infrastructure.
- Recognize the role that different public-sector and private-sector stakeholders play on freight transportation.
- Recognize the need for standards to assist in data exchange.
- Coordinate systematic development of reference datasets (e.g., comprehensive commodity code crosswalk tables).
- Develop systematic inventory of freight transportation data sources.

- Develop systematic inventory of user and data needs that are prerequisites for the development of freight data management systems.
- Use as a reference for the identification of locations where there may be freight data redundancy and inefficiencies.
- Use as a reference for requesting funding allocations in the public and private sectors.
- Use as a reference for the development of outreach, professional development, and training materials.

Using Information Systems for Intermodal Ports

Pacific Gateway Portal (PGP) is a port user information system in a web-based form, operated by the Port of Vancouver [43]. The information available on PGP includes container status, vessel activity, and real time video images from both the port terminal side and also truck and driver identification. This system also has an option of an appointment system for trucks and dangerous goods applications. A truck appointment system is in use at all three terminals within the Port of Vancouver, and is very successful. In order to make appointments truck companies use the terminal's web page. Appointments are matched with transactions determined by the terminal on the basis of capacities of terminal. Dedicated lanes are in use for trucks with an appointment. An approved Truck Licensing System (TLS) License is required by any party wishing to access Port of Vancouver's property for the purposes of draying marine containers to or from any of the terminals under the jurisdiction of Port Metro Vancouver. Trucks without a TLS license are not allowed to access Port Metro Vancouver property. Truckers also have to be in line at the gate entrance at least 15 minutes before expiration of their reservation time. If trucks arrive late they are required to go to the line for trucks with no reservation, or they will need a new reservation. There is no fee to use the reservation system, but there is a fee to use the web portal.

One of the major problems at marine container terminals is that the terminal gates, where trucks enter and exit the terminal to deliver or pick-up a container, are only open during certain hours on weekdays; due in part to union agreements, although operations within the terminal carry on 24/7. Consequently, trucks are forced to pick-up and deliver containers during specific hours of the day, resulting in high demand over certain periods. This phenomenon has led to inefficient gate operations that can spill traffic over to the surrounding roadway network causing serious safety and congestion problems. The problem of congestion also extends to the yard of the terminals where coupled with capacity issues, it can degrade the reliability and performance of carriers, shippers, and terminal operators. In addition to the deterioration of the performance of terminal and drayage operations, the environmental effects from idling trucks has also been starting to emerge as a serious problem as truck emissions have been linked to health conditions including asthma, cancer and heart disease [44].

Since intermodal freight terminals tend to be located in or near major cities, where right of way is limited and very expensive, implementing operational strategies to reduce the effect of the terminals' truck related traffic on the surrounding roadway network and the terminal operations becomes more important and more viable than physical capacity expansions. Because of this, there is much research focusing on improving efficiency in the operations of intermodal marine container terminals without having to expand physical capacity. Below are a few of the lessons learned through implementation of the types of systems used at the Port of Vancouver (2013-00652):

- **Coordinate between trucking companies and port intermodal terminals for efficient terminal operations.** Gates that are clogged can worsen terminal capacity and this creates not only an operational but also an environmental problem. For a tactical/operational level gate strategy system to be effective, a large percentage of trucks will have to use it, and there has to be some priority or benefit for trucks with appointments. Incentives are necessary to get trucking companies to buy into appointment systems and actually make appointments (and keep them). Incentives may also be needed for the terminals to use the systems effectively. Gate appointments are a more favored alternative than extended gate hours, since the cost is lower.

- **Deploy and expand gate appointment systems.** Gate appointment systems have the potential to dramatically improve operations inside the terminal as well as at the gate, and as a secondary result, reduce congestion on the roadway system, and therefore reduce harmful emissions in the neighboring communities. Of course, as freight shipping increases, there will be a point that limits the amount of trucks and containers that can physically be processed within the constraints of terminal boundaries, but there is certainly room for improvement now, before reaching that point. For extended gate hours, additional workers are required at off-peak times, but this is a viable option to increase throughput at terminals. It will require that additional workers be added, hours and pay contracts be adjusted and associated businesses buy-in, but there is potential for greater amounts of container movement without the need to expand terminals.

