NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP 03-101

Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies

FINAL REPORT

by
JULIE EVANS
HOLGER HINSCH
NICHOLAS KEHOE
FRANK PERRY
ANASTASIOS ZOGRAFOS
LEIDOS
Reston, VA

DECEMBER 2014

Acknowledgment of Sponsorship and Disclaimer

Acknowledgment

This study was conducted for the National Cooperative Highway Research Program (NCHRP) Project 03-101 “Costs and Benefits of Public-Sector Deployment of Vehicle to Infrastructure Technologies.” The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. Project 03-101 was intended to (1) to evaluate and document agency and societal benefits and costs of vehicle-to-infrastructure (V2I) technologies to assist with deployment decisions by state and local DOTs and (2) to describe the current state of dedicated short-range communications (DSRC) equipment capabilities, spectrum licensing, acquisition requirements, and the further development required to achieve vehicle to roadside communications.

Disclaimer

The opinions and conclusions expressed or implied in this report are those of the research agency that performed the research and are not necessarily those of the Transportation Research Board or its sponsoring agencies. This report has not been reviewed or accepted by the Transportation Research Board Executive Committee or the National Academies of Sciences, Engineering, and Medicine; or edited by the Transportation Research Board.

Contents

List of Figures

List of Tables

Executive Summary

The Connected Vehicle Program is a multimodal initiative that aims to enable safe, interoperable networked wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. This research is being sponsored by the U.S. Department of Transportation (USDOT) and others to leverage the potentially transformative capabilities of wireless technology to make surface transportation safer, smarter, and greener. If successfully deployed, the USDOT maintains that connected vehicle technologies will ultimately enhance the safety, mobility, and quality of life of all Americans, while helping to reduce the environmental impact of surface transportation. USDOT's goal is to advance the program to a deployment readiness state by 2014. In order for state transportation departments (DOTs) to fully benefit from this effort, AASHTO has formed a technical working group that developed a strategic plan and action plan for the development and deployment of the Connected Vehicle Program. A pooled fund program has been established to begin work on the plan. A need identified in the plan that has not yet been addressed is to evaluate and document the benefits and costs of public sector investment in technologies that allow communication between vehicles and the infrastructure (V2I). This information is intended to be used by these agencies to develop deployment plans consistent with these agencies' goals and planning cycles and to justify the necessary investment of resources to executives, commissions, planning organizations, and elected officials. The benefits and costs will include those accrued by the agency, including cost avoidance that may be realized by making DOT core business processes more efficient.

In response to the importance of assisting state and local DOTs with connected vehicle technology deployment decisions, NCHRP launched Project 03-101, "Costs and Benefits of Public-Sector Deployment of Vehicle to Infrastructure Technologies." The goals of this project are to (1) evaluate and document agency benefits and costs of vehicle-to-infrastructure (V2I) technologies and (2) describe the current state of dedicated short-range communications (DSRC) equipment's ability to achieve vehicle to roadside communications. To achieve these goals, the objectives of this study were to:

- Provide a catalog of connected vehicle applications in which state and local DOTs would have a role;
- Discuss the likely impacts of connected vehicle applications on the agency; site characteristics that affect an application's effectiveness; assess the readiness of the application to be deployed; the steps and time frame needed to bring the application to deployment readiness; necessary roadside and communications infrastructure; and expected costs to deploy, operate, and maintain the infrastructure.
- Develop methods that will be used to estimate the benefits and costs of V2I investments by state and local DOTs;
- Create a list of assumptions needed to assess the benefits and costs of public-sector V2I investments including market penetration rates for in-vehicle and personal devices (including after-market devices) for private vehicles, commercial vehicles, private-sector fleets, and public-sector fleets (including transit); public- and private-sector development of applications; technology enhancements; and mix of vehicle power-train types; and
- Identify core state and local DOT business practices that could be affected by implementation of V2I technologies.

This report contains the methods used in the cost benefit analysis and presents the findings, along with guidance on future deployments and an assessment of DSRC readiness.

Summary of Results

Connected vehicle technology represents a both a significant investment for public agencies, as well as an opportunity to provide a higher level of service to the agencies' customers – the traveling public. Findings presented in this report highlight the major components of a connected vehicle deployment, current and potential future costs, and how these components will impact public sector agencies.

For the quantitative analysis, the following benefits were quantified as data were available. A major outcome of this study was the conclusion that data required to make to quantify benefits are generally not available. Benefits included in this study are based upon available and adequate data, including:

- Crash response and cleanup cost reduction;
- Reduced need for traveler information infrastructure;
- Reduction of infrastructure required to monitor traffic;
- Lower cost of pavement condition detection; and
- Adaptive lighting energy savings.

For future investment decisions, agencies may need to take into account new data collection methods and metrics to support connected vehicle investment decisions

Key findings indicate that the benefits derived from these deployments will gradually offset a significant portion of the annual cost of connected vehicle technology, although the deployment will may not produce a positive net present value due to high initial costs. The variables with the greatest impact on the analysis are

- Accident Response Cost;
- Accident Rate Reduction;
- Roadside Equipment (RSE) Unit Cost;
- RSE Maintenance Cost; and
- Recurring Backhaul Cost.

Connected vehicle deployments over time have the ability to produce savings to the DOT that outweigh annual operations and maintenance costs. It is difficult to generate a net-positive cost-benefit ratio based solely on direct impacts to the agency; however, most transportation infrastructure projects are not profitable, so evaluating returns on investment may not be the best method for determining the value of the technology. Benefits will also vary greatly on the location of the deployment, as urban and suburban corridors will likely see greater benefits than rural areas due to the availability of ITS and energy infrastructure, increased interactions between vehicles and infrastructure, and richer concentration of data. Also, traffic incident rates and hence the cost avoidance associated with a reduction in accidents due to connected vehicle technology will likely be higher in urban areas. DOTs should further investigate the levels of cost avoidance associated with connected vehicle technology in specific locations prior to making connected vehicle technology deployment decisions in order to maximize the benefits.

In addition, the costs considered in this analysis were drawn from actual research deployments and will likely decrease as the technology matures and the market becomes more competitive. The recurring backhaul costs associated with connected vehicle deployments represent a major component of the investment and will not likely decrease at the same rate as the equipment costs, but it is difficult to quantify that cost as it varies on a case by case basis. Some factors that influence this cost include deployment size, scope, proposed applications, and existing infrastructure.

Connected vehicle technology may also have the ability to improve agency business practices by creating data rich environments which provide new, additional sources of information and data on asset condition for monitoring and maintenance. The technology also can provide agencies with the ability to proactively reach a wider audience of drivers than available with traditional methods (e.g.., geotracking, cellular crowd-sourcing, etc.) by providing a dedicated communication and data stream to government agencies.

Introduction of the technology also has the ability to add new roles for traditional transportation management agencies, including information technology-related fields, automotive engineering, application development, among many other potential roles.

Finally, the findings presented in this report can inform DOT decision making makers of the impacts of a connected vehicle deployment. With the exception of tolling, transportation investments are not generally executed with the aim of generating revenue to recuperate investment costs, but rather to promote the safety and mobility of the traveling public.

CHAPTER 1

Introduction

Background

The origins of the connected vehicle program trace back to the early 2000s when the United States Department of Transportation (USDOT) began to realize that vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication had the potential to address many transportation challenges. This led to the launch of the Vehicle Infrastructure Integration (VII) Program in 2003, which researched the use of wireless communication between vehicles (V2V) and with vehicles (V2I), with the goal of improving safety and mobility. While the VII Program had some success, it could not overcome several challenges that prevented the deployment of VII technologies:

- Achieving high levels of market penetration in the vehicle fleet would require a long time, as the time to turn over the fleet of U.S. vehicles was estimated at between 10 and 15 years.
- Achieving the levels of infrastructure deployment needed to support VII – estimated at more than 300,000 units – would be difficult, especially because these units would have to be deployed and maintained by a wide variety of State and local jurisdictions.
- Achieving the desired benefits appeared to require simultaneous availability of both technologies, and it did not appear to cost-effective to deploy either technology in isolation.

Recently, approaches to overcoming each challenge have emerged. First, a National Highway Traffic Safety Administration (NHTSA) crash data analysis indicated that V2V and V2I could impact a large percentage of crashes involving unimpaired drivers. With this information, NHTSA set a target date of 2013 for making a regulatory decision on whether to require V2V technology on new vehicles. This could help build the sufficient market penetration among vehicles to make deploying the infrastructure to support V2I cost effective. Second, research provided evidence that secure communications could be established with and between vehicles without the use of Dedicated Short Range Communications (DSRC). Also, widespread availability of wireless communication provided other means of supporting V2V and V2I communication for some applications. This means significant benefits could be achieved with much lower infrastructure deployment. With these changes, USDOT rebranded the VII Program as connected vehicles. In some sense, this rebranding also marked the change from an engineering research program (under the VII moniker) to a product development and testing program in preparation for deployments that could begin as soon as 2014.

Connected vehicle technology researchers have debated the costs and benefits of connected vehicle technologies since the concept was launched as the VII Program in 2003. Throughout much of that time, the focus of the cost assessments has been on the overall cost of the infrastructure required to support connected vehicle technologies (e.g., the roadside DSRC equipment, the backend networking connecting this equipment, and the in-vehicle equipment). The focus of the benefits assessments has been on crash reduction and mobility improvement and the consequent impacts on vehicle emissions. This focus was justified because the objective of these assessments was to verify that there was good reason to pursue connected vehicle technologies – that the overall costs of deploying connected vehicle technologies would be justified by the totality of benefits achieved. Now that the time is approaching for deploying connected vehicle technologies, a new focus is needed. Instead of focusing in the overall costs and benefits of

connected vehicle technologies, the focus should be on the costs and benefits that will be seen by those responsible for these deployments. Instead of justifying the connected vehicle technologies program as a whole, the focus needs to be on justifying deployment of connected vehicle technologies by those agencies and organizations that will be responsible for doing so and helping those agencies prepare for deploying connected vehicle technologies. That is problem addressed by this research.

In particular, this research estimates the costs and benefits that state and local DOTs will experience if they choose to deploy connected vehicle technologies. Doing so requires consideration of more than just safety, mobility, and environmental impacts. Connected vehicle technologies have the potential to also change DOT operations, including:

- Widespread deployment of connected vehicle technologies-ready vehicles could provide a source of real-time traffic information that covers almost all roads. DOTs may need to invest in new technologies to take advantage of this information in order to achieve improved traffic flow and incident response.
- Connected vehicle technologies-ready vehicles could also provide pavement condition data to DOTs (e.g., via readings taken from in-vehicle accelerometers), which could be used to enhance road maintenance practices.
- Connected vehicle technologies-ready vehicles could provide the in-vehicle infrastructure needed to support new approaches for distributing transportation costs, such as Mileage-Based User Fees (MBUF) and advanced toll operations (e.g., HOT lanes, congestion pricing).

Purpose

To begin a connected vehicle deployment, the connected vehicle roadside infrastructure must be deployed by state and local Departments of Transportation (DOTs). State and local DOT connected vehicle investment decisions require knowledge of the costs and benefits the DOTs will incur. That is the study's objective; to evaluate and document agency benefits and costs of connected vehicle to assist with deployment decisions by state and local DOTs. Just as importantly, this project used this cost-benefit information to produce materials that are appropriate for briefing State decision makers about connected vehicle and the value of connected vehicle deployment.

The research conducted during this project produced cost-benefit analyses (CBAs) by combining information on safety, mobility, and environmental impacts of connected vehicle technologies and the costs of deploying, operating, and maintaining connected vehicle technologies infrastructure, taking advantage of existing research in these areas. This information will help guide DOT decision makers in deploying connected vehicle technologies.

While the costs and benefits of connected vehicle technology play a key role in State and local agency decision making, so will their understanding of the DSRC spectrum. The AASHTO Technical Committee for the USDOT Connected Vehicle Program has completed an *AASHTO Infrastructure Deployment Plan for the Connected Vehicle Program* describing the vision and process for deploying connected vehicle infrastructure from 2011 to 2035. During the development of this plan, AASHTO determined that State and local DOTS have limited knowledge about the capabilities of the DSRC spectrum and its operating requirements. As such, an objective of this study was to describe the current state of DSRC equipment capabilities, spectrum licensing, acquisition requirements and the further development required to achieve vehicle to roadside communications.

Methodology

As shown in Figure 1-1, this project combined existing research, expert knowledge, and stakeholder interviews to produce all findings.

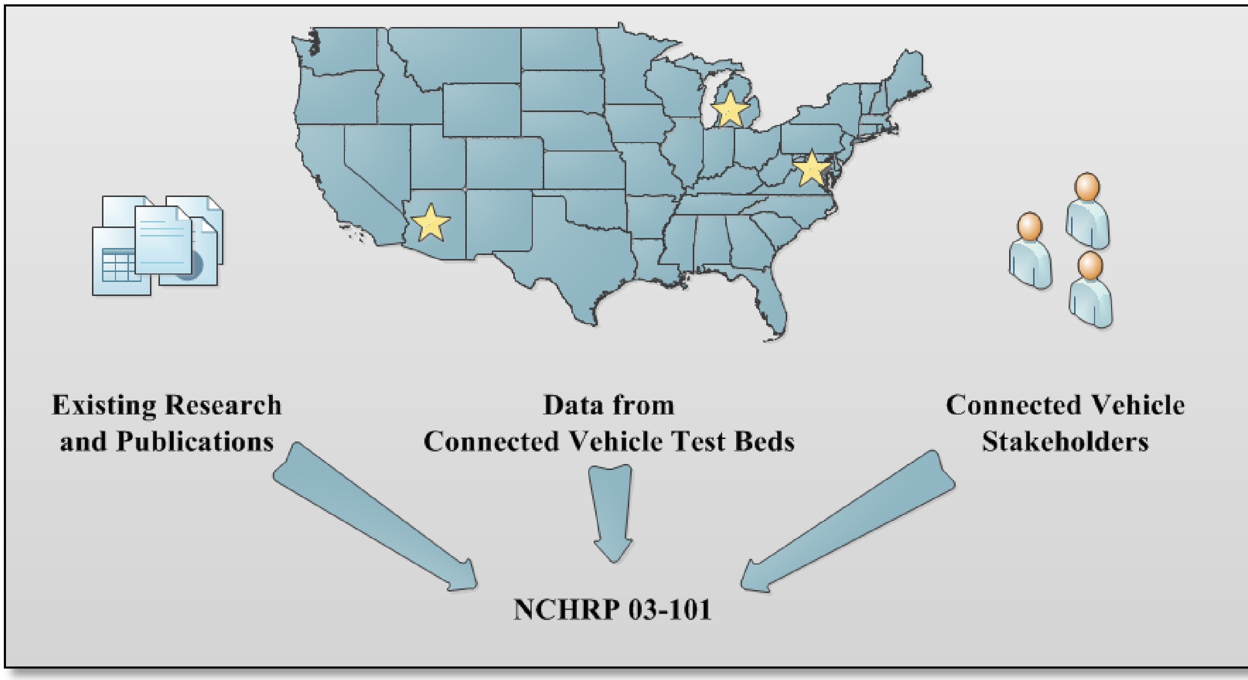


Figure 1-1. NCHRP 03-101 Methodology

Over the course of this project, the following activities were completed:

1. Transportation Analysis,
2. Cost Benefit Analysis,
3. DSRC Readiness Analysis, and
4. Outreach and Reporting.

Transportation Analysis

The transportation analysis conducted under this project is discussed in detail in *Chapter 2 – Data Collection*. As the chapter title suggests, this analysis served as the data collection phase of the project. Researchers reviewed existing publications to identify connected vehicle applications. Researchers also conducted outreach efforts to identify potential case study sites that plan to or have deployed connected vehicle technologies. Following the identification of applications and study sites, the team developed a guide, presented in Appendix A, to conduct structured interviews with connected vehicle stakeholders. These interviews served as a foundation to document impacts of a connected vehicle deployment to DOTs, as well as to provide inputs to the cost benefit analysis.

Cost-Benefit Analysis

Outputs and information obtained during the transportation analysis were then compiled for inclusion in the cost-benefit analysis. Needs in terms of both costs and benefits were identified. Existing deployments and research were reviewed to fill these needs. In instances where data were not available, assumptions were documented. Once the data were collected and assumptions documented, the analysis was completed. Details can be found in *Chapter 3 – Cost-Benefit Analysis.*

Deployment Guidance

The combination of information gathered during the transportation analysis and the output of the cost-benefit analysis provided the research team information needed to develop deployment guidance to assist decision makers with planning for and deploying connected vehicle technologies. Information under this guidance includes connected vehicle application selection, prioritizing deployments over time, and locating deployments over geography. More information can be found in *Chapter 4 – Deployment Guidance*.

DSRC Readiness Analysis

Researchers analyzed the state of readiness for DSRC technologies in parallel to the transportation analysis and cost-benefit analysis tasks. Researchers documented the state of DSRC deployments in test beds across the country through interviews with State and local agencies, as well as the state of readiness of the technology through interviews with the technology vendors. Additionally, guidance was developed in regard to licensing required with the Federal Communications Commission (FCC) to use the 5.9 GHz spectrum associated with DSRC technology. More information on these activities can be found in *Chapter 5 – DSRC Technology Readiness.*

Outreach and Final Report

Once all other activities were completed, the research team compiled the information into final reports for dissemination. In addition to the final report, guidance was developed in form of a deployment plan template and corresponding Microsoft Excel tool to assist agencies with prioritizing relevant connected vehicle applications. The research team also developed a brochure and Microsoft PowerPoint presentation highlighting the findings and guidance produced under this effort. Both the brochure and PowerPoint presentation are customizable to allow agencies to tailor to meet their own needs.

CHAPTER 2

Data Collection

Applications

Introduction

Broadly speaking, a connected vehicle deployment consists of two major categories of components: *hardware* and *software*. The connected vehicle *hardware* includes components such as RSEs and in-vehicle technology. The hardware is often the focus of the discussion and analysis as much of the current research is working to develop these components and it is expected that much of the initial and up-front deployment costs will center on the costs and quantity required. The connected vehicle *software* as discussed in this report is referred to as applications. It is these applications that will provide the benefits to the agency (e.g., providing vehicle position information) or to the motorist (e.g., providing safety alerts).

Application Selection

Each connected vehicle application includes a software application that takes advantage of vehicle network connectivity. These applications are currently being developed in many different ways, including USDOT-sponsored research programs and commercial development. For this project, we will assume that applications will be developed through a consortium of stakeholders or other organization (e.g., USDOT) and thus the agency conducting a connected vehicle deployment will not need to fund application development.

For the purpose of discussing potential benefits, a list of connected vehicle applications was developed through existing research. Table 2-1 below highlights the list of 26 applications considered during the course of this research. A more detailed list of these applications can be found in Appendix B. Of those applications:

- 11 applications could improve safety,
- 7 applications could improve mobility,
- 4 applications could provide better data,
- 2 applications could lower costs to the DOT, and
- 2 applications could provide revenue to the DOT.

Table 2-1. List and Description of Connected Vehicle Applications

Application Name	Description
CICAS–Signalized Left Turn Assist (CICAS-SLTA)	Assist vehicles waiting to turn left at signalized intersections with permitted left turns. The application area assists the driver with gap acceptance. The relevant crash type is a multi-vehicle crash involving a left turning vehicle and a through vehicle.

Application Name	Description
CICAS–Traffic Signal Violation (CICAS-TSV)	Address crashes that result from signal violations. This application area provides a warning to both the driver who is in danger of violating the signal and the driver on the conflicting approach.
CICAS–Traffic Signal Adaptation (CICAS-TSA)	Address crashes that occur at the onset of the red interval at signalized intersections from signal violations. Upon sensing that a vehicle is about to violate the signal at the onset of the red interval, the application would adapt the traffic signal timings so the conflicting approach would be held at a red signal instead of being released with a green signal. Similar to the CICAS-TSV system in that it is intended to address crashes that result from signal violations.
CICAS–Stop Sign Assist (CICAS-SSA)	Address crashes that result from poor gap acceptance at two-way stop-controlled intersections. This includes stop-controlled vehicles that are going straight or turning at the intersection.
CICAS–Stop Sign Violation (CICAS-SSV)	Address crashes that result from stop sign violations at stop-controlled intersections. This includes two-way, four-way, and other stop-controlled intersections.
Cooperative Curve Speed Warnings	Provide a warning to vehicles approaching horizontal curves on segments or interchange ramps above a threshold speed to address crashes that are speed related.
Cooperative Speed Limit Zone Warnings	Provide a warning to speeding drivers approaching reduced speed zones.
Cooperative School Speed Zone Warnings	Provide a warning to speeding drivers when reduced speeds are in effect in school zones.
Cooperative Work Zone Speed Warnings	Provide a warning to speeding drivers when approaching active work zones.
VMT-based User Fees	Facilitate the collection of roadway user fees (MBUF) based on vehicle miles traveled (VMT).
HOT Lanes	Facilitate the collection of fees for travel in high-occupancy toll lanes and similar facilities.
Pothole (Pavement Defect) Detection	Probe data could provide agencies with a view of road surface conditions as experienced by vehicles riding on pavement in near real time. Current industry practices provide incidental surveys of the pavement by maintenance personnel, but depend on annual (or even less frequent) inspections for performance measurement and reporting. Gathering pavement-related data from even a small population of vehicles would provide significantly more data than are currently available. Data such as accelerometry, tire pressure, and steering angle, for example, may be able to be correlated with pavement defects and roughness. When state and local transportation agencies have accurate, up-to-date estimates of pavement quality for specific roadway sections they can better plan their response and better manage their maintenance resources.
Pavement Condition Monitor	Probe data could provide agencies with a view of road surface conditions as experienced by vehicles riding on pavement in near real time. Current industry practices provide incidental surveys of the pavement by maintenance personnel, but depend on annual (or even less frequent) inspections for performance measurement and reporting. Gathering pavement-related data from even a small population of vehicles would provide significantly more data than are currently available. Data such as accelerometry, tire pressure, and steering angle, for example, may be able to be correlated with

Application Name	Description
	pavement defects and roughness. When state and local transportation agencies have accurate, up-to-date estimates of pavement quality for specific roadway sections they can better plan their response and better manage their maintenance resources.
Traffic-responsive Adaptive Signal Control	Monitor approaching traffic streams to create phase and timing plans that optimize flow.
Weather-responsive Adaptive Signal Control	Monitor weather conditions and forecasts to for input to algorithms for phase and timing plans that optimize flow.
Traffic Signal Prioritization for Transit Vehicles	Provide priority service for transit vehicles at signalized intersections
Traffic Signal Preemption for Emergency Vehicles	Provide preemptive service for emergency vehicles at signalized intersections
Arterial Network Signal Coordination	Enhance traffic flow across the arterial network through area-wide traffic monitoring and coordination of signal states
Variable Speed Management (Speed Harmonization)	Dynamically and automatically reducing speed limits in or before areas of congestion, accidents, or special events to maintain flow and reduce risk of collisions due to speed differentials.
Cooperative Adaptive Cruise Control	Automatically controls the gap between vehicles, typically under highway driving conditions, based on gap measurement and status data exchange between the vehicles.
Adaptive Ramp Metering	Dynamic control of vehicle entry to limited access facilities (freeway ramps) based on mainline traffic conditions.
Adaptive Corridor Management	Enhance flow of people and goods along/through a corridor through multi-mode area-wide traffic monitoring and control coordination
Real-Time Traveler Information	Provide near real-time traffic, weather, special event, and work zone information travelers
Real-Time Commercial Vehicle Data Exchange	Commercial vehicle operations have a series of unique needs that can be supported or accommodated by Connected Vehicle applications. USDOT, under the leadership of the Federal Highway Administration (FHWA) and the Federal Motor Carrier Safety Administration (FMCSA), is developing the Smart Roadside initiative as part of the V2I program. Major desired capabilities of the Smart Roadside initiative have been identified in a recent white paper. Some of those capabilities are described in the Real-Time Traveler Information and other application; this application captures those capabilities that are specific to commercial vehicles. Specifically, this app would provide: Unique vehicle identifier shared with the enforcement agencies, Routing clearance, parking, and time restriction information shared with driver, Vehicle size and weight shared with enforcement agencies, Real-time driver/carrier/truck information shared with enforcement agencies for inspection decisions, Roadside inspection results (violation and non-violation) shared with Federal enforcement agencies
Real-Time Emissions Reporting	Provide near real-time emissions data to assess operating efficiencies, energy use, and carbon footprint
Agency Data Applications (Trip-based Traffic Studies)	Gather trip-based travel data for traffic and transportation management performance measures, origin-destination studies, turning movement analysis, traffic model baselining, and predictive traffic studies

Case Study Sites

Unlike a traditional cost-benefit analysis where one would compare alternatives using known costs and established benefits, many of the costs and benefits for a connected vehicle deployment are unclear. Much of the existing and currently deployed V2I equipment is research-grade, produced in limited quantities as needed for research activities. Further, as the technology has evolved over recent years, the costs and technology have changed. Because of this evolution, costs have not yet been standardized across types of technology, and a single component (e.g., RSE) may vary drastically between current test beds and in future deployments when the technology matures from research-grade to enterprise-grade.

To develop the most robust cost-benefit analysis, case study sites were selected to serve as a model for the analysis. These case studies fulfill multiple purposes: using a case study as a foundation for the model allows for real costs to be used in the analysis; additionally, by selecting multiple case study sites (e.g., corridor, suburban area, and a county-wide example), a range of deployment types can be related to the results.

To determine potential case study sites for the stakeholder interviews and data collection, the research team reviewed states that either had or were planning to deploy connected vehicle technologies. States were selected based on roadway miles, vehicle miles traveled (VMT), Urban versus Rural VMT, Population and Density and Experience with Connected Vehicle projects and persons known to the research team that we could interview. Selections were also based on an attempt to provide representation of the aforementioned criteria. Table 2-2 shows this information with quartiles ranked 1 (greatest) to 4 (least).

Table 2-2. Potential Case Study Sites

State	Miles Quartile	Interstate Miles (%) Quartile	Urban Miles (%) Quartile	VMT Quartile	Urban VMT Quartile	Population Quartile	Population Density Quartile	Test Bed
Arizona	3	1	1	2	2	2	3	Y
New York	1	2	1	1	1	1	1	Y
Florida	1	2	1	1	1	1	1	Y
California	1	1	1	1	1	1	1	Y
Virginia	3	1	2	1	2	1	2	Y
Michigan	1	3	2	1	2	1	2	Y
Kentucky	3	3	3	2	4	3	2	N
Washington	2	3	2	2	2	2	3	N
Texas	1	3	2	1	2	1	3	N
Minnesota	1	4	3	2	3	2	3	N
Iowa	2	4	4	3	4	3	3	N
Utah	3	1	3	3	2	3	4	N
Idaho	3	3	4	4	4	4	4	N
Alaska	4	1	3	4	4	4	4	N

Interviews

After compiling the list of potential case study sites, the research team began an outreach effort to schedule and conduct structure interviews with stakeholders at each site. Table 2-3 below highlights the 15 organizations that were interviewed by the research team.

Table 2-3. Completed Interviews

STATE	ORGANIZATION
Arizona	Arizona-Maricopa County DOT
California	Metropolitan Transportation Commission (MTC)
California	Caltrans
Idaho	Idaho DOT
Kentucky	Kentucky Transportation Center
Michigan	Michigan DOT
Michigan	Oakland County
Michigan	Michigan DOT
Minnesota	Minnesota DOT
New York	New York State DOT
Texas	Texas DOT
Transport Canada	Transport Canada
Utah	Utah DOT
Virginia	Virginia DOT
Washington	Washington State DOT

Due to time constraints, an abbreviated interview was conducted with the Wisconsin Department of Transportation. During this interview, only high-level thoughts on connected vehicle deployment were captured; a discussion on the potential connected vehicle applications was not conducted. Each interview discussed the following topics:

- Introduction to the NCHRP 03-101 Project,
- Overview of Connected Vehicle Activity in the State/MPO,
- Connected Vehicle Impacts to DOT Business Practices,
- Introduction to Potential Connected Vehicle Applications,
- Level of Interest for the Potential Connected Vehicle Applications,
- Potential Deployment Strategies,
- Discussion on Potential Funding Sources/Strategies, and
- Perceived Challenges at the State/MPO.

The length of the discussion on each topic was guided by the interviewee's experience or thoughts on the subject. More information on each topic is presented in the sections below. The following sections describe the stakeholder interview topics.

Introduction to the NCHRP 03-101 Project

To facilitate the most relevant discussion, it was critical that each interviewee understands the purpose of the interview as well as the goals of the larger project that the interview is a part of. With this in mind, each interview began with an introduction of the NCHRP 03-101 project. Following the introduction, questions related to the project were solicited from the interviewees.

Overview of Connected Vehicle Activity in the State/MPO

In order to provide a foundation for discussing the effects of a connected vehicle deployment to the DOT/MPO, the interviewee was asked to provide a brief summary of the DOT's/MPO's involvement with connected vehicle activities. An understanding of past connected vehicle involvement allowed the interviewer to understand some of the history and decision making processes at the DOT/MPO concerning connected vehicle or ITS. For example, if a DOT/MPO has spent a considerable amount of time evolving their incident response program, it is likely that incident response will be an important focus to that DOT/MPO, and this could be expanded on during the later topics in the interview.

Connected Vehicle Impacts to DOT Business Practices

Throughout the interviews, all stakeholders clearly stated that a connected vehicle deployment has a unique opportunity to impact nearly all facets of DOT business practices. Stakeholders were asked what aspect of a connected vehicle deployment would have the greatest impact to DOT business practices as well as to rank impacts to DOT business practices in the following areas: safety, mobility, DOT operations, and environmental impacts.

Introduction to Potential Connected Vehicle Applications

Prior to the beginning of the interview, the interviewee was provided a copy of the connected vehicle applications listed in Table 2-1, as well as the of likely impacts to the DOT and to society, required infrastructure, deployment readiness, synergies with other applications, and synergies with other agency objectives. Interviewees reviewed this document and any application related questions were discussed.

Level of Interest for the Potential Connected Vehicle Applications

After providing an overview of the potential connected vehicle applications, the interviewees then were offered the opportunity to select which of the potential applications would have the highest level of interest from their organization.

Potential Deployment Strategies

Interviewers explored potential deployment strategies given the connected vehicle background each interviewee's organization. The purpose of this topic was to obtain an understanding on how each stakeholder could foresee connect vehicle technology being deployed in their region.

Discussion on Potential Funding Sources/Strategies

Similarly to the previous topic, interviewees were also asked to determine if they had thoughts on potential funding sources or strategies to deploy connected vehicles in their region. While the identification of funding *sources* is not critical for the cost-benefit analysis, it is useful in developing guidance for a connected vehicle deployment.

Perceived Challenges at the State/MPO

Lastly, interviewees were asked to define major challenges they believe may impede connected vehicle deployment in their agency. These challenges will need to be understood and addressed prior to deployment and will make for possible topics to include in outreach material developed later under this project.

Impacts on DOT Business Practices

Connected vehicle applications have the ability to significantly impact DOT business practices. To capture these impacts, interviewees were asked to define the greatest impact to their business practices as well as to prioritize safety, mobility, operations and maintenance, and environmental impacts. To define this prioritization, the interviewer asked each stakeholder to speculate how his or her organization may allocate limited funding.

Safety

Nearly every interviewee stated that safety is the area that connected vehicles will most significantly impact. Those interviewees who did not select safety as a primary focus instead mentioned areas that directly affect safety (weather management and incident response). A common theme across all interviews was that the DOT's primary focus is safety, with many citing their Towards Zero Deaths initiatives. Many interviewees discussed Cooperative Intersection Collision Avoidance Systems (CICAS) applications stating that they seemed to have the potential for significant increases in safety for the DOT.

Mobility

Mobility was often noted as the second area perceived to be most significantly impacted by connected vehicle applications. Many interviewees believed that mobility was interrelated to many of the other areas (e.g., safety, operations, environmental). Additionally, it was often stated that the traveling public is the DOT's 'customer' and that any applications to increase the customer's mobility would be of great interest to the DOT. One interviewee noted that current methods and strategies deployed at DOTs have seemed to reach a plateau concerning the amount of benefit they can provide to the traveling public as well as the DOT. This interviewee believes the connected vehicles are the next step to enable DOTs to greatly increase their ability to provide mobility benefits to the public through the ability to collect, analyze, and disseminate more detailed data regarding trip routing and travel times.

DOT Operations

When discussing impacts on DOT operations, two groups of impacts were discussed: impacts on asset management and impacts on data collection and analysis. Impacts to a DOT's asset management practices varied in priority among interviewees, but were most prominent in States with a harsher climate (e.g., Idaho, Michigan). The most common items that stakeholders believed would be improved using connected vehicle applications were pavement condition monitoring and weather monitoring.

Pavement condition monitoring focuses on the identification of potholes and general pavement health. DOTs cited that they generally have significant operations implemented to monitor pavement condition and being able to successfully obtain this information through connected vehicles would be a considerable cost reduction.

Weather monitoring through connected vehicle applications could be improved by having vehicles serve as mobile weather stations. DOTs in colder climates spend large amounts of funding on stationary weather stations to monitor weather for the safety of motorists as well as for plowing operations. If connected vehicles could create mobile weather collection stations, DOTs would be able to obtain information across their entire network, depending on occupancy and market penetration, in addition to at fixed locations.

While the perceived connected vehicle impact to asset management practices varied in priority among interviewees, many interviewees perceived data collection and analysis impacts due to connected vehicles to be significant. Nearly half of the interviewees discussed data collection during this portion of the interview to describe how connected vehicles would improve the DOTs data collection abilities. Data collection will be improved in three ways: reduced cost, expanded coverage, and provide higher quality data.

DOTs currently spend a significant amount of funding to collect data on their roads. This funding goes to installation of data collection equipment (e.g., inductive loops, etc.) as well as maintenance of this equipment. It is costly to retrofit routes with collection equipment and thus more difficult to deploy collection equipment to areas which were not constructed with collection equipment. Connected vehicle applications will be able to track the location of vehicles across the network and transmit this information back to the DOT without addition of strictly data collection equipment. For example, the equipment which will be deployed to enable different connected vehicle applications will be able to collect data as a secondary function as opposed to traditional methods, such as loop detectors, where their only function is for data collection. By being able to collect data on vehicle positions through connected vehicle application, DOTs can reduce spending on data collection equipment while maintaining a higher standard of data collection.

As noted above, traditional data collection techniques rely on stationary detectors placed strategically by the DOT. Because these detectors are stationary, they are often placed in locations where DOTs can justify their cost (e.g., high density or high risk locations). As a result of this strategy for detector placement, DOTs often struggle with understanding what is occurring on their arterial or local routes. Connected vehicle applications would greatly benefit the DOT by providing them information on motorist behavior on these routes.

While DOTs can and do traditionally collect, analyze, and implement strategies with data on their transportation network, the data used in traditional collections methods is collected in aggregate. Using aggregated data affects the DOT in numerous ways. First, aggregate data can make it difficult to optimize systems (e.g., signal timing) as data in this form does not capture the micro-level interactions. Second, DOTs can struggle in measuring performance on systems where they are unable to capture a complete picture of how the transportation network is being utilized as well as what changes affecting the network occur due to optimization efforts. If real-time data from connected vehicle applications can provide the DOT more detailed information (such as travel times), the DOT would be able to understand changes shortly after optimizing signals. High quality data collected from connected vehicle applications will enable DOTs to more accurately apply measures of effectiveness (MOEs) to their strategies to measure performance.

Environment

In general, interviewees did not focus on the impact of connected vehicle deployment to environmental aspects of DOT business practices. The lack of focus was generally due to the thought that environmental impacts would generally follow as a function of mobility, and to a lesser extent safety. For example, increasing motorist mobility would result in a reduction in greenhouse gas emissions and a decrease in fuel consumption due to excess idling.

Potential Connected Vehicle Applications

Applications with High Level of Interest

Interviewees were offered the opportunity to review the list of potential connected vehicle applications, request more information, and select applications that would have a high level of interest in their State/region. A summary of stakeholder responses is documented in Table 2-4.

The application with the highest level of interest was the Real-Time Traveler Information application with nearly all interviewees stating that they had interest in the application. The importance of this application aligns with many of the interviewees' thought that connected vehicles will provide much benefit to DOTs with the ability to obtain more and higher quality data about their transportation network.

Many of the other applications receiving high levels of interest from the stakeholders were CICAS-based or other applications that would be deployed at traffic signals. One theme, discussed below, is that many

interviewees felt a feasible deployment strategy would be to include connected vehicle equipment when systematically modernizing traffic signals.

Interviewees generally felt that speed limit warnings would be ignored by many motorists. The Pothole (Pavement Defect) Detection application received a low level of interest for two reasons. First, interviewees from warmer climates did not put as much of an emphasis on monitoring pavement condition as those from the colder climates. Secondly, some of the interviewees from both colder and warmer climates indicated that they had already established policies and procedures which efficiently monitor their pavement condition and a similar connected vehicle application would need to produce significant cost savings in order to consider implementation. Regarding Real-Time Emissions Reporting, interviewees generally believe environmental issues are closely related to mobility issues and by improving mobility issues, environmental issues would also be improved.

Table 2-4. Summary of Application Interest by Stakeholder

Application / Agency	CA	ID	KY	Mari-copa	MI	MN	MTC	NY	RCOC	TC	TX	UT	VA	WA	Total
Real-Time Traveler Info	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	**13**
CICAS–Signalized Left Turn Assist	✓		✓		✓		✓	✓	✓			✓	✓	✓	**9**
CICAS–Traffic Signal Violation	✓		✓		✓		✓	✓	✓			✓	✓	✓	**9**
CICAS–Traffic Signal Adaptation	✓		✓		✓		✓	✓	✓			✓	✓	✓	**9**
Cooperative Curve Speed Warnings	✓	✓	✓		✓			✓	✓		✓	✓	✓		**9**
Trip-based Traffic Studies	✓			✓	✓	✓		✓	✓		✓	✓	✓		**9**
VMT-based User Fees	✓		✓			✓	✓	✓	✓	✓				✓	**8**
Traffic-responsive Adaptive Signal Control	✓		✓	✓	✓		✓	✓	✓					✓	**8**
Weather-responsive Adaptive Signal Control	✓	✓		✓			✓	✓	✓	✓				✓	**8**
Real-Time Commercial Vehicle Data Exchange	✓	✓	✓	✓				✓	✓	✓				✓	**8**
CICAS–Stop Sign Assist	✓		✓		✓	✓		✓	✓			✓	✓		**8**
CICAS–Stop Sign Violation	✓		✓		✓	✓		✓	✓			✓	✓		**8**
Cooperative School Speed Zone Warnings	✓		✓		✓			✓	✓		✓	✓	✓		**8**
Cooperative Work Zone Speed Warnings	✓		✓		✓			✓	✓		✓	✓	✓		**8**
Pavement Condition Monitor		✓			✓	✓	✓	✓	✓		✓		✓		**8**
Arterial Network Signal Coordination	✓	✓		✓			✓	✓	✓				✓	✓	**8**
Adaptive Ramp Metering	✓		✓	✓			✓	✓		✓			✓	✓	**8**
HOT Lanes	✓						✓	✓	✓	✓	✓			✓	**7**
Variable Speed Management	✓			✓			✓	✓	✓	✓				✓	**7**
Traffic Signal Preemption for Emergency Vehicles	✓			✓			✓	✓	✓				✓	✓	**7**
Adaptive Corridor Management	✓			✓	✓		✓	✓					✓	✓	**7**
Cooperative Speed Limit Zone Warnings	✓		✓		✓			✓	✓			✓			**6**
Traffic Signal Prioritization for Transit Vehicles	✓			✓			✓	✓	✓					✓	**6**
Pothole (Pavement Defect) Detection					✓	✓		✓	✓		✓		✓		**6**
Cooperative Adaptive Cruise Control	✓	✓	✓	✓				✓							**5**
Real-Time Emissions Reporting	✓			✓				✓	✓		✓				**5**

Deployment Strategies

There are many different deployment strategies that could be followed for connected vehicle, and the costs and benefits achieved will be different for each. Interviewees were asked their thoughts on the feasibility of deploying connected vehicle in their region, and the following deployment strategies were discussed:

- Pilot Approach,
- Local Approach, and
- Blanket Approach.