Increased efficiency at intermodal port terminals due to any or all of the strategies discussed in this paper can affect the overall transportation community and all other types of intermodal transportation by allowing more containers to be shipped, and moved more quickly away from the ports, onto the other forms of transportation, and to their final destinations. Appointment systems and extended hours, as well as the managing technologies can be used by other modes experiencing congestion and air quality concerns to increase efficiency, thereby lowering congestion and emissions. The key to developing effective gate appointment systems is to ensure participation from all key stakeholders.

17 Electronic Payment and Pricing

17.1 Introduction

Congestion pricing, also known as road pricing or value pricing, uses ITS technology to charge 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. Congestion pricing is different from tolling in that pricing strategies are used primarily to manage congestion or demand for highway travel, while also generating revenue to repay a bond or debt.

The U.S. DOT Congestion Pricing Primer describes four main types of congestion pricing strategies [45]:

- 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.

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:
http://www.ops.fhwa.dot.gov/tolling_pricing.

17.2 Benefits

Electronic toll collection is a proven technology that has greatly reduced toll plaza delays, with corresponding improvements in capacity, agency cost savings, and fuel consumption reductions. Congestion pricing builds on this success and "benefits drivers by reducing delays and stress, businesses by improving delivery and arrival times, transit agencies by improving transit speeds, and state and local governments by improving the quality of transportation services without tax increases or large capital expenditures, and by providing additional revenues for funding transportation" [46]. Recent congestion pricing initiatives have produced positive benefit-cost ratios, ranging from 1:1 to 25:1, as shown in Table 17-1.

Table 17-1: Benefit-Cost Ratios of Congestion Pricing Strategies.

Benefit-Cost Ratio	Description	Application
1:1 to 8:2	Benefit-cost estimates for dynamic pricing applications on freeway shoulder lanes ranged from 1.1 to 8.2. (2011-00777)	Freeway shoulder lanes
7:1 to 25:1	Integrated Corridor Management (ICM) strategies that promote integration among freeways, arterials, and transit systems can help balance traffic flow and enhance corridor performance; simulation models indicate benefit-cost ratios for combined strategies range from 7:1 to 25:1. (2009-00614)	Integrated Corridor Management
6:1	In the Seattle metropolitan area the net benefits of a network wide variable tolling system could exceed $28 billion over a 30-year period resulting in a benefit-cost ratio of 6:1. (2011-00694)	Network wide – freeways and arterials

Figure 17-1 shows ranges of benefits for select entries in the ITS Knowledge Resource database at: http://www.itsknowledgeresources.its.dot.gov/. Benefits can be seen with many different measures across multiple goal areas including mobility, safety, and the environment. In this case, congestion pricing benefits include travel speed increases, traffic reduction, crash reduction, carbon dioxide emissions reduction, and transit ridership increases.

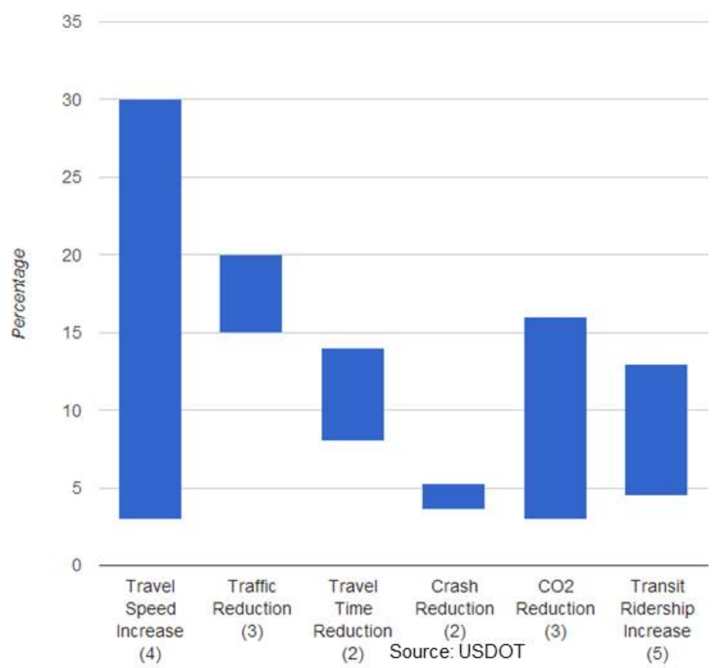


Figure 17-1: Range of Benefits for Congestion Pricing (Source: ITS Knowledge Resources).