Pilot Approach

The pilot approach for deploying connected vehicles would be an approach where connected vehicle equipment is deployed at a small number of sites, expanding as experience is gained. While a pilot approach would produce the least amount of benefit to the DOT at the onset of deployment, it allows any technological or procedural issues to be resolved prior to deploying on a larger scale.

Nearly all interviewees indicated that this approach would be the most likely approach in their State or region because of the need of demonstrated benefits to obtain leadership buy-in. Interviewees believed that decision makers value tangible results, and the production of a successful pilot approach can provide those real-world tangible results needed to further connected vehicle deployment.

Many of the interviewees in favor of a pilot approach deployment strategy believed that connected vehicle applications would be just another “tool in the toolbox.” This means that while connected vehicle applications may benefit all locations, deployment of these applications may not be the ideal choice in all locations. Interviewees believed that when determining what improvement are needed at a location, connected vehicle application would be considered as well as other options (e.g., ITS), and a cost-benefit analysis would be conducted. If connected vehicle deployment to the given location proved to have the highest benefit-to-cost ratio, it could be deployed.

A variation of the pilot approach noted by some interviewees was an approach where passive and non-safety related connected vehicle applications were deployed using State/MPO owned fleet vehicles. The thought behind this approach is twofold: the DOT can control market penetration as well as prove the technology before deploying connected vehicles to the public.

As highlighted in below in the *Challenges to Deployment* section, interviewees feel that one of the limitations to a connected vehicle deployment would be the initial lack of market penetration, or the number of equipped vehicles traveling in the State/region that can communicate with the connected vehicle roadside equipment (RSE). Without a large number of equipped vehicles, the information transmitted to the RSEs would be sparse thus making it difficult for DOTs/MPOs to obtain useful information. If connected vehicle deployment was restricted to fleet vehicles in a pilot approach, the DOT/MPO would have the ability to control both how many vehicles were outfitted with connected vehicle technology as well as where the vehicles would be traveling to at any given time. An added benefit to outfitted fleet vehicles is that the DOT/MPO will be able to better manage these vehicles as they will know their location at all times.

A second reason for considering deployment on fleet vehicles is similar to the reason for deploying with a pilot approach: deploying to fleet vehicles will provide the DOT/MPO with demonstrated benefits prior to a larger-scale deployment involving passenger vehicles. Demonstrating non-safety related connected vehicle applications with fleet vehicles can serve as a filter to remove any applications that may not show enough benefit to warrant full-scale deployment, but at the same time capture a view of the benefits that can be obtained in a larger and public deployment.

Local Approach

A local approach to deploying connected vehicles is an approach where connected vehicle infrastructure is deployed in concentrated regions, one at a time. This approach varies from the pilot approach in that although only one region at a time is being deployed, the scale of deployment is greater than a pilot. For example, a pilot approach may equip a single corridor while a local approach would equip multiple corridors in one region.

About half of the interviewees indicated that a local approach would be feasible in their State/region, with the majority of these interviewees indicating that the systematic modernization of their traffic signals being the likely method to deploying connected vehicle equipment. A systematic modernization approach could serve as a logical method to deploy connected vehicle equipment, but depending on the rate of deployment, there may be significant lag time between the time the first signal is modernized and upgraded to include connected vehicle equipment and the time when tangible results can be obtained from the connected vehicle applications.

Other strategies noted by the interviewees who responded that a local approach might be feasible to deploy connected vehicle infrastructure include deployment through tolling applications or through commercial vehicles. Deployment through both tolling applications and commercial vehicle applications may serve as a path of least resistance because many drivers involved with tolling or commercial vehicles are familiar with having equipment in their vehicle (e.g., transponders) and thus this allows an opportunity to replace traditional transponders within connected vehicle technology.

Blanket Approach

A blanket approach is similar to the local approach, but on a larger scale where connected vehicle infrastructure would be deployed across a State/region at a much higher volume. With this approach, equipment would be in place quickly and would produce the most benefit to both motorists and the DOT. The disadvantage with this type of deployment is the high cost and dependency on the traveling public to produce a market penetration high enough to produce any viable information.

None of the interviewees indicated that they believed a blanket approach would be feasible in their State/region. Interviewees described that the amount of funding required to deploy connected vehicle equipment in a blanket approach was generally not available. Additionally, connected vehicle equipment and applications have not yet been thoroughly tested in real-world environments nor have tangible benefits generally been produced.

Funding Strategies

Interviewees were asked to discuss their thoughts on potential funding strategies for the deployment, operations, and maintenance of connected vehicle infrastructure. Many interviewees believed that the business case for connected vehicles had to be further refined before an in-depth funding strategy discussion could take place. However, even if the interviewee believes that the business case for connected vehicles needed further refinement, they often had some thoughts on possible funding strategies.

Outside Funding Sources

Many interviewees believed that in order to deploy connected vehicles, their State/region would need to be a recipient of funding from outside of their organization and these interviews often listed examples of previous ITS-related efforts in their State/region initiated using outside funding. Even with outside funding to initiate the DOT’s connected vehicle program, interviewees were cautious on identifying sources of funding for operating and maintaining the connected vehicle infrastructure in the future. One interviewee had indicated that their DOT has already identified a potential source of funding for connected vehicles.

The Utah DOT has a line item in their Long Range Plan for VII Deployment tied to the Congestion Mitigation and Air Quality Improvement (CMAQ) program.

Public-Private Partnership

A concept discussed with a number of the interviewees was the idea of a public-private partnership to secure funding needed to initiate, operate, and maintain a connected vehicle system. Such partners have yet to be defined, but could include cellular companies who transmit data for connected vehicle applications on smartphone devices, or another organization that would install and maintain equipment directly on to the transportation network to collect data to be sent to the DOT. This type of partnership would be beneficial to the DOT because the DOT would not need to own the connected vehicle equipment and if the equipment became outdated, it would not be the DOTs responsibility for replacing it with newer technology.

However, some interviewees were hesitant in considering this type of partnership for deploying connected vehicles because of concerns with liability or data access times. Interviewees noted that they do not currently see any organization that would be willing to take on the liability of maintaining connected vehicle infrastructure. In addition, some interviewees believed that if the information were collected through a third party and distributed to the DOT, the latency times would be too large for the DOT to achieve any meaningful benefits that outweigh the costs.

Reallocation of Funds

Interviewees indicated once connected vehicle applications demonstrate proven benefits in real-world applications, they believe that funding will be able to be allocated from currently existing sources to go towards connected vehicle deployment. For example, if connected vehicle applications demonstrate greater benefits at informing drivers than variable message signs (VMS), funding could be diverted from the construction on new VMS and invested in connected vehicles. Similarly, if connected vehicle applications show strong safety benefits, it may be possible to use funding originally to be used on safety improvement instead for connected vehicles. Finally, interviewees believed that connected vehicle infrastructure could be deployed by incorporating the equipment into other large-scale construction projects in the State/region where the total cost of the project would outweigh the cost of the connected vehicle equipment.

Challenges to Deployment

Funding

For many of the interviewees, securing funding for connected vehicles was the most significant challenge to deploying connected vehicles in their State/region. Many of the interviewees noted that their budgets are the leanest they have been in years, and a deployment of connected vehicles would be difficult without outside funding. Interviewees feel that the deployment of connected vehicle infrastructure will come at a high price, and this currently causes concern as the return on investment is not yet proven. Additionally, even if funding was secured to deploy connected vehicles, funding would need to be available for maintenance of the system.

Similar to funding, interviewees indicated that they felt the need for a nationwide and unified strategy for deploying connected vehicles. It seems that many agencies are hesitant of selecting a connected vehicle system where there is a chance that after they spend significant amount of funding on the system they learn that it will not be the system deployed in other States/regions.

Technology

A second challenge noted by many of the interviewees was that of the technology which will be used for connected vehicles. There has not been a defined and set standard regarding the use of DSRC and/or cellular equipment to transmit connected vehicle information. DSRC equipment can provide DOTs direct access to the data and lower latency times, but will also require the installation of more RSEs. Cellular equipment can utilize already existing cell towers, but will require the information to be transmitted through a third party.

Because there is not a definition on how data will be transmitted to connected vehicle applications, there is also no defined technology that will be standard for all connected vehicle deployments. Although the 5.9 GHz communication DSRC equipment is standard now, this standard for DSRC equipment has not been set and new technology could be discovered in the near future. As mentioned above, States do not want to spend funding on a system that may not be deployed elsewhere because newer technology has emerged. States want assurance that the technology will have a long-term life span and do not want to spend a significant amount of funding on the equipment only to find in a few years that their equipment is obsolete.

Similarly to defining a set technology to be used in connected vehicle deployment, States are concerned with the interoperability of connected vehicle infrastructure. An important component of a connected vehicle deployment is that a vehicle can travel from region to region within a State, or even from State to State without needing different OBE to continue being registered on the connected vehicle network. This concern aligns with the concern for the need of a unified strategy described in the previous section, but some assurance is needed to the States that their system will be interoperable with others.

Some interviewees have concerns regarding driver acceptance of technology or that of driver distraction due to in-vehicle equipment. While the public has generally been receptive to smartphones and their applications, there is some concern regarding user privacy that will need to be researched further prior to deployment. In the same way, there has been limited research on driver distraction due to the different connected vehicle applications. It is likely that the level of distraction related to the applications may vary with the application, but some interviewees felt that more research was needed to ensure that any driver distraction from the applications would not outweigh potential application benefit.

Finally, many interviewees were concerned with market penetration of connected vehicles stating that without significant users of the system, limited benefits will be observed either by the users or by the DOT. Much of this concern may be alleviated in 2014 when the NHTSA makes their decision regarding vehicle-to-vehicle communication. More information on the state of readiness for DSRC technology can be found in *Chapter 5- DSRC Technology Readiness.*

Tangible Benefits

As with any new and innovative technology, many interviewees noted that it is difficult to obtain leadership buy-in without the production of tangible benefits. While there have been a number of connected vehicle application demonstrations, interviewees noted that these demonstrations are more academic in nature and lack effects from real-world deployment. Additionally, many of the benefits observed in these demonstrations are societal in nature (e.g., reductions in fatalities) and do not directly reduce cost or produce revenue to the DOT. Interviewees indicated that both benefits to society and to the DOT are desired, but often projects which also demonstrate benefits to the DOT can receive priority over those which produce only societal benefits.

A concern voiced by interviewees in areas with large amounts of low population density (rural areas) was that there has been limited testing of connected vehicle applications for rural areas. While the exposure rate for RSEs in rural areas will be much less than the rate in an urban area, rural roads account for the majority of both crashes and fatalities. Because of this higher rate of fatal crashes, connected vehicle applications in rural areas can produce significant safety benefits, and these benefits should continue to be explored. It was noted that the Utah DOT currently is spending more funding on ITS equipment deployed in rural areas than it is in urban. Utah contains three major rural interstates with high truck volume. During

the winter or other extreme weather, these routes often become dangerous to travel on. Connected vehicle applications could be used to produce significant safety benefits in these rural areas and thus provide substantial cost-savings to the agency.

CHAPTER 3

Cost-Benefit Analysis

Introduction

Background

It is widely understood that the most significant benefits of the connected vehicle program will come in the form of improved safety and mobility. The anticipated cost avoidance from this program, in terms of injuries, fatalities, and delay to the nations' travelers are the major financial incentives for investment in connected vehicle infrastructure. Separate from the projects that are currently underway to quantify the potential cost savings to society, the focus of this project is to investigate the direct cost savings to the state and local transportation agencies that will fund the infrastructure deployment. This analysis documents a cost benefit analysis of public sector agencies deploying connected vehicle infrastructure based on three case studies of existing deployments in Arizona, Michigan, and Virginia.

There were several challenges involved in the given scope of work, largely attributable to the fact that the connected vehicle program is still in the early stages of development. The existing deployments of connected vehicle infrastructure were initiated for the purposes of research and development, while the scope of this project is to evaluate the cost-benefit ratio of an operational deployment. Additionally, many of the equipment components of connected vehicle infrastructure are still undergoing development and it is anticipated that the cost of this equipment will go down over time as the individual component designs are finalized and production increases. Finally, the data necessary to quantify the anticipated benefits was derived from multiple reporting measures and scaled in accordance with the size of the deployments. Data to match the identified benefit categories are not currently consolidated into metrics that directly tie to agency budgets and much of the spending data are not publicly available.

The findings of this analysis are intended to support policy makers in decisions related to connected vehicle investments based on the ability to produce annual cost savings for system operations and maintenance, specifically with respect to crash response and cleanup costs, traveler information infrastructure, and monitoring traffic and system infrastructure. While investment in this program is not expected to generate revenue, it is anticipated that cost savings to state DOTs will outweigh the annual costs of maintaining the deployed infrastructure across the program lifecycle. Ultimately, the major benefit to the public sector agencies is anticipated to be an increase in operational efficiency as the deployed infrastructure will provide real-time information to support daily operation and maintenance activities.

Connected vehicle technology is anticipated to have large-scale benefits in the form of reduced crashes, congestion, and harmful emissions. Outside studies have sought to quantify these benefits, such as the *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*, conducted by the Volpe Center in 2008. The scope of this analysis is limited to the direct financial benefits, in the form of cost-savings, to the State DOTs that will implement connected vehicle infrastructure. This research explores the value proposition to individual agencies that consider allocating funding for the roadside infrastructure and communication infrastructure necessary to support connected vehicle applications.

Several potential benefit categories were identified to complete this analysis. Each category is tied to an existing operations cost item in agency budgets. These benefit categories include:

- **Crash cleanup cost reduction.** Benefits under this category represent cost avoidance for the agency due to a reduction in crashes and subsequent crash cleanup. This includes reduction in costs related to police, fire and EMS response, hazardous material cleanup, accident debris cleanup, etc.
- **Work zone crash reduction.** In addition to crash cleanup cost reduction listed above, work zones crashes can be more severe due to the tighter confines (e.g., lane drops or lane width reductions) as well as the opportunity for unexpected queuing. As such, benefits under this category represent cost avoidance for public agencies specific to reduction of crashes in work zones. This cost reduction involves the same savings as the crash cleanup benefit, only confined to those related to work zones, but also includes the cost avoidance from damage to right of way and property under construction, lost time for construction to address the accident, etc.
- **Lower cost of pavement condition detection.** Connected vehicle technology can provide agencies the ability to use equipped vehicles to sense potholes and other deficiencies in pavement. Data such as accelerometry, tire pressure, and steering angle, for example, may be able to be correlated with pavement defects and roughness. Benefits in this category represent cost avoidance for agencies due to the availability of pavement condition information.
- **Adaptive lighting.** The combination of advances in lighting technology and the availability of data regarding both traffic and the environment in real-time to public sector agencies through connected vehicle technologies can allow agencies to modify the light output of equipped overhead lighting based on selected inputs (e.g., traffic volume or weather conditions) providing the agency with energy reductions and cost avoidance.
- **Reduction of infrastructure required to monitor traffic.** One benefit of connected vehicle technologies is that data provided from the equipped vehicles will augment the DOT's understanding of traffic volumes and vehicle trips. This enhanced understanding will allow agencies to decrease spending on infrastructure (e.g., inductive loop or microwave detectors, variable message signs) required for traffic management while still maintaining the same level of understanding of their transportation system usage.

In addition to the benefit categories above, this project identified several other potential benefits to public sector agencies that did not have data currently available with an appropriate level of detail to quantify for the purpose of this cost benefit analysis. These types of benefits include:

- **Improved access to data for planning studies.** Due to connected vehicle technology, agencies will likely have ready access to data traditionally captured through stand-alone data collection activities to support transportation planning studies.
- **Potential for improved long-term planning, program management.** Similar to improved access to data for planning studies, the availability of vehicle data through connected vehicle technology can assist agencies in more efficient long-term planning and program management.
- **Annual DOT vehicle highway maintenance contracts.** By providing an agency a better understanding of their roadway infrastructure (e.g., through pavement condition detection), agencies may be able to more efficiently manage highway maintenance contracts.
- **Faster and more cost effective response to public issues and policy change.** Through better and more ready access to transportation data, agencies will be more equipped to respond to public issues and discuss the impacts the agency's actions provided to the traveling public.
- **Ability to measure performance of DOT operations on an accelerated schedule.** For example, if an agency was interested in understanding changes to travel times on a corridor due to recent improvements, traditionally, this agency may use floating cars or deploy Bluetooth readers. If probe vehicle data is readily available through connected vehicle technologies, this data would be available without the need to conduct a formal data collection effort.

- **Cost savings to transit agencies by better optimizing fleet**. Connected vehicle technology can better support transit agency routing to maximum vehicle capacity and reduce unnecessary trips through communications with other vehicles, as well as with potential riders through handheld devices.
- **Increased safety, which may allow for reorganization of safety roles at the DOT.** A reduction in crashes due to connected vehicle technology may allow for agency personnel to take on additional or different roles while providing the same quality of service to the travel public.

As connected vehicle programs mature and are deployed on a wider scale, it is assumed that data will likely be available to quantify agency benefits in these categories.

Methodology

In order to determine typical costs and benefits of the deployment of RSEs needed to realize connected vehicles technology performance enhancements; we evaluated three pilot projects located in Michigan, Virginia, and Arizona. For each pilot project we determined the individual costs and benefits of RSE deployment. The costs represent the expenditures for the roadways covered by the deployment and supporting infrastructure. The benefits are those generated by the equipped corridor only. In some cases, the benefits were interpolated to the deployment area roadways covered from regional data in order to compare the cost and benefits correctly. In other cases, data was extrapolated based upon small-scale costs or one-time expenses in order to understand the cost in a larger deployment area. Depending on the available information, cost data was drawn from actual expenditures or was based on existing studies of RSE deployments. These costs were compared to the savings generated by the DSRC deployments. The study was conducted in constant dollar terms as it represents an analysis of potential cost and benefits for future deployments to support the decision making process rather than being a budgetary analysis.

Cost Analysis

For each case study under consideration, the analysis captured the lifecycle costs associated with the RSE deployment. This includes acquisition, deployment, and operations and maintenance (O&M), as well as the cost associated with backhaul set up and annual backhaul expenses.

Benefits Analysis

In general, benefits represent improvements in, or progress towards, a project's goal. As previously mentioned, the main goal of deploying RSE technology to support connected vehicle technology is to improve safety and mobility for the public. However, this study is focused on the direct impact to State DOTs and other public sector stakeholders involved in the investment decision. Hence, only direct benefits to these stakeholders were considered. The benefits vary somewhat between the three case studies, but the main categories and drivers of cost avoidance are:

- Crash response and cleanup cost avoidance due to reduced accidents from connected vehicles technology,
- Work zone accident reduction,
- Lower cost of pavement condition detection, and
- Reduced expenditures related to traffic monitoring and traveler information systems.

In addition, each pilot has locale-specific benefits related to weather conditions or urban setting, such as adaptive lighting or reduction of costs to winter maintenance programs through the optimization of maintenance vehicle routes or activities.

Risk and Sensitivity Analysis Approach

Like most investment analyses the analysis of cost and benefits of investments into RSE to facilitate connected vehicle technology contains uncertainty and variability in input assumptions (e.g., accident related cost, system performance). Reflecting this uncertainty and variability in the financial analysis is too complex to be solved by strict analytic methods, such as linear extrapolation from historical data (e.g. sensitivity analysis, high-low analysis). Furthermore, these analytic techniques result in single-point estimates that do not convey the probability of actually being achieved. Single-point estimates may indicate what is possible, but they will not identify what is probable.

Investigating uncertainty and variability of model inputs and output through sensitivity or high-low analysis alone is inadequate to accurately capture the true relationship between variables. These types of analyses manipulate essential variables individually and independently to assess the impact on investment criteria. This problem is particularly acute when variables are correlated (i.e., the value of one variable is dependent on the value of another).

These techniques are also inadequate when dealing with large complex problems where an unforeseen combination of values may yield an unanticipated result. In addition, there are usually too many possible combinations of input values to calculate every possible answer, yet insight about the range of possible outcomes is critical information for stakeholders.

To address these shortcomings, a Monte Carlo risk analysis was conducted. Monte Carlo specifies the simulation's sampling technique. Other sampling techniques exist such as Latin Hypercube. Monte Carlo randomly samples inside a probability distribution's while Latin Hypercube divides an assumption's probability distribution into intervals of equal probability and then randomly samples from each interval the same number of times. The Monte Carlo simulations systematically address the underlying uncertainty and variability in model inputs. Rather than developing a single input value, a probability distribution describes the input uncertainty and variability. This allows the entire range of possible outcomes to be calculated, as well as the likelihood of achieving them. As a result, decision-makers benefit from a more robust and informative analysis.

One sensitivity analysis output is the tornado chart. A tornado chart measures the impact of each model variable one at a time on a target forecast. This method differs from the correlation-based sensitivity chart in that the tornado chart tests each assumption independently. While analyzing one variable, the other variables are frozen at their base values. This chart measures the effect each variable has on the forecast while removing the effects of the other variables. This allows decision makers to focus on the most important variables when analyzing the overall analysis. An example tornado chart is shown in Figure 3-1. The red bar indicates outcome worsening as the input variable changes in the indicated direction, while the blue bar shows improving results. This can be to the left or right depending on the variable. For example, if the percentage of accidents avoided due to connected vehicle technology increases, overall results will improve. Using the same example, an increase in the cost of the RSE units will worsen overall results. The numbers shown for each variable show the range of the variable and the numbers at the top show the relative impact on the target forecast. In this example, if the installation labor costs per unit are $3,500 than the resulting net present value (NPV) is about negative $1.23M, while if the installation cost is only $1,800 per unit the result is improved to a NPV of roughly negative $1.1M.

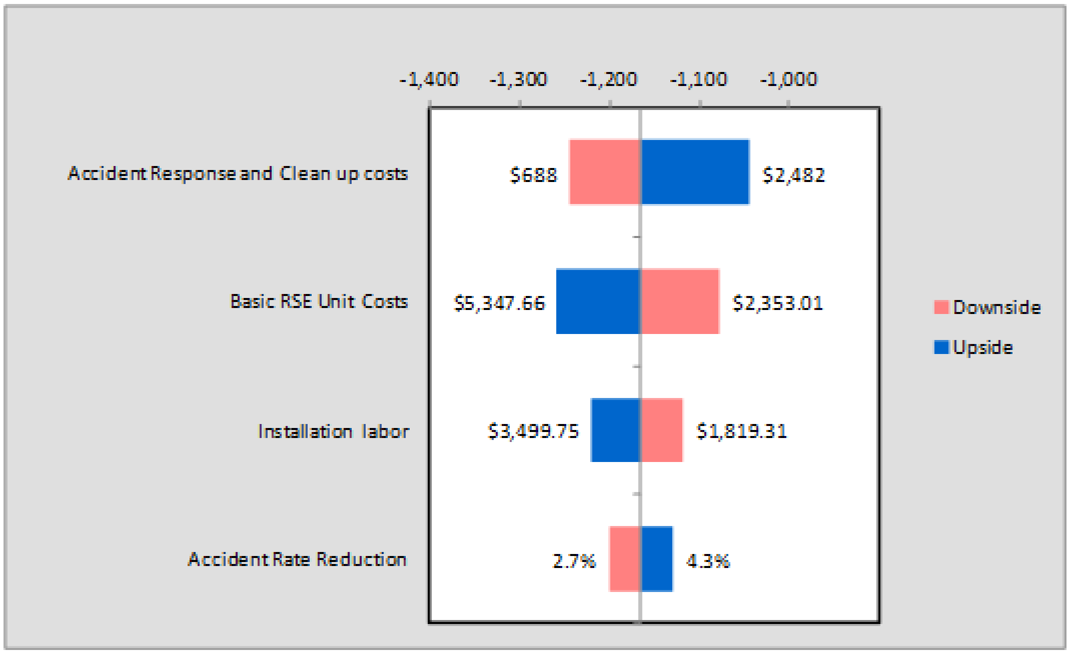


Figure 3-1. Sample Tornado Chart (Horizontal Axis in $000)

Assumptions

A number of global assumptions have been made for this study. In addition, there are assumptions specific to the analysis of each of the three case studies reviewed, which are listed in the description of the case studies. The global assumptions are:

- Crash response and cleanup costs have a mean of $500 and a range between $200 and $5,000,
- The average cost associated with a work zone accident is $3,687 based on previous studies,
- Accident reduction from connected vehicles technology is modeled as a singled side normal distribution with a maximum value of 26% percent at full market penetration of DSRC technology-equipped vehicles and minimum value of 10% representing the assumption of a crash reduction of up to 26 percent, and
- Market Penetration of DSRC technology will reach 90 percent in fifteen years, as discussed in the follow section.

Supporting details for these assumptions can be reviewed in Appendix C.

Market Penetration

While some vehicle manufacturers will include DSRC technology earlier as a desired feature, it is assumed that DSRC technology will be mandated by 2020 model year. Further, Bureau of Transportation Statistics (BTS) data shows approximately 230 million light duty vehicles registered in the United States as of 2010 and the National Automobile Dealer Association (NADA) data shows average new light duty vehicle sales 2000 to 2010 as 15 million per year, or approximately 6 percent of registered vehicles. Based on this the assumption and the data we projected penetration rates using a typical technology diffusion S-Curve based on Pearl growth curve. This diffusion is governed by the following equation:

$$y = \frac{L}{1 + \alpha e^{-bt}}$$

Where y is the penetration rate in a given year, L is the final penetration rate reached at market saturation, and a and b are coefficients calculated through Microsoft Excel's Solver function. It was assumed that y equal to 1 percent in year 1 after initial deployment of RSEs and reaches 90 percent after 15 years. The resulting market penetration curve is shown in Figure 3-2 below.

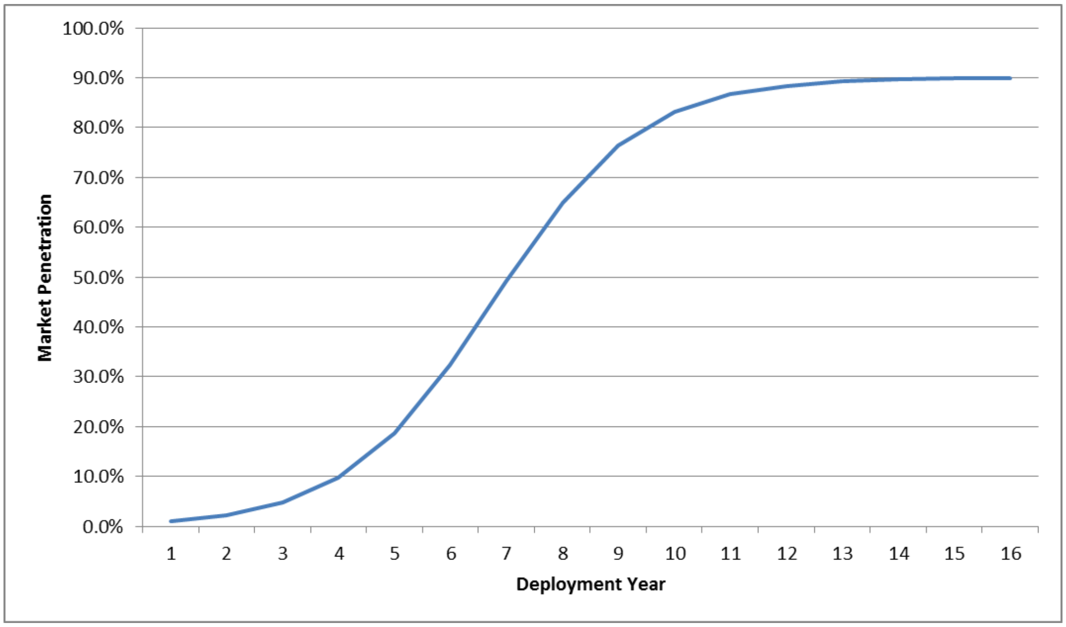


Figure 3-2. DSRC Technology Market Penetration Curve

Case Studies

As discussed in the Introduction and Background of this report, the objective of this effort is to develop a sound cost-benefit analysis on a public sector connected vehicle deployment linking each cost and benefit directly back to the public agency. However, the challenge associated with this task is that because connected vehicle deployments are currently in a research phase and the corresponding equipment is generally not available for public purchase, there are no full scale deployments available to analyze. To overcome this challenge, the analysis presented below focuses on three connected vehicle deployment case studies modeled around existing research or pilot deployments focusing on all real-world costs and benefits where available. While each of the case studies considered in this analysis represent a small portion of roadways managed by each agency, the intent is that the findings from these analyses can be utilized to extrapolate results to other jurisdictions.

Michigan

The Michigan connected vehicle Test Bed was deployed in partnership by the USDOT, Michigan Department of Transportation (MDOT), and the Road Commission of Oakland County (RCOC) beginning in 2007 to serve as a proof of concept testing for 5.9 GHz DSRC. This test bed consists of 55 RSEs installed along Interstate, divided highway and arterial roadways spanning representative of a typical suburban environment. The test bed site contains approximately 50 miles in Novi, Michigan and was selected for a

connected vehicle deployment in part because the transportation system has deficiencies, such as congestion and high crash rates.

The Michigan test bed is the longest standing connected vehicle test bed; this fact allows analysis to identify trends in equipment costs. Because this test bed has been active for the longest period of time, much of the equipment originally purchased for the test bed was in early stages of research. As the technology matured from strictly research and approaching enterprise grade equipment, competitors entered the market place and the prices of the various connected vehicle components have decreased. The ability to quantify this change in cost is useful for researchers and practitioners to begin to understand and estimate future costs. In addition, the Michigan test bed serves as an excellent source of backhaul related cost data, a significant component to the overall operations and maintenance cost of a connected vehicle deployment.

Because the Michigan test bed site is the longest standing test bed, the equipment included in this test bed have higher costs than should be anticipated for future deployments. Regardless of these higher costs, the history of this test bed allowed an extensive model to be built highlighting the various cost components that will exist in a wide scale deployment. Finally, the Michigan test bed allowed researchers to identify benefits not applicable in the other case studies, namely decreases in winter maintenance costs due to a better optimization of staff and equipment based on real-time weather conditions.

Virginia

The Northern Virginia Test bed was deployed in Fairfax County by the Virginia Department of Transportation (VDOT) in 2012 to support research by the connected vehicle/Infrastructure University Transportation Center. The deployed equipment spans approximately four square miles of an urban sample of Virginia's most heavily trafficked roadways. The site was selected for deployment because of the potential for research to improve system deficiencies, including heavy traffic, high crash rates and air quality non-attainment. For the purposes of this study, the Virginia Test bed represents a newer deployment with more current cost values.

The distinctive features of this deployment include four major merge and diverge locations, access to metro stations and commuter routes, managed lanes, and major roadway construction. Additionally, this small deployment encompasses a fire station, multiple schools and pedestrian trails, and a mix of commercial and residential land uses. This case study encompasses 55 roadside equipment devices, installed along I-66, US-29 (Lee Highway), US-50 (Arlington Blvd), Gallows Road and I-495. Cost information was provided by VDOT and benefits information for this deployment was derived from publicly available national, state and regional-level statistics.

Arizona-Maricopa County Region

The Arizona-Maricopa County Regional Deployment, while currently not in existence, is based upon a cost-benefit analysis conducted by the Arizona State University for the Arizona and Arizona-Maricopa County DOT projecting infrastructure costs and requirements for a region-wide network of connected vehicle technology. The availability of this data and estimate provided the ability to analyze cost and benefit impacts of connected vehicle technology deployments at a much larger scale than the other two sites, which were more corridor or small-area based. This allows the analysis to more accurately depict regional impacts and provides a more cumulative cost benefit analysis than is currently available at the Michigan or Virginia test sites.

The Arizona-Maricopa County Regional Deployment encompasses both county-managed roadways as well as right-of-way from over 20 different municipalities, townships, and cities within the boundaries of Arizona-Maricopa County. Arizona-Maricopa County is of the most populous counties in the state of Arizona and nation, encompassing over half of the state's residents. The case study site features both urban and suburban areas, a large mix of land uses, multiple interstates and state highways, and numerous activity centers, among other characteristics that would make this case study site comparable to other large urbanized regions within the United States. This deployment extrapolates data from the Arizona Emergency

Vehicle Infrastructure Integration (E-VII) implementation to the regional level, inclusive of over 2,478 roadway miles.

The Arizona CBA projected that a network of 2,680 RSEs would be necessary to define a region-wide deployment of connected vehicle technology specifically to address emergency management and traffic management applications. These projections were based off of the small-scale E-VII deployment in Anthem, Arizona.

Costs

This section documents the expenditures required for RSE acquisition, deployment, and O&M, as well as the cost associated with backhaul set up and annual backhaul. The cost are broken down in the one non-recurring cost associated with putting the RSE and support systems and services in place and the annual recurring cost of O&M and backhaul costs. Both categories of costs are provided for each of the case studies reviewed.

Non-Recurring Costs

Michigan

The costs for the Michigan connected vehicle Test Bed are derived from actual cost incurred in setting up the test bed. These costs are likely higher than future implementation costs would be as the equipment was still research stage and already we see costs for RSE come down from the levels incurred by the Michigan project. The mean unit installation costs for the items making up the costs of RSE are shown below.

Table 3-1. Michigan Test Bed RSE Unit Costs

RSE Unit Costs	Mean
Basic RSE Unit Costs	$3,750
RSE Incidentals	$1,000
Communication Connection Equipment	$1,300
Power Connection Equipment	$300
Installation labor	$2,500
Installation Equipment	$3,500

The cost shown above results in a mean cost per installed RSE for the Michigan test bed of $12,350. There are 50 units installed at the test bed site, resulting in a total installation cost of $617,500 for the Michigan test bed site. In addition, each site required a $5,000 investment to setup backhaul, resulting in an additional $250,000 in cost. This resulted in a total cost to establish the Michigan connected vehicle Test Bed of $868,000.

Virginia

For the Virginia I-66 Connected-Vehicle Test Bed, the installation and equipment costs were provided by VDOT and are based on the actual cost incurred in setting up the test bed. Where actual costs were not available, such as the cost associated with the backhaul prior research findings were used to estimate those costs. The costs are broken down into three categories. The overall installation cost, including program management and oversight, are captured at the project level, while RSE equipment, installation, and backhaul setup costs are captured at a per unit basis. Each cost category is shown in the subsequent tables.

Table 3-2. VDOT Test Bed Installation Costs

Installation Costs	Mean
Oversight/PM/Integrator Costs	$29,560
Arterial Installation Costs	$47,018
Interstate (I-66 and I-495) Installation Costs	$135,044
Savari Labor	$11,948
D4 Labor	$6,674

Table 3-3. VDOT Test Bed RSE Unit Costs

Equipment Costs	Mean
Savari RSE Unit	$3,500
Installation Support	$2,500

Table 3-4. VDOT Test Bed Backhaul setup costs

Backhaul Costs	Mean
Urban Non-Recurring	$1,956

Program Management and installation cost add up to $240,000. The Equipment and installation support for 55 units comes to $330,000 and the backhaul setup for these units cost $108,000. This resulted in a total cost to establish the Virginia I-66 Connected-Vehicle Test Bed of $678,000.

Arizona-Maricopa County Region

The Arizona-Maricopa County Region deployment costs were derived from the Arizona E-VII data and of the three case studies, represent the most current or *generic costs* that practitioners can expect for the near future. The study costs the deployment of 2,680 RSE throughout the Arizona-Maricopa County Region. PM and governance as well as backhaul setup costs are captured at the projects level. RSE installation related costs are captured by unit and add up to $9,600 per unit. This results in an installation cost of just under $26 million and combined with the PM and backhaul setup costs in a total project cost of roughly $32 million.

Table 3-5. Arizona-Maricopa County Region oversight costs

PM and Governance	Mean
Equipment, Installation, & Deployment	$1,400,000

Table 3-6. Arizona-Maricopa County Region oversight costs

Backhaul Costs	Mean
Non-Recurring	$4,590,000

Table 3-7. Arizona-Maricopa County Region oversight costs

Cost Values RSE Unit Costs	Equipment	Labor	Rental Equipment	Total
Basic RSE Unit Costs	$1,000	$2,400	$3,600	$9,600
RSE Incidentals	$1,000			
Communication Connection Equipment	$1,300			
Power Connection Equipment	$300			

Recurring Costs

In addition to the initial project setup costs there are annual recurring costs associated with RSE deployment to support connected vehicle technology. The costs are based on estimates by the operators of the pilot or study projections and vary among the different pilot projects reviewed for this study. This section captures these costs for each of the three pilot projects.

Michigan

The annual recurring cost for the Michigan test bed was derived from information provided on the actual costs incurred from operating the test bed. O&M expenses are estimated at 3.5 percent of original implementation costs annually for both the RSEs and backhaul based on the experience from the Michigan test bed. In addition there is an annual communications costs of approximately $1,000 per unit for wireless service. Combined these numbers result in a total annual recurring cost of $80,000. This represents a per unit cost of roughly $1,607 per unit. Based on the cost input variables, the 80 percent percentile of the annual recurring costs ranges between $71,000 and $91,000, as shown in Figure 3-3. This represents a per unit cost between $1,430 and $1,813.