17.3 Costs

Congestion pricing is becoming more popular as a viable and sustainable solution to traffic congestion. Increasingly, highly congested areas in the U.S. are looking at HOT lanes as an alternative to under-used HOV lanes.

Typically, the highest costs for congestion pricing stem from converting existing toll lanes to HOT lanes or building new ones. Operations and Maintenance, including enforcement, and maintaining toll readers, dynamic message signs and surveillance equipment is also a significant expense. In many cases these costs are borne or shared by a private entity that builds and manages the high occupancy toll lanes in exchange for some or all of the revenue generated by them.

Table 17-2: Congestion Pricing Capital Costs.

Description	Capital Cost	Type of Congestion Pricing	Location
Cost to convert HOV to HOT on an eight-mile section of I-15 in San Diego. (2008-00135)	$1.85 million	Variable priced lanes	California
Cost to convert HOV to HOT on a seven-mile section of I-25/U.S.-36 in Denver. (2010-00201)	$9 million	Variable priced lanes	Colorado
Cost to convert HOV to HOT on an eleven-mile section of I-394 in Minneapolis. (2010-00201)	$13 million	Variable priced lanes	Minnesota
Cost to convert HOV to HOT on a nine-mile section of SR-167 in Puget Sound. (2010-00201)	$17 million	Variable priced lanes	Washington
Planning level estimate to convert HOV lanes to managed lanes on I-75/I-575 in Georgia. (2007-00128)	$20.9 to $23.7 million	Variable priced lanes	Georgia
Congestion pricing example in Italy. (2011-00213)	$72 million	Cordon charge	Rome
Congestion pricing example in Sweden. (2011-00213)	$500 million	Cordon charge	Stockholm
Congestion pricing example in the United Kingdom. (2011-00213)	$170 million	Cordon charge	London
Cost for the Orange County Transportation Authority (OCTA) to purchase a four-lane 10-mile-long limited access variable toll facility. (2010-00202)	$207.5 million	Variable priced lanes	California
Estimate to implement a network-wide variable tolling system in Seattle. (2011-00235)	$749 million	Variable toll – entire network	Washington

Estimate to implement a comprehensive VMT-based charging system for all road use in the Netherlands by 2016. (2011-00241)	$2.26 billion	Area charge based on Vehicle miles travelled	The Netherlands

Table 17-3: Congestion Pricing Operating Costs.

Description	Annual Operating Cost	Type of Congestion Pricing	Location
Congestion pricing example in Italy. (2011-00213)	$4 million	Cordon charge	Rome
Congestion pricing example in Sweden. (2011-00213)	$35 million	Cordon charge	Stockholm
Congestion pricing example in the United Kingdom. (2011-00213)	$161 million	Cordon charge	London
Rough estimate to operate a network-wide variable tolling system in Seattle. (2011-00235)	$288 million	Variable toll – entire networks	Washington
Rough estimate to operate a comprehensive VMT-based charging system for all road use in the Netherlands by 2016. (2011-00241)	$667.6 million	Area charge based on Vehicle miles travelled	The Netherlands

Congestion pricing projects can be costly to implement and operate, but the costs are offset by toll revenues, typically resulting in an overall positive benefit-cost ratio. Between 2003 and 2007, annual operating costs and revenues at 15 tolling agencies averaged $85.825 million and $265.753 million, respectively. In 2007, tolling agencies expended about 33.5 percent of revenues on toll collection operations, administration, and enforcement costs (2011-00240).

Recent lessons learned show that educating the public about the benefits of congestion pricing and engaging political champions early in the process lead to successful congestion pricing projects.

17.4 Lessons Learned

Engage political champions to keep controversial High-Occupancy Toll (HOT) lane projects on track.

In 2008, Los Angeles County Metropolitan Transportation Authority (Metro), with Caltrans and local mobility partners, was selected to participate in a one-year demonstration program beginning Fall 2012 to convert 25 miles of High-Occupancy Vehicle (HOV) lanes to High-Occupancy Toll (HOT) lanes on the I-10 and I-110 corridors.

In 2009, six public hearings were conducted prior to the adoption of the tolling policy and toll rates by Metro. In 2010, two environmental impact reports (EIRs) and the Low Income Commuter Assessment were completed, and a contractor was selected to implement a design-build-operate-maintain (DBOM) contract. In 2011, construction was initiated and in 2012 operations were scheduled to begin on the I-110 followed by the I-10.

The following lessons learned were highlighted during the Urban Partnership Agreement (UPA) - Congestion Reduction Demonstration (CRD) program update webinar held December 15, 2011 (2011-00609).

- **Have a political champion to ensure successful implementation of HOT Lane projects.** Champions are critical to launch pricing projects to gain acceptance among key policy makers and other stakeholders.
- **Engage the public early and often throughout the life of the project.** Corridor advisory groups comprised of business and community leaders can collaborate on goals and refine project elements. Communication and public outreach is most important at key milestones.
- **Make HOT Lane projects multi-modal.** A multi-modal approach increases public acceptance. Advancing a variety of modal options enables everyone to benefit.
- **Address equity issues early in the planning process**. A comprehensive plan gains more acceptance if equity issues are integrated into the pricing project. So, while low income commuters generally use transit, they appreciate the opportunity to use the ExpressLanes when they choose.

Overall, the program is expected to reduce congestion and greenhouse gas emissions, increase travel time savings, and improve trip reliability. Updates are available on the Metro ExpressLanes project website: http://www.metro.net/projects/expresslanes/.

17.5 Case Study - I-394 MnPASS and I-35W Expansion

In May 2005, Minnesota implemented High-Occupancy Toll (HOT) lanes along 11 miles of Interstate 394 from downtown Minneapolis through the western suburbs. In 2009, the system was expanded to I-35W. In 2012, a study was conducted to see if the benefits initially reported were maintained over time (2013-00854).

Findings

The benefits of HOV to HOT conversions and expansion have been maintained over time with lower operating costs.

The 6 percent increase in travel speed and 5 percent increase in volume reported during peak periods in the six-month period after I-394 HOT lane implementation in November 2006 have been maintained through year 2012. Expansion of the system to I-35W required a capital investment that was 37 percent that of the initial I-394 investment with an operating cost increase of only 17 percent above I-394 operating costs.

Benefits from the I-35W expansion were observed in a 3 percent increase in corridor volume while maintaining consistent speed on the mainline and HOT lane. Overall cost per transponder transaction has declined by 32 percent from year 2006 to year 2011. So while benefits are slightly lower, the lower operating costs may result in a higher benefit-cost ratio compared to the initial implementation. The overall benefit-cost ratio for the Urban Partnership Agreement (UPA) Projects that included the I-35W expansion was 6:1 (2014-00910).

- Have the initial impacts of the system on I-394 changed over time?
  - No, benefits were maintained
- Did the expansion to I-35W result in similar benefits?
  - No, slightly lower benefits
- Have economies of scale been obtained by I-35W expansion?
  - Yes, 32 percent lower cost/transaction

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APPENDIX A. List of Acronyms

Acronym	Meaning
ACC	Adaptive Cruise Control
A-CMBS	Advanced Collision Mitigation Braking System
ACN	Automated Collision Notification
ADMS	Archived Data Management System
AERIS	Applications for the Environment: Real-Time Information Synthesis
AFV	Alternative Fuel Vehicle
ALPR	Automatic License Plate Reader
AMS	Analysis, Modeling and Simulation
API	Application Program Interface
APIS	Automated Parking Information System
ASCT	Adaptive Signal Control Technologies
ATA	American Trucking Association
ATCS	Adaptive Traffic Control Systems
ATDM	Active Traffic Demand Management
AVL	Automatic Vehicle Location
AWWS	Automated Wind Warning System
BART	Bay Area Rapid Transit
BNSF	Burlington Northern Santa Fe
BRT	Bus Rapid Transit
CACC	Cooperative Adaptive Cruise Control
CAD	Computer Aided Dispatch
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CAP	Centralized Accident Processing
CARS	Condition Acquisition Reporting System
CATT	Center for Advanced Transportation Technology
CCTV	Closed Circuit Television
CDOT	Colorado Department of Transportation
CMV	Commercial Motor Vehicle
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO2	Carbon Dioxide
CVIEW	Commercial Vehicle Information Exchange Window
CVII	Commercial Vehicle Infrastructure Integration
CVISN	Commercial Vehicle Information System and Network
CVO	Commercial Vehicle Operations
CWS	Collision Warning Systems
DBMS	Driver Behavior Management System
DMA	Dynamic Mobility Applications
DMS	Dynamic Message Signs
DOE	Department of Energy
DOT	Department of Transportation
DPS	Department of Public Safety