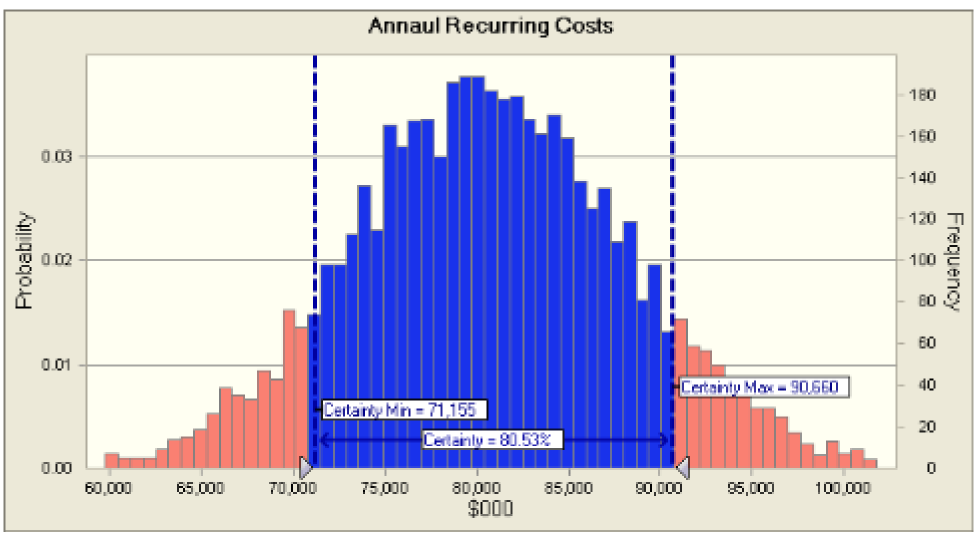


Figure 3-3. Michigan Test Bed Annual Costs

Virginia

For the VDOT test bed the RSE maintenance costs are estimated to be 12.5 percent of the original equipment purchase price based on data provided by VDOT. Annual recurring backhaul costs are based on the previously cited USDOT research study, which estimates annual backhaul costs at $846 in urban settings. Combined, these numbers result in a total annual recurring cost of $71,000. This represents a per unit cost of roughly $1,285 per unit. Based on the cost input variables the 80 percent percentile of the annual

recurring costs ranges between $64,000 and $79,000, as shown in Figure 3-4. This represents a per unit cost between $1,157 and $1,435.

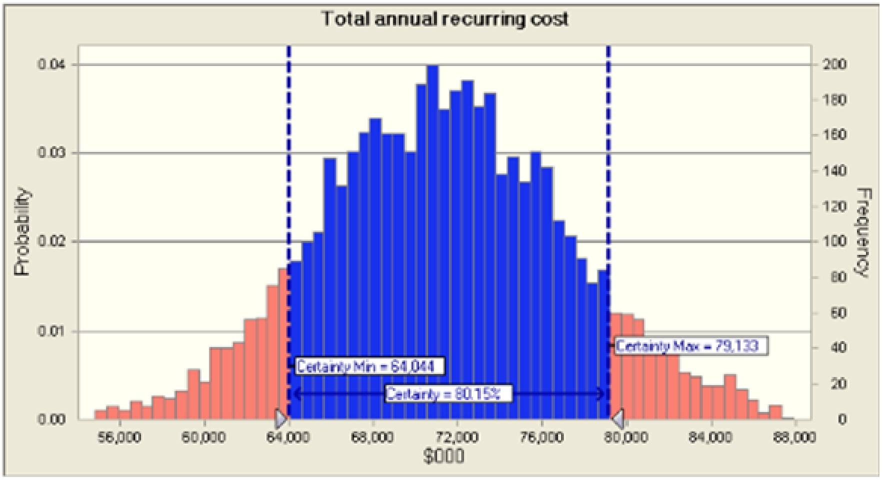


Figure 3-4. VDOT Test Bed Annual Costs

Arizona-Maricopa County Region

The cost benefit analysis of the Arizona-Maricopa County Regional Deployment assumed an annual maintenance cost of 15 percent of the total deployment cost, which includes field losses due to collisions, weather, vandalism, replacement of equipment at the end of its life span and other factors. Further, the study estimates the annual backhaul cost for the 2680 RSEs at $3.3 million. This annual recurring costs is the yearly aggregate of monthly recurring charges, including the provider's fee for its service to its customers. This also includes an annual cost of $210,000 for maintenance, operation and staffing at the program level. Combined these costs result in an annual recurring cost of $4.957 million, which represents a per unit cost of roughly $1,850. Based on the cost input variables, the 80 percent percentile of the annual recurring costs ranges between $4.4 and $5.4 million, as shown in Figure 3-5. This represents a per unit cost between $1,646 and $2,012.

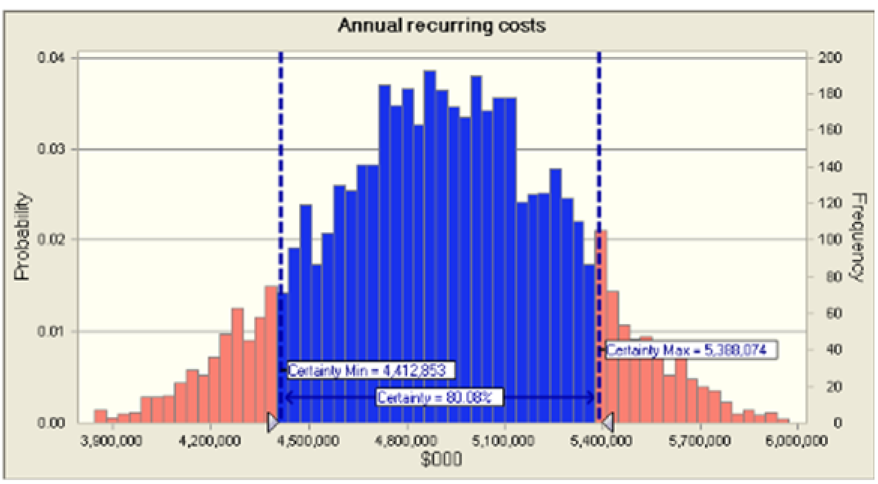


Figure 3-5. Arizona-Maricopa County Regional Deployment Annual Costs

Cost Analysis Across Case Studies

Shown in Table 3-8 and based on the case studies analyzed, the implementation cost range from as much as nearly $20,000 per installed unit in Michigan to $11,000 to 12,000 per installed unit in Virginia and Arizona-Maricopa County Region with all cost including overhead expenses such as program management accounted for. The annual recurring costs are forecasted to range from $1,200 to $2,000.

The biggest drivers are RSE unit costs and backhaul, both set up and annual costs. Reviewing the cost differential from the earlier test bed in Michigan and the subsequent test bed in Virginia, one can see that RSE unit costs are going to be reduced in the future as technology matures and more hardware providers enter the market space. There does not appear to be a specific trend in recurring costs in these case studies as recurring costs are largely correlated with the size and scope of the deployment. For example, the Arizona-Maricopa County deployment was estimated to be on a much larger scale with many more RSEs than Michigan or Virginia. Further, each test bed is developing and deploying varying numbers and types of applications which also affect recurring costs. This finding shows that it is difficult to develop a generic cost estimate for deployment costs as many costs are very much a function of the size and scope of the deployment as well as existing infrastructure in the region. Backhaul costs remain a concern for the future deployments. Experts predict large recurring costs to deploy and maintain backhaul infrastructure. For example, recurring costs may amount to as much as 50 percent of total deployment cost when considering the costs such as installing fiber, providing power, and maintaining communications.

Table 3-8. Unit Costs Across Case Studies

Case Study	Number of RSEs	Initial Cost (per unit)	80 Percentile Range of Recurring Costs (per unit)	
			Low	High
Michigan	50	$17,360	$1,430	$1,813
Virginia	55	$12,327	$1,157	$1,435
Arizona-Maricopa County	2,680	$11,940	$1,646	$2,012

Benefits

Benefit Categories

Connected vehicle technology has functionality in areas such as improved safety, reduced congestion, and emissions, as well as for improving DOT operations. This study focuses on functionalities of connected vehicle technology that can provide direct benefits to State DOTs, and the following were selected for the analysis:

- Crash response and cleanup cost reduction,
- Work zone accident reduction,
- Lower cost of pavement condition detection,
- Adaptive Lighting, and
- Reduction of infrastructure required to monitor traffic.

All of the benefits are derived from cost avoidance over current operations, i.e., fewer accidents to respond to or less expensive means to collect data or provide information to the public. Which benefits were assigned to each pilot depended on the availability of data. This analysis only included the direct

benefits for which a reasonable estimate of monetary savings could be developed. For all three case studies, there were measurable benefits from crash response and cleanup cost reduction, work zone accident reduction, and from lower cost of pavement condition detection. There were also savings related to traveler information systems or traffic monitoring systems for each of the pilots which slight variations for each location. Additional site specific savings were included as applicable.

Direct Monetary Benefits

The accident reduction related savings were calculated the same for all the locations:

$$Current\ number\ of\ accidents \times Average\ cost\ per\ accident \times Percent\ reduction\ in\ accidents$$

The average cost for accident response and cleanup was assumed to be $500 with a range of $200 to $5,000 based on averages derived from research into legislative initiatives trying to recoup accident related costs. This is the average cost over all accidents that would occur in a year, not the range of costs per individual accident. There will be accidents that have lower response costs than $500; however, the annual average will be in the predicted range due to more costly accidents occurring through the year, raising the average cost. The average cost for a work zone accident was taken as $3,687 based on prior research. The reduction in accidents due to connected vehicle technology was assumed to be up to 26 percent based existing National Highway Traffic Safety Administration (NHTSA) research. The model uses a single sided normal distribution ranging from 10% to 26% for the actual reduction in crashes to be conservative. As previously mentioned, this is the accident reduction rate at full penetration of DSRC technology. Prior to full market penetration, the benefits will be reduced based on the market penetration curve shown in Figure 3-2, i.e., in year 7 after introduction, the accident reduction would be 50 percent of the full penetration level or up to 13 percent rather than up to 26 percent. Savings from pavement condition detection were assumed to be derived from eliminating the need for either DOT vehicles or contractors to specifically drive roads to assess pavement condition, as this information would be collected by DSRC technology. Research determined the current cost to be between $15 and $25 per mile depending on if the work was carried out by government vehicles or contractors. The following sections will describe the detailed benefits for each of the three locations analyzed.

Michigan

The annual number of accidents along the test bed corridor are derived from the number of accidents in the Southeast Michigan Council of Governments (SEMCOG) region scaled down to the corridor based on the percentage of roadway miles covered. Similarly the number of work zone accidents was derived from data at the regional level, scaled down to the size of the corridor. The test bed covers 50 miles of roadway, and therefore only represents a small portion of the region's roadways; however, this is the best method to estimate the impact of connected vehicle technology based on the data that is currently available. A specific savings for the Michigan test bed came from the reduction of infrastructure required to monitor traffic and collect traffic data internally. In the SEMCOG region there are currently:

- 200 microwave sensors at a cost of $110 per month (leased),
- 20 detection systems at intersections at $4,000 per unit,
- 20 Sydney Coordinated Adaptive Traffic System (SCATS) units at a cost of $5,000 per unit, and
- 2,260 inductance loops with an annual life-cycle cost of $2,660.

Again, scaling by the size of the test bed versus the region and assuming a 20 percent reduction of equipment needed once connected vehicle technology is in place was used to determine the savings in this category. Another Michigan-specific benefit of connected vehicle technology is derived from the cost avoidance of collecting weather data and optimizing the fleet of maintenance vehicles. The average cost per lane mile for winter maintenance (plowing and salting) is roughly $3,100. Assuming a small reduction

in this cost due to better real-time information collected by connected vehicle technology results in a small direct benefit to the state DOT. Table 3-9 below shows the summary of the benefits derived from connected vehicles technology scaled to the size of the test bed area for 10 years of operation.

Table 3-9. Michigan Test Bed Benefits

Benefit	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Crash clean up cost reduction	$0	$0	$0	$913	$1,937	$4,049	$8,207	$15,706	$27,298	$41,552	$54,867	$154,529
Workzone accident reduction	$0	$0	$0	$181	$385	$805	$1,631	$3,122	$5,426	$8,259	$10,905	$30,714
Lower cost of pavement condition detection	$0	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$10,000
Reduced winter maintenance costs	$0	$1,550	$1,550	$1,550	$1,550	$1,550	$1,550	$1,550	$1,550	$1,550	$1,550	$15,500
Reduction of infrastructure required to monitor traffic	$0	$8,792	$8,792	$8,792	$8,792	$8,792	$8,792	$8,792	$8,792	$8,792	$8,792	$87,915
Total Benefits	$0	$11,342	$11,342	$12,436	$13,663	$16,195	$21,180	$30,170	$44,066	$61,152	$77,114	$298,658

Virginia

The VDOT test bed covers 200 of the 2,600 miles of roadway in Fairfax County, Virginia. The total number of accidents in 2012 in Fairfax County was 14,233, so for the analysis of the test bed this was scaled down to roughly 1,095 to calculate the savings from reduced accident response and cleanup costs. Savings from reduced work zone accidents were derived from state data showing 3065 work zone accidents annually, scaled first to the Fairfax County level (11.7 percent of all Virginia accidents occur in Fairfax County), and then to the test bed based on the number of miles of roadway covered. As was done for the Michigan test bed, the Virginia benefits were phased in with the projected increase in market penetration of DSRC technology.

The savings from adaptive lighting are based on research underway by the Virginia Tech Transportation Institute into adaptive lighting technology. The most significant impact of adaptive lighting technology is energy savings. It is estimated that a lighting system can be dimmed to a 50 percent level for at least 50 percent of the system burn time, which would result in a 25 percent energy savings in the lighting system cost. The savings for the VDOT test bed were based on the following data:

- 4 streetlights per mile,
- 200 miles of roadway in this example,
- Each streetlight has a 200 watt high pressure sodium fixture,
- Streetlights run 12 hours per day 365 days per year, and
- Energy Costs are $0.133 per kilowatt hour in the DC area.

It is also assumed that expenditures for traveler information infrastructure would not be reduced until 50 percent market penetration of DSRC technology is reached. Subsequently, it is assumed that the DOT would reduce its spending on this equipment by 10 percent annually as information can be pushed directly to most vehicles, reducing the need for message signs. A reduction of infrastructure required to monitor traffic will result from the increasing the amount of probe data pushed directly from vehicles, reducing the need for microwave vehicle detectors and other in-road sensors. This benefit will accrue more quickly as it requires fewer vehicles to generate relevant data similar to crowd sourced information applications such WAZE. For the analysis we assumed that after 10% of vehicles have DSRC technology providing data, investment into traffic monitoring infrastructure will be reduced starting at 10% annually increasing to an annual reduction of 50% over 5 years. Table 3-10 below shows the summary of the benefits derived from connected vehicle technology scaled to the size of the test bed area for 10 years of operation.

Table 3-10. VDOT Test Bed Benefits

Benefit	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Crash clean up cost reduction	$0	$0	$1,538	$3,264	$6,822	$13,830	$26,466	$45,999	$70,017	$92,453	$108,632	$369,021
Workzone accident reduction	$0	$0	$287	$608	$1,271	$2,577	$4,931	$8,571	$13,046	$17,226	$20,240	$68,756
Lower cost of pavement condition detection	$0	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$40,000
Adaptive Lighting	$0	$22,776	$22,776	$22,776	$22,776	$22,776	$22,776	$22,776	$22,776	$22,776	$22,776	$227,760
Reduced need for 511 infrastructure	$0	$0	$0	$0	$0	$0	$0	$0	$0	$61,050	$61,050	$122,100
Reduction of infrastructure required to monitor traffic	$0	$0	$0	$0	$0	$0	$51,300	$102,600	$153,900	$205,200	$256,500	$769,500
Total Benefits	$0	$26,776	$28,600	$30,648	$34,869	$43,183	$109,473	$183,946	$263,739	$402,705	$473,198	$1,597,137

Arizona-Maricopa County Region

The Arizona-Maricopa County Regional Deployment annual accident rates were derived from state and county data averaged over the past 5 years. Arizona-Maricopa County accounts for roughly 70 percent of all Arizona accidents. Based on data from 2007 through 2011, it was estimated that there are 81,138 accidents in Arizona-Maricopa County annually. The number of work zone accidents was determined by adding crashes that were listed as "Under Construction Thru Traffic Allowed", "Under Construction Traffic Detoured", "temporary lane closures", and "under repairs" for a total of 4,046 work zone crashes in Arizona. If 70 percent of all crashes in Arizona occur in Arizona-Maricopa County, the same percentage could be applied to work zones, multiplying 70 percent by the 4,046 crashes in the state, totaling 2,832 crashes in Arizona-Maricopa County. Consistent with the other case studies, the benefits are stepped-up with the gradual market penetration of the DSRC technology.

For the Arizona-Maricopa County Regional Deployment, the savings from reduced costs for pavement detection were based on actual expenditures in prior years. Statewide, AZDOT spends $575,000 annually for pavement detection. Arizona-Maricopa County Region represents 10.25 percent of total lane miles, and therefore annual expenditure for the Arizona-Maricopa County Region that can be saved by using data from DSRC technology is $59,000.

Transportation management systems savings are based on regional data for current expenditures for the Metropolitan Phoenix Freeway Management System. Similar to the analysis of the VDOT test bed, it was assumed that savings will not to start until 50 percent market penetration of DSRC technology is reached. Subsequently, it is assumed that the DOT would reduce its spending on this equipment by 10 percent annually as information can be pushed directly to most vehicles, reducing the need for message signs and increasing the amount of probe data pushed directly from vehicles, reducing the need for microwave vehicle detectors and other in-road sensors. Table 3-11 below shows the summary of the benefits derived from connected vehicles technology scaled to the size of the test bed area for 10 years of operation.

Table 3-11. Arizona-Maricopa County Regional Deployment Benefits

Benefit	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Crash clean up cost reduction	$0	$241,869	$505,570	$1,024,922	$1,961,358	$3,408,957	$5,188,903	$6,851,622	$8,050,601	$8,763,335	$9,139,394	$45,136,530
Workzone accident reduction	$0	$62,306	$130,236	$264,022	$505,250	$878,155	$1,336,674	$1,764,994	$2,073,854	$2,257,456	$2,354,330	$11,627,280
Lower cost of pavement condition detection	$0	$59,000	$59,000	$59,000	$59,000	$59,000	$59,000	$59,000	$59,000	$59,000	$59,000	$590,000
Transportation Management Systems Saving	$0	$0	$0	$0	$0	$0	$0	$532,000	$585,200	$643,720	$708,092	$2,469,012
Total Benefits	$0	$363,175	$694,806	$1,347,945	$2,525,608	$4,346,112	$6,584,577	$9,207,616	$10,768,655	$11,723,511	$12,260,817	$59,822,822

Cost Benefit Summary

As discussed in the introduction, investments into connected vehicle technology, notably the roadside equipment devices (RSEs), will improve safety and mobility for the traveling public. The macro economic benefits will come from reduced fatalities, injuries, and property damage, as well as reduced delays for the nations' travelers. These benefits are the major drivers for the investment; however, as this analysis demonstrates, there are also direct benefits to the state DOTs that would finance the deployment of roadside infrastructure. These benefits accrue over time and are dependent on the market penetration of in-vehicle devices purchased by the public. As this market penetration reaches significant levels of around 50 percent

of all vehicles, the direct benefits become significant and can offset the anticipated annual recurring cost of maintaining the RSEs. As an example, we are providing the cost benefit results for the Virginia test bed. The results for the Michigan test bed and the Arizona-Maricopa County regional deployment are included in Appendix C. In the Virginia example, the annual savings increase to a level significantly above the annual recurring cost in year 7, as shown in Table 3-12. Because of the 10 year time horizon of the analysis and the high upfront investment required, with no anticipated revenue generated by the RSEs, neither the Benefit/Cost ratio or Net Present Value (NPV) of the investment are positive.