Acronym	Meaning
DSRC	Dedicated Short Range Communications
DTA	Dynamic Traffic Assignment
E85	Ethanol (85%)
EDC	Every Day Counts
EMS	Emergency Medical Services
EPA	Environmental Protection Agency
ESC	Electronic Stability Control
ETC	Electronic Toll Collection
FARS	Fatality Analysis Reporting System
FBI	Federal Bureau of Investigation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	Field Operational Test
GHG	Greenhouse Gas
GLTS	Green Light Transportation System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
HAR	Highway Advisory Radio
HAWK	High-Intensity Activated Crosswalk
HAZMAT	Hazardous material
HOT	High Occupancy Toll
HOV	High-Occupancy Vehicle
HUT	Highway Use Tax
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
IDOT	Illinois Department of Transportation
IMT	Incident Management Team
ISIG	Intelligent Traffic Signal System
ITD	Idaho Transportation Department
ITS	Intelligent Transportation Systems
IVDR	In-Vehicle Data Recorder
JPO	Joint Program Office
LAN	Local Area Network
LNG	Liquefied Natural Gas
LTL	Less than TruckLoad
MAG	Maricopa Association of Governments
MAP-21	Moving Ahead for Progress in the 21st Century
MDSS	Maintenance Decision Support System
MMITSS	Multi-Modal Intelligent Traffic Signal System
MMTPS	Multi-Modal Intelligent Traffic Signal System
MMUCC	Model Minimum Uniform Crash Criteria
MOVES	MOtor Vehicle Emissions Simulator
MPG	Miles Per Gallon
MPO	Metropolitan Planning Organization
MSAA	MOtor Vehicle Emissions Simulator

Acronym	Meaning
NCDOT	North Carolina Department of Transportation
NG9-1-1	Next Generation 911
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NORPASS	North American Pre-clearance and Safety System
NOVA	Northern Virginia
NOx	Nitrous Oxide
NYC	New York City
NYS	New York State
NYSDOT	New York State Department of Transportation
OBD	On-Board Device
OCR	Optical Character Recognition
O-D	Origin-Destination
OS/OW	Oversize/Overweight
PAYD	Pay as you Drive
PCB	Professional Capacity Building
PDA	Personal Digital Assistant
PGP	Pacific Gateway Portal
PM10	Particulate Matter 10
PM2.5	Particulate Matter 2.5
PRISM	Performance and Registration Information Systems
PTMS	Portable Traffic Management Systems
RFID	Radio Frequency Identification
RICAS	Rural Intersection Collision Avoidance System
RITA	Research and Innovative Technology Administration
RITIS	Regional Integrated Transportation Information System
ROI	Return on Investment
RSIP	Rural Safety Innovation Program
RTA	Regional Transit Authority
RWIS	Road Weather Information Systems
RWM	Road Weather Management
SAFER	Safety and Fitness Electronic Records
SARTRE	Safe Road Trains for the Environment
SCAQMD	Safety and Fitness Electronic Records
SEMP	Systems Engineering Management Plan
SFMTA	San Francisco Municipal Transportation Agency
SHRP 2	Second Strategic Highway Research Program
SIE	Safety Information Exchange
SRIS	Smart Roadside Inspection Stations
SSP	Safety Service Patrol
STH	State Trunk Highway
SUV	Sport Utility Vehicle
TCRP	Transit Cooperative Research Program
TLS	Truck Licensing System
TMC	Transportation Management Center

Acronym	Meaning
TOC	Transportation Operations Center
TREDS	Traffic Records Electronic Data System
TSP	Transit Signal Priority
U.S	United States
URL	Uniform Resource Link
U.S. DOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VES	Vehicle Enforcement System
VIDS	Video Imaging Detector Systems
VMT	Vehicle Miles Traveled
VPP	Vehicle Probe Project
VSL	Variable Speed Limit
WIM	Weigh-In-Motion
WMATA	Washington Metropolitan Area Transit Authority
WRI	Wireless Roadside Inspection
WRTM	Weather-Responsive Traffic Management
WSDOT	Washington State Department of Transportation

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