Table 3-12. VDOT Test Bed Costs and Benefits

Costs	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Non-Recurring	668	0	0	0	0	0	0	0	0	0	0	668
Recurring	0	71	71	71	71	71	71	71	71	71	71	706
Total	**668**	**71**	**71**	**71**	**71**	**71**	**71**	**71**	**71**	**71**	**71**	**1,374**

Benefits	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Cost Savings	0	27	29	31	35	43	109	184	264	403	473	1,597
Total	**0**	**27**	**29**	**31**	**35**	**43**	**109**	**184**	**264**	**403**	**473**	**1,597**

Net Benefit/Cost	**-668**	**-44**	**-42**	**-40**	**-36**	**-27**	**39**	**113**	**193**	**332**	**403**	**223**

NPV	**-126**

While the initial analysis results in a negative NPV value at -$126,000, the sensitivity analysis shows a 80 percent confidence interval for the NPV of the investment into RSE in the I-66 corridor that ranges from about negative $217,000 to positive $496,000, indicating an upside potential that could result in a positive return over time, as shown in Figure 3-6. The trend in cost of the RSE is declining and the potential for additional benefits beyond what could be analyzed in this study based on available data could further improve these results. For example, the availability of data from equipped vehicles may allow for reorganization of responsibilities or improvements to efficiency within an agency. Statewide deployments of RSEs will likely have network effect benefits that go beyond what is captured for a relatively small test bed corridor. Those savings could include items such as reduced fleet-related accident costs, further reduction in maintenance related cost beyond pavement detection savings, and benefits from improved planning efforts due to better data.

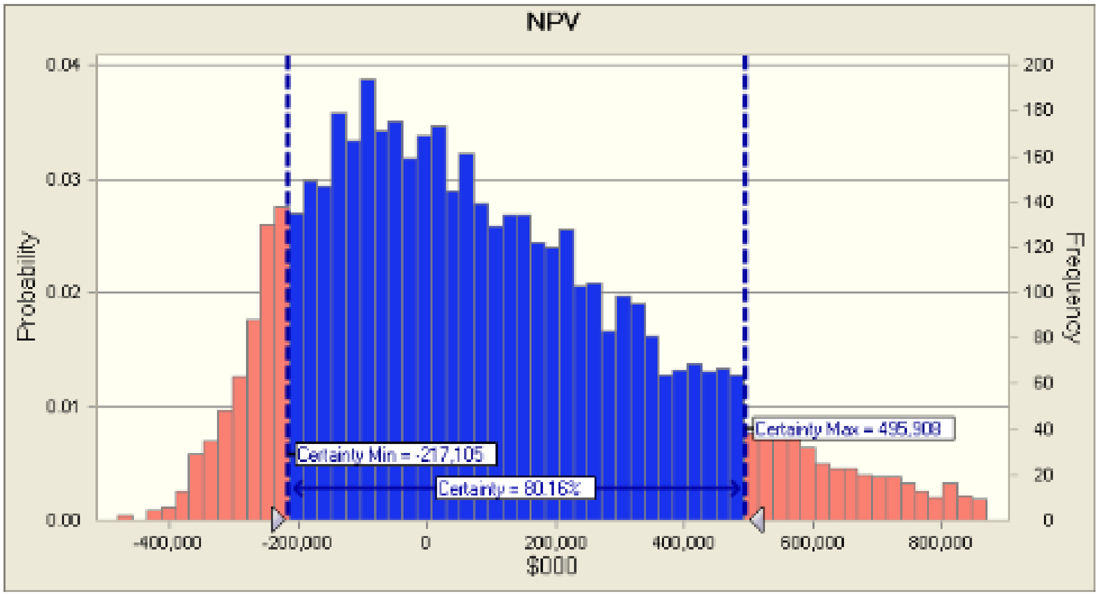


Figure 3-6. VDOT Test Bed Investment NPV

In addition to the range of likely cost and benefit results, the sensitivity analysis conducted also provides insight in the relative importance of each of the considered input variables. The results of the sensitivity analysis are presented in a tornado chart, as explained in the Methodology section. Figure 3-7 through Figure 3-9 depict the tornado charts for each case study. For all three study sites, the average cost for accident response and cleanup is the main driver of the results, representing the majority of the cost avoidance, but it is noteworthy that in the later projects other benefits categories and the annual recurring backhaul costs become more important than the initial equipment purchase. This is due to decline in the cost of RSEs over time, but it also indicates that decision makers should focus on ways to minimize backhaul costs.

It is important to consider that connect vehicle technology, applications, and deployments are rapidly evolving. As these technologies mature, market penetration increases, and deployments become more commonplace, additional benefits may be realized. Similarly, this evolution will likely also provide agencies with the ability to provide a better quality of service to motorists. Because cost-benefit analyses considering the societal impacts of connected vehicle deployments have been and continue to be completed through other research efforts, this effort purposely focused solely on impacts that researchers could directly link to a transportation agency's budget. Because transportation-related cost-benefit analyses are not typically conducted in this way and rather consist of significant analysis on societal impacts, this analysis illustrated the difficulty assessing direct benefits to the agency due to the lack of available data. As agencies continue to deploy connected vehicle technologies, it is assumed that these data would become more assessable and can be included in future, similar analyses. Finally, nearly all of the applications and technologies covered in this analysis are still being researched. As research continues, these applications and technologies will evolve, and new applications will be developed. This progress will likely offer practitioners more substantial benefits in the future.

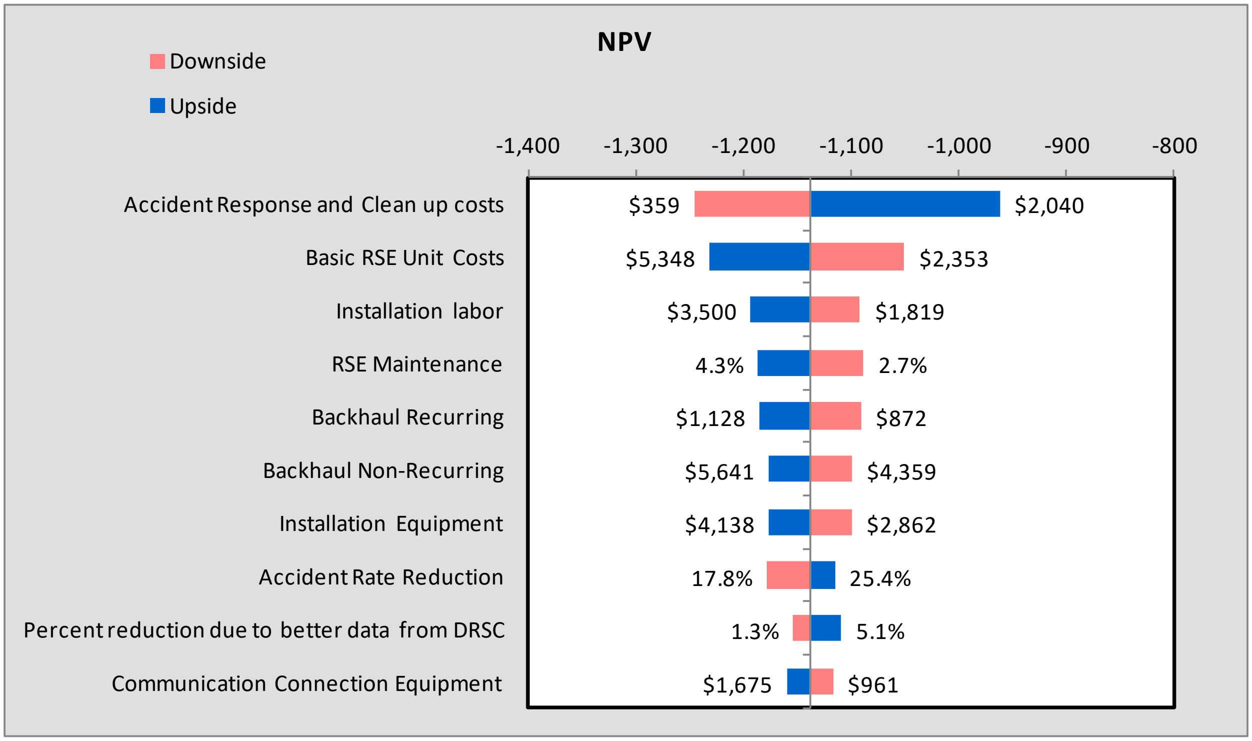


Figure 3-7. Tornado Chart for Michigan Test Bed (Horizontal Axis in $000)

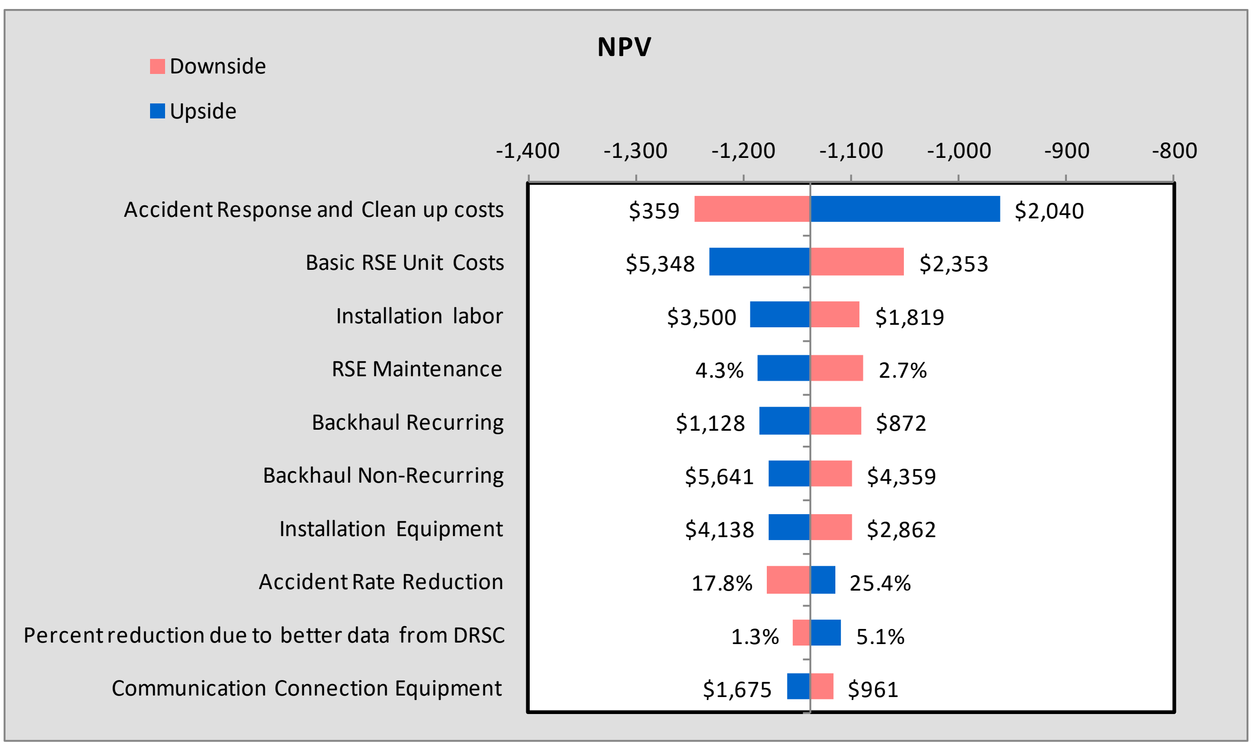


Figure 3-8. Tornado Chart for Virginia Test Bed (Horizontal Axis in $000)

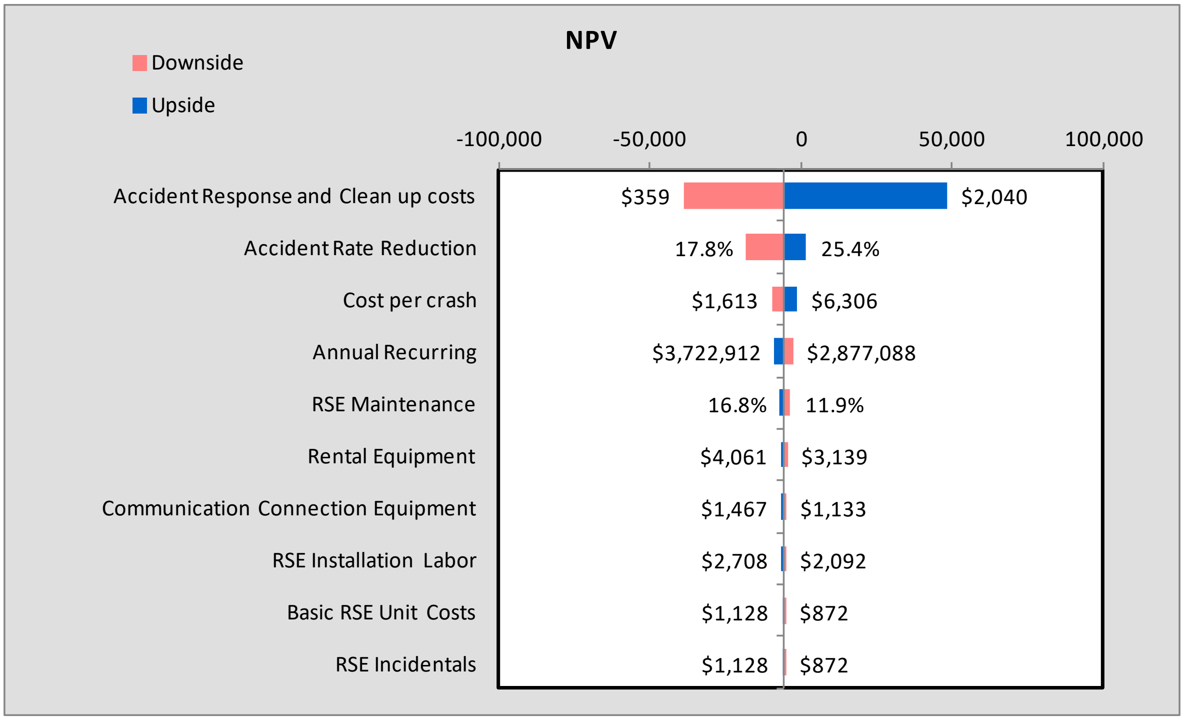


Figure 3-9. Tornado Chart for Arizona-Maricopa County Regional Deployment (Horizontal Axis in $000)

CHAPTER 4

Deployment Guidance

Introduction

The deployment guidance includes information for agencies for to assist in the deployment of connected vehicles technologies. This section includes guidance on application selection, RSE deployments, and funding approaches for connected vehicle deployments.

Application Selection

CVAST Tool

Connected vehicle technology affords agencies with a number of applications that have the potential to streamline operations and help transportation management agencies achieve various goals for their respective transportation system. It is difficult to determine which applications will provide the greatest utility to an agency without understanding what the applications are, what they can do, what they require technologically, and what resources they require from an agency.

In order to facilitate the decision-making process for which applications to deploy, an Excel®-based connected vehicle application selection tool – **CVAST v1.0** – was developed specifically for state and local transportation agencies to use. The tool is provided in an electronic ".xlsm" format. Figure 4-1 is a screenshot of the main page of the tool:

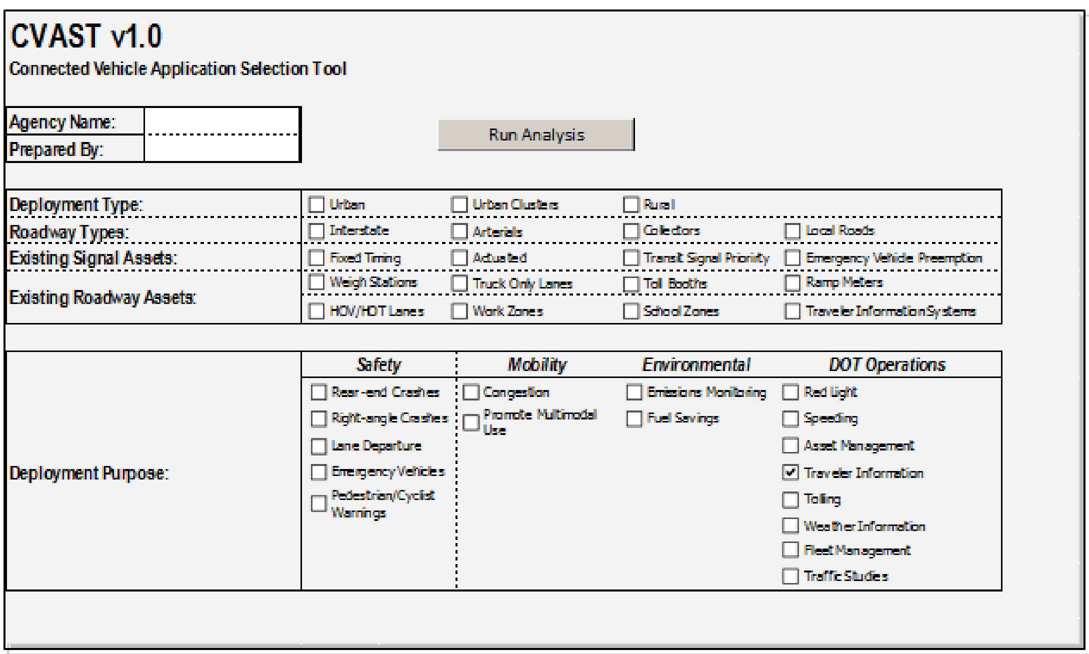


Figure 4-1. CVAST v1.0 Main Page

The purpose of this tool is to provide users with a prioritized list of applications tailored to the specific interests of a user. Users are able to provide input regarding their deployment in terms of the following characteristics:

- Deployment Type,
- Roadway Types,
- Existing Signal Assets,
- Existing Roadway Assets, and
- Deployment Purpose.

The **deployment type** describes the population of the region where the connected vehicle deployment is being considered, as some applications are better suited for metropolitan areas with high traffic volumes and others for rural areas.

The **roadway types** characteristic allows the user to enter the types of roadways contained within the potential deployment region.

Because many of the connect vehicle applications discussed in this tool are related to traffic signals, users are able to enter the **existing signal assets** included within the deployment region.

Similar to the **existing signal assets**, the **existing roadway assets** allows users to input relevant roadway assets that may exist in the deployment region to better prioritize applications that may leverage (or be leveraged) by these assets.

Finally, **deployment purpose** allows the user to input their preferences on the deployment purpose (e.g., to address safety-related goals, etc.).

The list of all characteristics and the relevant options can be found in Table 4-1. The list of applications included with this tool can be found in Appendix B of this report.

Table 4-1. Deployment Characteristic Descriptions

	Characteristic	Description
Deployment Type	**Urban**	Areas of 50,000 or more people.
	Urban Clusters	Areas of at least 2,500 and less than 50,000 people.
	Rural	All other areas.
Roadway Types	**Interstate**	Roads that provide highest level of mobility and the highest speeds over the longest uninterrupted distance.
	Arterials	All other roads that provide the high level of service with long uninterrupted distances and limited access.
	Collectors	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
	Local Roads	Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through movement.
Existing Signal Assets	**Fixed Signal Timing**	Indicates the deployment scenario includes existing traffic signals with fixed timings.
	Actuated Signals	Indicates the deployment scenario includes existing actuated traffic signals.
	Transit Signal Priority	Indicates the deployment scenario includes existing transit signal priority

	Characteristic	Description
	Emergency Vehicle Preemption	Indicates the deployment scenario includes existing emergency vehicle preemption.
Existing Roadway Assets	**Weigh Stations**	Indicates the deployment scenario includes existing commercial vehicle weigh stations.
	Truck Only Lanes	Indicates the deployment scenario includes existing truck only lanes.
	Tolling Facilities	Indicates the deployment scenario includes existing tolling facilities.
	Ramp Meters	Indicates the deployment scenario includes existing ramp meters.
	HOV/HOT Lanes	Indicates the deployment scenario includes existing High-Occupancy Vehicle (HOV) or High-Occupancy Tolling (HOT) lanes.
	Work Zones	Indicates the deployment scenario includes existing work zones.
	Schools Zones	Indicates the deployment scenario includes existing school zones.
	Traveler Information Systems	Indicates the deployment scenario includes existing traveler information systems (e.g., 511).
Deployment Purpose: Safety	**Rear-End Crashes**	Indicates that the deployment is intended to reduce rear-end crashes.
	Right Angle Crashes	Indicates that the deployment is intended to reduce right-angle crashes.
	Lane Departure Crashes	Indicates that the deployment is intended to reduce lane departure crashes.
	Emergency Vehicles	Indicates that the deployment is intended to improve emergency vehicle operations.
	Pedestrian and Bicyclists	Indicates that the deployment is intended to improve safety for pedestrians and bicyclists.
Deployment Purpose: Mobility	**Congestion Management**	Indicates that the deployment is intended to assist in managing congestion.
	Promote Multimodal Use	Indicates that the deployment is intended to promote multimodal use.
Deployment Purpose: Environment	**Emissions Monitoring**	Indicates that the deployment is intended to assist in monitoring emissions.
	Fuel Savings	Indicates that the deployment is intended to assist in reducing fuel consumption.
Deployment Purpose: DOT Operations	**Red Light Running**	Indicates that the deployment is intended to reduce red light running.
	Speeding	Indicates that the deployment is intended to reduce speeding.
	Asset Management	Indicates that the deployment is intended to support an agency's asset management program.
	Traveler Information	Indicates that the deployment is intended to support an agency's traveler information program.
	Tolling	Indicates that the deployment is intended to support an agency's tolling program.

	Characteristic	Description
	Weather Information	Indicates that the deployment is intended to provide weather information.
	Fleet Management	Indicates that the deployment is intended to assist an agency manage their fleet.
	Traffic Studies	Indicates that the deployment is intended to provide data to support an agency conduct traffic studies.

To develop the prioritized list, this tool follows the logic depicted in Figure 4-2.

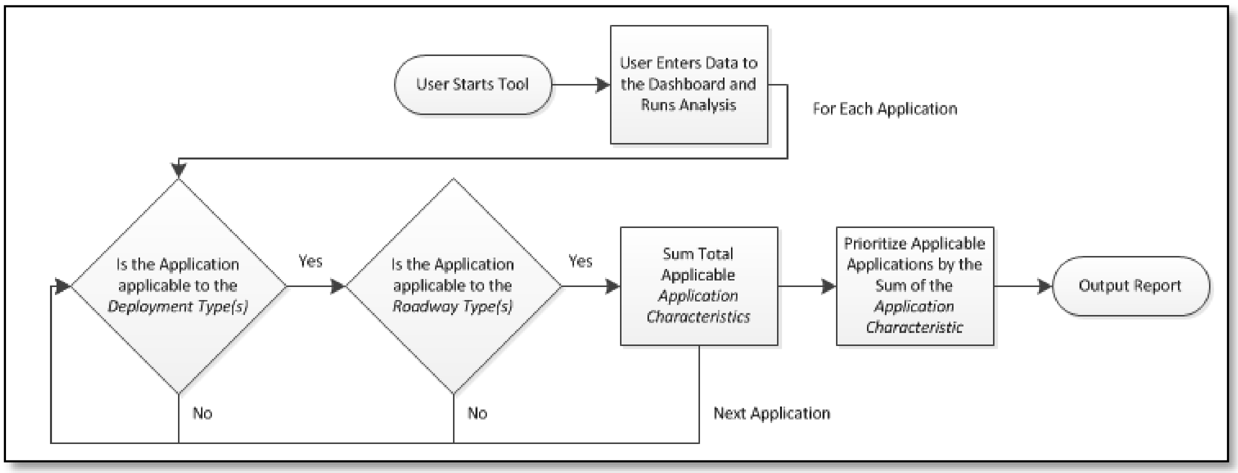


Figure 4-2. Deployment Plan Tool Logic

The user enters data corresponding to their deployment scenario and runs the analysis. The tool reviews the criteria of each application to determine if it would be relevant to the scenario input by the user with regard to the *Deployment Type* and the *Roadway Type(s)*. If the application is relevant, the tool aggregates the number of characteristics for each application relevant to the user-defined scenario. Finally, the list of relevant applications is prioritized by the number of relevant characteristics, and a report is presented to the user.

Identifying a Need/Purpose for an Application

An interested deploying agency should consider the needs and characteristics of their deployment scenario and select the most appropriate applications based on these needs. CVAST provides the ground work for building a decision tree based off a baseline set of deployment characteristics and can be a useful tool in helping an agency conduct a needs analysis.

CVAST is also a flexible database that can be retrofitted to suit the needs of a deploying agency should the characteristics in the database not be suitable or robust enough. The system is Excel-based making it easy to modify the formulas and inputs should an agency require it. Moreover, as new applications become available, these applications can be input using the logic form in Appendix D and applied to CVAST to provide decision-makers with even more potential solutions.

Once an agency has selected the applications that are most appropriate for their particular scenario, some research as to application developers and vendors must be conducted to determine how the applications is implemented as well as what the base requirements might be.

Developing Functional Requirements

Each application must have a set of basic requirements for it to function. These requirements should include technical requirements, such as necessary interfaces and data characteristics, as well as deployment requirements, such as the condition of agency infrastructure and backhaul systems.

Table 4-2 provides a sample set of key requirements that are necessary to determine whether an application is deployment ready. This list is not exhaustive; however, it provides a framework for the types of information application developers must provide to deploying agencies in order for the agency to determine whether their deployment is prepared for the application to run.

Table 4-2. Sample Requirements Checklist

Functional Component	Requirement
Data Processing	• Is there a local application processor external to the RSE? • Does the application require remote application processing (i.e., for speed data, travel time, roadway condition, etc.)?
Traffic Signal Controller	• Is there access to the signal controller? • What are the signal controller requirements for the applications (i.e., NTCIP, serial port, Ethernet port, etc.)?
ITS Devices	• Does the applications require access to other ITS devices (e.g., weather station)? • How will the application interface with these devices (i.e., fiber, cellular, etc.)?
Backhaul	• What is the appropriate size of the backhaul system necessary to run the application? • Is the network IPv6 capable? Or will it need to be retrofit from IPv4?
Security	• Is there a need for a security credential management system to run the application securely? • What types of data/network security protocols are needed for the application?
Penetration	• What type of market penetration or data robustness does the application require to function? How will this level of penetration be ensured? • Will the application require interfacing with data sources outside of V2I or DSRC-based sources (e.g., mobile phone data, geotracking devices, satellite data, etc.)? If so, how will this information be incorporated?
Maturity	• How mature is the application and the technology upon which it runs? • Will it require frequent updates? If so, what is the process for conducting those updates?
Asset Condition	• What is the condition of existing infrastructure assets (e.g., RSEs, fiber connections, power sources, signal controller software, etc.)? • Will there be a need to update any assets before the application can be deployed?

Testing and Certification

Once application requirements are determined and the application(s) meet the minimum requirements, testing should be conducted to demonstrate successful operation under all potential deployment conditions. Particular attention must be paid to safety applications which should undergo a more rigorous testing program.

All applications must pass a number of tests where the application's operation could be compromised. For example, applications requiring weather data should be tested under multiple weather scenarios to ensure that data is being correctly gathered and interpreted. Proving that these applications are operational under various test scenarios can be done by constructing a test plan and organizing a test team to carry them out.

The test team must include a quality assurance mechanism, or alternatively, a certification body that will attest and verify an application's functionality according to the functional requirements listed. The certifying authority must observe that the application deployed does not cause harm to other operating systems already in place and that the application operates in a manner that fulfills its purpose.

Estimation of Application Benefits and Costs

Estimating application benefits and costs will be a key challenge for deploying agencies to overcome. Currently an effective framework for collecting relevant benefit-cost data specific to connected vehicle technology and/or applications does not exist. Deploying agencies in the near-term will need to develop a set of metrics that will aid them in understanding the impacts connected vehicle applications will have on their operations. The USDOT is in the process of identifying a number of metrics for which to quantify societal benefits, including reduction in highway fatalities, reduction in traffic incident-related travel delay, and reduction in vehicle emissions. However, these metrics do not address direct costs and benefits of connected vehicle applications for transportation management agencies.

As many agencies will be faced with the decision to deploy connected vehicle technology in the near-term, it is imperative that these agencies be equipped with the right resources to determine costs and benefits of deployment. In the near-term, the only ways to estimate cost data will be from current research-level deployments, such as those in Novi and Ann Arbor, Michigan, Northern Virginia, and Arizona-Maricopa County, Arizona. However, these costs will be higher than they will be for operational deployments. Costs will decrease as technology matures and the industry's understanding of connected vehicle operations and maintenance needs improves. Benefits data will need to be gathered and expressed in the form of potential operational cost-savings and reductions in spending associated with technologies that may be rendered obsolete once the appropriate market penetration threshold for connected vehicle technology and applications is reached.

There is a high level of variability in benefits and costs among different applications. Many applications, such as those that may run on probe data collected from cellular crowd-sourcing applications, will bear little cost to the agency and yield valuable benefits. Other applications, such as those reliant upon infrastructure (e.g., weather stations, GPS grounding systems, etc.), may require a significant investment by the agency, but yield valuable information which may not have been possible to collect in the past. Deploying agencies must focus on data that is available today and extrapolate or interpolate the impact that each individual application will have on various line items within their respective budgets and spending plans.

Table 4-3 below lists a number of primary resources for which to collect data necessary to quantify benefit-cost data for various applications:

Table 4-3. Benefit-Cost Data Resources

Source	Respective Data Available	Benefit-Costs Associated with Data
Operating Budget	• ITS capital costs • Traveler Information System (TIS) program and operating costs • Roadside communication systems cost (e.g., DMS signage, 511, etc.) • Probe data collection costs	➲ Savings from spending reductions in ITS infrastructure ➲ Savings from spending reductions in TIS software and hardware ➲ Savings from spending reductions in roadside communications signage

Source	Respective Data Available	Benefit-Costs Associated with Data
	• Asset management costs • Snow removal costs • Adaptive lighting costs • Incident response costs • Cost of data collection for planning studies	➲ Savings from elimination of probe and asset condition data collection contracts ➲ Savings from more predictive or more focused snow removal ➲ Energy savings from reductions in up-time for roadside lighting ➲ Incident response savings from reductions in crashes ➲ Reduced spending on data collection for planning studies
Crash Reports & Records	• Number of crashes per year • Costs related to crashes • Number of fatalities per year	➲ Savings from reductions in "cost of a life" ➲ Crash clean-up savings from crash reductions ➲ Travel time savings ➲ Increased productivity due to improved throughput
Transit Operations & Performance Reports	• Transit-related ITS costs • Transit scheduling software and geo-tracking costs	➲ Savings from spending reductions in ITS infrastructure ➲ Fleet management software and contract savings
Work Zone Safety Statistics	• Work-zone crashes per year • Costs related to crashes	➲ Savings from reductions in "cost of a life" ➲ Crash clean-up savings from crash reductions ➲ Travel time savings ➲ Increased productivity due to improved throughput ➲ Costs savings from reduced damage to work-zone area infrastructure and construction delays

RSE Deployment

Sequencing Deployments

It is envisioned that there could be many variations on the approaches that could be adopted by state and local agencies to deploy a connected vehicle infrastructure. Six strategies are discussed in this section:

1. Pilot approach,
2. Isolated approach,
3. Local approach,
4. Area approach,
5. Regional approach, and
6. Private sector investment approach.

A separate section is devoted below to each of these strategies.

Pilot Approach

A pilot approaches assumes that the initial deployment of connected vehicle infrastructure is intended to support the development or evaluation of a new system or application. In this approach, it is likely that the deployment will be limited in scale and restricted to certain geographic area where the hypothesis of the experiment can best be tested. It is also possible that the initial pilot deployment will not be interfaced to necessary core and support systems that would be required for an operational connected vehicle system, has only limited data communications infrastructure, and does not have the required back-office processing systems that would allow the application to transition to an operational status.

However, the pilot approach further assumes that if the initial experiment is successful, the deploying agency could use the pilot infrastructure as a building block toward the implementation of an operational system. This approach takes advantage of the earlier investment in field equipment but would most likely require further investment in hardware, software, and communication systems to address the shortcomings described above and to create an operational system. A further challenge would relate to whether the scale of the pilot system is sufficient to create a meaningful operational system. While it may be possible to evaluate the efficacy of, say, a corridor management application with a handful of equipped intersections, a meaningful operational system could require the equipping of dozens of intersections before real operational benefits begin to accrue.

Overall, the pilot approach encourages continued investment in small-scale research and development projects by state and local agencies. It further encourages agencies to consider longer-term deployment issues as they conduct these pilot projects, such as compatibility with core system component that would allow a future expanded deployment to operate within the national connected vehicle system, or the choice of initial deployment locations where future expansion would provide the greatest operational benefits.

Isolated Approach

The isolated deployment approach focuses on connected vehicle infrastructure deployments where an individual deployment site can provide operational benefits. This could include sharp bends where a curve speed warning application could be deployed, or the implementation of a collision avoidance system at a single high accident location intersection.

The benefits of the isolated approach include the opportunity to provide direct safety benefits to travelers and other operational benefits to agencies (e.g., elimination of emergency response costs; reduced crash cleanup costs). However, the selection of isolated locations for deployment also implies the need to provide data communications infrastructure and connectivity to connected vehicle core and support systems from each individual location. This will likely result in higher costs for these system components than could be achieved with a more geographically-concentrated approach. This approach will, however, allow for an incremental deployment approach that can be phased over an extended time period.

Local Approach

The local approach to deployment is a strategy where connected vehicle infrastructure is implemented in a single, concentrated area. Other local areas may be added one at time, and could ultimately merge into a much larger system deployment.

The local approach shares much in common with the isolated approach. However, whereas the isolated approach provides the opportunity to generate operational benefits from deployment at a single location, the local approach is deemed appropriate for connected vehicle applications that require at least multiple, closely-linked deployment locations to be effective. This could, for example, include a traffic signal application intended to provide a “green wave” on a key inbound or outbound route to a metropolitan business district.

The multiple deployment sites that are a component of the local approach also provide the opportunity to begin bundling applications; something that is unlikely to be possible with the isolated approach where

the infrastructure will support a single type of application. For example, infrastructure put in place for the coordinated signal application could potentially also serve the implementation of transit or emergency vehicle pre-emption applications.

Area Approach

The area approach to deployment is used when a broader base of connected vehicle infrastructure must be implemented in order to facilitate a particular application. An example could include integrated corridor management (ICM) applications where an entire corridor incorporating freeways, arterial streets, transit systems, and park-and-ride facilities must be equipped with appropriate connected vehicle systems for the operational benefits of ICM to be achieved. Another example could be an application to collect mileage-based user fees where the system will only operate effectively if the entire area covered by the fee collection program is covered.

Inevitably, the costs of deploying on this scale are significant. In general, the entire system must be deployed before any benefits can be derived; a phased deployment approach cannot be adopted. However, the area approach will clearly produce the potential for significant bundling of applications that take advantage of the deployed infrastructure. With a broad base of field infrastructure and the required connected vehicle core and support systems and data communications systems in place to implement applications of this scale and complexity, it is simple to envision the many opportunities to put in place other connected vehicle applications.

Regional Approach

The regional approach to connected vehicle deployment is similar to the area approach described above. However, in this case widespread deployment of connected vehicle infrastructure is required to support applications that operate on a multi-state basis or other similar large geographic area. Examples could include the infrastructure and systems needed to support commercial vehicle preclearance or safety monitoring applications. In this case, deployment over a large area is necessary to make the application sufficiently appealing for motor carriers to participate.

A disadvantage of the regional approach versus the area approach is that the connected vehicle infrastructure may be much more sparsely deployed. Infrastructure needed for commercial vehicle applications may be required at only weigh stations and ports-of-entry to be effective. However, this infrastructure is unlikely to support many other connected vehicle applications.

Private Sector Investment Approach

An example of the private sector investment approach could be an instance where a state or local agency selects a third party who is contracted to install, operate, and maintain connected vehicle infrastructure as well as provide the state or local agencies access to infrastructure and information. The benefits of this type of deployment are that the costs of deployment will likely be lower than other deployment approaches of the same scale and that the public agency will not have to purchase, own, or maintain any of the connected vehicle infrastructure. In this approach, the public agencies would be investing in a service rather than purchasing infrastructure thus alleviating some concern about costly state-owned technology becoming quickly outdated. A disadvantage of this type of approach is that the public agencies will have little control of the connected vehicle system and depending on how such a system is deployed, there can be concern regarding data latency. Many of the connected vehicle benefits, especially those related to safety, are a function of data latency and if a privately owned system cannot provide the public agency data with low enough latency, many of the benefits of a connected vehicle deployment may not be fully achieved.

While this approach does currently have many uncertainties, a private sector investment deployment approach may be attractive to public agencies. Further research will assist in defining roles of the public and private sector as well as identifying potential candidates to support this deployment approach.

Identification of Necessary Pre-Deployment Conditions

Determining what conditions are appropriate to deploy an application is not a prescriptive task. Each application will have unique requirements for deployment, specific to its purpose as well as its deployment scenario. Applications requirements will also vary by vendor, model or version, and other elements, so it is difficult to pinpoint a set of specific pre-deployment conditions.

Instead, deploying agencies can focus on a checklist of conditions or requirements before deploying an application. The following section describes a number of considerations to take into account when implementing any connected vehicle application.

Delivering a Basic Connected Vehicle Infrastructure System

An interested deploying agency must deploy a basic connected vehicle system in order to run any of the applications accounted for in this Deployment Plan. The equipment and systems needed to support connected vehicle operations can be divided into six broad categories:

1. **In-vehicle or mobile equipment**. The in-vehicle or mobile equipment represent the systems or devices through which most end users will interact with the connected vehicle system in order to gain the benefits of the anticipated applications.
2. **Roadside equipment (RSE).** This equipment is the roadside DSRC equipment that supports three main types of functionality. First, it provides connectivity between vehicles and roadside systems, such as systems integrated with traffic signal controllers, which allow users to participate in local applications such as intersection collision avoidance. Second, the roadside equipment provides the connectivity between vehicles and network resources that are necessary for the implementation of remote applications – for example, for supporting the collection of probe vehicle data used in traveler information applications. Third, the roadside equipment may be required to support connected vehicle security management.
3. **Core systems**. Core Systems refer to the systems that provide the functionality needed to enable the data exchange required to provide the set of connected vehicle applications with which various system users will interact. The core systems exist to facilitate interactions between vehicles, field infrastructure, and back office users. Current thinking envisions a situation of locally and regionally oriented deployments that follow national standards to ensure that the essential capabilities are compatible no matter where the deployments are established.
4. **Support systems.** Support systems include the security credentials certificate and registration authorities that allow devices and systems in the connected vehicle environment to establish trust relationships.
5. **Communications systems**. Communications systems refer to the data communications infrastructure needed to provide network connectivity from RSEs to other system components. These system components will include core systems, support systems, and application-specific systems. In-vehicle equipment will access these system components via the RSEs using the communications systems. The communications systems will include the appropriate firewalls and other systems intended to protect the security and integrity of data transmission.
6. **Application-specific systems**. This refers to the equipment needed to support specific connected vehicle applications that are deployed at a particular location, rather than the core systems that facilitate overall data exchange within the connected vehicle environment. An example could be software systems and servers that acquire probe data from connected vehicles, generate travel times from that probe data, and integrate those travel times into Traffic Management Center systems.

A separate section is devoted below to each of these categories of equipment and systems.

In-Vehicle and Mobile Equipment

In-vehicle and mobile equipment comprise the various systems and devices through which connected vehicle system users interact with the various connected vehicle applications. From an in-vehicle perspective, this may include equipment originally-installed as part of the vehicle manufacturing process or as aftermarket, retrofit, and carry-in devices. In this context, vehicles may include light vehicles, heavy vehicles, transit vehicles, emergency vehicles, and specialty vehicles, such as snow plows. Mobile devices may include smartphones and tablets that allow pedestrians to participate in the connected vehicle system.

Roadside Equipment

For the purposes of this analysis, roadside equipment is assumed as DSRC equipment installed at the roadside to support V2I communications within the connected vehicle environment. It is envisioned that RSEs may be deployed in a variety of configurations; for example for certain applications a single DSRC antenna may be sufficient, but recent experience has shown that multiple antennas may be required for intersection-based applications to ensure adequate DSRC coverage. Further, it is anticipated that future deployments at signalized intersections may see DSRC equipment more tightly integrated with traffic signal controllers.

RSEs will be deployed to provide three types of functionality within the connected vehicle system. In the first, an RSE exists to support data communications between participating vehicles in the vicinity of the RSE and the systems running a local application. Examples of these applications may include: curve speed warning systems, intersection collision avoidance systems, and transit and emergency vehicle preemption systems.

A second form of functionality provided by RSEs is to gather data from participating connected vehicles and send the data to a remote location for use in a system running an application. Examples include gathering probe vehicle data that is used in traveler information systems, road-weather data that is used in weather-responsive traffic management systems, and roadway usage data that are used to determine mileage-based user fees or other road user charges.

A third form of functionality that may be provided by RSEs is in the use of DSRC to support connected vehicle security management. This topic is currently the subject of USDOT-sponsored research and, therefore, there is a level of uncertainty around the role of a DSRC-based infrastructure for security management versus other methods such as the use of the cellular network. This federal research is also analyzing cost models and revenue generation opportunities of the alternative deployment approaches, which creates further uncertainty in cost-benefit analysis to be conducted in this project.

Core Systems

The concept of the connected vehicle Core System is complex. Broadly speaking, core systems refer to the systems that provide the functionality needed to enable trusted and secure data exchange required to provide the set of connected vehicle applications with which various system users will interact. An understanding of the Core System concept requires that the discussion be set in context with the communications systems and connected vehicle applications.

The communications systems are the wireless or, potentially, wired services that allow the Core System to communicate with the various connected vehicle safety, mobility, and environmental applications. The communications mechanisms that are implemented in each deployment of a Core System will vary, and could include cellular, WiMAX or DSRC. Applications provide benefits in the area of safety, mobility, or the environment to connected vehicle system users. Applications use the Core System to facilitate their interactions with other applications or users.

The Core System also interacts with a number of other entities:

- Mobile entities include vehicles and other platforms, such as portable personal devices, used by travelers to provide and receive transportation information.
- Field devices distributed along the transportation network which perform surveillance, traffic control, information provision, or fee-based transactions.
- Centers which include the back office that provide management, administrative, information dissemination, and support functions.
- Core System personnel that operate and maintain the Core System, including network managers, operations personnel, and developers.
- The Core System also interacts with other Core Systems. More than one Core System may exist in the connected vehicle environment, each providing services over given geographic or topical areas, or providing backup services for others.

Support Systems

Support systems include the security credentials certificate and registration authorities that allow devices and systems in the connected vehicle environment to establish trust relationships. Security management is a key concern in connected vehicle operations. DSRC message integrity and authenticity must be ensured to prevent bad actors from abusing the system and potentially compromising vehicle safety. Vehicle privacy must also be protected to prevent organization with access to connected vehicle data from compromising the privacy of vehicle drivers.

Communications Systems

Communications systems refer to the data communications infrastructure needed to provide network connectivity from RSEs to other system components. These system components will include core systems, support systems, and application-specific systems. The communications mechanisms that are implemented at each deployment location will vary. Communications mechanisms could include cellular (such as commercial 3G or 4G services), WiMAX or other wide-area wireless services, a network of DSRC installations, or more traditional hardwired communications systems. The communications systems that are envisioned in the connected vehicle environment could be privately operated (e.g., the existing cellular network), or a publicly implemented and operated data communications network.

Application-Specific Systems

Application-specific systems refer to the equipment and services needed to support the various connected vehicle applications that are deployed at a particular location or in a region. Each of the infrastructure components described above are deployed for the purpose of enabling various connected vehicle safety, mobility, or environmental applications. Examples of applications include intersection collision avoidance systems, curve speed warning systems, or pavement condition monitoring systems. Application-specific systems costs can be considered to comprise a number of components:

- The hardware components that support the applications. This may include the computer systems running the software that acquires connected vehicle data, processes the data, and generates the outputs of the various safety, mobility, or environmental applications. Other hardware may include routers, storage devices, or devices that support interfacing to other equipment, such as traffic signal controllers. These hardware components may exist at the roadside or in remote back-office locations.
- Application software development components. These are the software applications that use the connected vehicle and other related data to provide the various safety, mobility, and environmental improvements. Applications are, and will continue, to be developed through a variety of mechanisms including federally-sponsored research, individual state and local project initiatives, and the work of multi-state and regional entities. It is envisioned that due course the software developed for connected

vehicle applications will be open source and broadly available to state and local agencies wishing to deploy a particular type of application.

- Application integration costs. Connected vehicle applications software will need to be integrated into existing operational environments at state and local agencies. This may include the development of interfaces to the existing systems in traffic management centers, or to various field devices such as traffic signal controllers or dynamic message signs.

Paying for Connected Vehicle Deployments

Among the key tasks facing state and local DOTs that wish to deploy connected vehicle technologies is the need to identify a funding mechanism to pay for those deployments and to operate and maintain the equipment once it is deployed. This could be challenging because connected vehicle deployments involve new technologies that do not necessarily fall neatly into a single cost category. For example, connected vehicle technologies could be considered a form of Intelligent Transportation System (ITS) technology, and an agency might consider funding connected vehicle deployments through its specific or dedicated ITS budget. Connected vehicle technologies are expected to have strong impacts on vehicle and highway safety, so funding connected vehicle deployments with funds set aside for safety programs might be appropriate. Mobility impacts of connected vehicle technologies and consequent emission reductions could warrant funding some connected vehicle deployments with funds set aside for congestion mitigation or air quality improvement projects. Alternatively, given the large anticipated capital costs and ongoing commitment to operations and maintenance of connected vehicle systems, agencies might consider it appropriate to explore other public-private partnerships to obtain access to the desired connected vehicle infrastructure.

This section identifies and briefly discusses various potential funding approaches. It does not go into significant detail on any individual funding approach – those details are likely to differ from agency to agency. This section does not evaluate the appropriateness of any individual funding approach. Instead, the purpose is to identify approaches that could be considered.

Possible Funding Approaches

The following sections describe funding approaches that have the potential to be used for connected vehicle technologies.

Conventional Sources of Funds

Intelligent Transportation System (ITS) Programs. Connected vehicle systems can be viewed as an example of ITS technology deployment and, at least during their nascent stages, connected vehicle development and deployment initiatives are likely to be led by the groups responsible for ITS development within the agency. Many state and local agencies establish a specific ITS budget. The Moving Ahead for Progress in the 21st Century Act (MAP-21) which follows the precedent set in prior legislation, however, continues to provide broad eligibility for ITS deployment using National Highway System (NHS) and Surface Transportation Program (STP) funds, and so connected vehicle infrastructure implementation could be funded from these sources. It must be noted, however, that in this situation, connected vehicle deployments will be competing against conventional highway construction and improvement projects, and will be subject to the same transportation planning processes and inclusion in the TIP or STIP.

Safety Projects. Most DOTs have funds set aside specifically to support projects that improve transportation safety. In fact, the recently signed MAP-21 legislation continues the Highway Safety Improvement Program (HSIP), which provides funds to states to support highway safety. One of the expected benefits of connected vehicles is a significant reduction in crashes. States considering deploying connected vehicle systems could consider whether the safety benefits that might result are sufficient to warrant including connected vehicles in their Strategic Highway Safety Plan (SHSP) and the deployment

of connected vehicle systems as part of their safety program. Typically, safety program funding does not cover ongoing maintenance and operations costs.

Congestion Mitigation and Air Quality Improvement Projects. Connected vehicle systems also have the potential to result in significant mobility improvements, with consequent reductions in vehicle emissions. This could come through general improvements resulting from improved traffic condition monitoring and traveler information systems that rely on connected vehicle technologies. It could also come about through applications more specific to connected vehicles, such as Signal Phase and Timing (SPaT) applications that allow drivers to better manage their speed to generate fuel savings and reduce emissions by reducing unnecessary deceleration at signalized intersections. The MAP-21 legislation continues the Congestion Mitigation and Air Quality (CMAQ) Program, which requires some states to use a portion of its funds to address particulate matter emissions. Agencies considering deploying connected vehicle systems could consider whether CMAQ funds could be used to support these deployments. For example, CMAQ funds have been used to support Transit Signal Priority (TSP) systems, and connected vehicle technologies can be used for TSP. It is important to note, however, that CMAQ program rules limit the use of these funds to three years of operations and maintenance (O&M) on a deployed project and, therefore, do not currently provide a long-term solution to the O&M funding needs of connected vehicle system deployments.

Creating Synergies with Other Projects

Deploying connected vehicle infrastructure in conjunction with scheduled signalized intersection upgrades could be more cost-effective than retrofitting an existing signalized intersection. Requiring upgraded signalized intersections to include connected vehicle capabilities would help ensure that connected vehicle infrastructure was deployed in a cost-effective way. If a signalized intersection was being updated in response to new development and the developers were responsible for a portion of the cost of signalizing the intersection, this type of requirement could also reduce the agency's cost for deploying connected vehicle infrastructure. For example, typical upgrades to a signalized intersection include cabinets, poles, detectors, and wiring at a cost ranging anywhere from $70,000 upwards to $200,000 whereas the cost of the DSRC upgrade would likely be a small portion of the total cost, likely less than $10,000. Furthermore, since the expected life of a traffic signal installation is 15 years, it is reasonable to consider replacing all retired traffic signal controllers with connected vehicle enabled devices on a rolling basis.

Projects of National and Regional Significance

The recently signed Map-21 legislation includes another round of funding for Projects of National and Regional Significance (PNRS). Although previous PNRS projects have not been awarded for deploying transportation technologies, connected vehicle technologies could be viewed as sufficiently transformative of the transportation system that PNRS funding might be a possibility. Agencies that want to be early adopters of connected vehicle technologies could consider applying for PNRS funding to support connected vehicle deployments.

Private Sector Participation

In this era of constrained funding, it is reasonable for state and local agencies to look to public-private partnerships or some other form of private sector investment to support the implementation of connected vehicle systems. There are increasing numbers of examples where private sector entities will construct needed roadway facilities in exchange for the right to collect tolls for a number of years to recoup their investment and generate profits. There are also emerging examples of state and local agencies obtaining the data used in their traffic management and traveler information initiatives from private sector enterprises

where they might traditionally have installed their own infrastructure to gather this information. In these instances, the provider is able to use the data in their commercial products to generate revenue.

The nature of the arrangements with the private sector has the potential to be very wide and varied. For example, for some agencies it may be most important to avoid the high up-front capital costs associated with a connected vehicle infrastructure deployment. In this case, the agency may prepared to contract under some sort of build-operate-maintain arrangement that allows the agency to spread payments over a number of years and lets the private investor generate sufficient profit during the operations and maintenance period.

Alternatively, a private sector company might agree to deploy a connected vehicle infrastructure in exchange for the rights to use and sell the data generated by the system. In this case, the users of so-called "big data" will likely extend beyond the commercial traveler information service providers to other entities in the wireless ecosystem, including telematics providers and other location-based service providers. This situation will demand that the public agencies also obtain access to the infrastructure or to the generated data for their various connected vehicle safety, mobility, and agency operations activities. The use of the infrastructure or data could be negotiated on a subscription fee basis or some type of bartering transaction where are agency forgoes right-of-way encroachment or other fees from the private sector investor.

Impacts on DOT Connected Vehicle Decision-Making

The funding approaches described in this section run the gamut from very likely (e.g., deploying connected vehicle infrastructure as an ITS project) to more speculative (e.g., receiving funding for a large-scale connected vehicle deployment as a PNRS). The main point is that, because of the broad range of impacts that could result from connected vehicles, many different funding approaches are possible and different approaches might better meet different objectives for different agencies. Some approaches (e.g., using DSRC for TSP) would work well for deploying a smaller connected vehicle infrastructure at a relatively low cost. Other approaches (e.g., applying for PNRS funds or pursuing some form of public-private arrangement) could be more appropriate for a big bang roll out across a broad region. Each agency interested in connected vehicles should consider their planned deployment approach and consider funding approaches that are consistent with their needs.

While it is easy to focus on the capital-intensive costs associated with the deployment of a broad new infrastructure for connected vehicle applications, it is important to remember the long tail of operations and maintenance costs that come with these systems. After deployment, there will be ongoing day-to-day operations costs (e.g., power and backhaul communications from the connected vehicle field sites), maintenance costs (both scheduled and unscheduled), the costs of replacement of field and back-office devices at the end of their lives, and DOT staffing needs due to the increased sophistication needed to maintain and operate this technology. Agencies must consider a funding strategy that is appropriate for their individual needs and abilities in funding these continuing O&M commitments.

CHAPTER 5

DSRC Technology Readiness

Dedicated-Short Range Communications (DSRC) refers to the 5.9GHz band of frequency that was allocated by the Federal Communications Commission (FCC) in 1999 for exchanging data to promote vehicle safety and mobility. To utilize this network, several manufacturers have been developing radios specifically for installation in vehicles and with roadside infrastructure to broadcast vehicular and transportation system status data. These radios have been deployed across the nation at various “testbeds” where states are testing the system architecture and various Connected Vehicle applications. This first part of this section includes information about the equipment that has been developed and the testbeds that have been deployed to-date. The second part of this section provides a detailed overview of AASHTO’s deployment scenarios for the connected vehicle deployment, from the early stages through maturity. Finally, the third part of this section provides guidance for obtaining an FCC license and determining the location for new deployments of roadside equipment.

State of Readiness

As the Connected Vehicle program advances, new technologies are being developed to support new applications to support State DOT operations. The purpose of this section is to provide information about equipment that has been developed to support connected vehicle applications, including detection, roadside and in-vehicle equipment. The USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO) published a list of vendors that meet USDOT acceptance criteria for use in the Safety Pilot Model Deployment program, the largest scale deployment of connected vehicle equipment to date. For Roadside Equipment, Arada Systems, Cohda Wireless, Kapsch TrafficCom, Inc., Savari Networks and Industrial Technology Research Institute (ITRI) equipment has been accepted based on testing that was completed in May 2012. For Vehicle Awareness Devices, Arada Systems, Inc., Cohda Wireless and Savari Inc., have been accepted, based on product testing that was completed on September 2012. A survey was pre-populated with information specific to different vendors and completed by a contact from the manufacturer. A copy of the completed surveys is included in Appendix G.

Table 5-1. State-of-Readiness Surveys Issued

MANUFACTURER	TYPE OF DEVICE
Sensys	Wireless Vehicle Detectors
Kapsch	Roadside Equipment
Savari	Roadside Equipment
Savari	Vehicle Awareness Device
Denso	After-Market Safety Device

The Sensys wireless detection devices are designed for in-ground deployment to count and detect bicycles, motorcycles, and vehicles and can be deployed in split roadways or damaged pavement and resist water damage. The low-power radio ensures an average battery life of ten years and can be upgraded with new firmware over-the-air.

Kapsch manufactured the original roadside equipment device, the MCNU, which was deployed in Florida and New York, and subsequently submitted an updated version of the equipment for research Qualified Product Testing in preparation for the Safety Pilot Model Deployment. Their survey provides information on the latest version of their equipment, although it is expected to be updated to comply with the new specifications, which will be issued by the end of the year.

Savari developed their equipment for the second generation of RSEs and were approved for use in the Safety Pilot Model Deployment, where many of their devices have been deployed. Their devices have subsequently been deployed in Arizona, California, and Virginia to support ongoing research into applications for the connected vehicle program. The Savari Vehicle Awareness Device has been used extensively at the Safety Pilot Model Deployment and has been subsequently updated with new firmware. The USDOT is currently using Savari VADs to collect a large sample of data for publication on the Research Data Environment (RDE) and to support ongoing and future research.

Representatives from Denso responded that their device is currently undergoing development, and because the existing specifications will not be relevant to devices issued for future deployments they did not wish to include information about their device in this report.

Overall, the roadside and vehicle-based equipment is still considered “research” grade equipment, and being continuously developed to increase robustness and stability. Currently, a new specification for roadside equipment is being written to support a fourth generation of roadside equipment that will be tested in the Spring of 2014. Although the existing generations of equipment are not yet commercial-grade, or suitable for operational deployments, they are still useful for the development and testing of Connected Vehicle applications.

State of Deployment

As the Connected Vehicle program advances, new technologies are being developed to support new applications to support State DOT operations. The purpose of this section is to provide information about equipment that has been deployed by states to support Connected Vehicle research and applications. To date, Arizona, California, Florida, Michigan, New York, Virginia, and the Turner Fairbank Highway Research Center have the most substantial deployments of Connected Vehicle technology, and a summary of each deployment is included in Appendix F. A survey was pre-populated with information specific to each deployment site and was completed by a contact from the State DOTs.

Table 5-2. State-of-Deployment Surveys Issued

STATE	ORGANIZATION
Arizona	Arizona-Maricopa County DOT
California	Caltrans
Florida	Florida DOT
Michigan	Michigan DOT
New York	New York State DOT
USDOT	FHWA (Turner Fairbank Highway Research Center)
Virginia	University Transportation Center – Connected Vehicle Initiative

The existing deployment in Arizona-Maricopa County, Arizona was installed to support testing of the Multi-Modal Intelligent Traffic Signal System (MMITSS) prototype development that will evaluate use of an advanced multiple vehicle signal priority technology in a live traffic environment. Fiber optic cabling was installed to support communication along the testbed, which is also equipped with CCTVs and loop detectors. Arizona-Maricopa County has conducted a cost-benefit analysis of expanding the deployment across the entire county and may proceed with the expansion in the future.

The California testbed was deployed in Palo Alto to evaluate a wide variety of applications, including traveler information, Cooperative Intersection Collision Avoidance Systems (CICAS), ramp metering, and curve-speed warnings (among others) and will also support the MMITSS prototype development. This testbed includes updated signal controllers and is connected to a back-end server in Oakland to monitor system performance. California is interested in evaluating the potential for using private and third-party models for operation and maintenance of the equipment that might avoid creating an excessive and ongoing burden on state agencies.

The Florida testbed was established to support the 2011 Intelligent Transportation System (ITS) World Congress, hosted in Orlando. The network integrates 24 roadside equipment devices with the Florida DOT fiber network and terminates at back-end servers that are operated by FDOT's District 5. The survey included in Appendix F includes information about the equipment deployed to support the demonstrations of new technologies and applications at World Congress, but no additional information was provided by state representatives on updated or ongoing operations.

The oldest and largest deployment of Connected Vehicle infrastructure is hosted in Michigan, originally selected to host the Safety Pilot Model Deployment project to support a decision by the National Highway Traffic Safety Administration (NHTSA) regarding a mandate that vehicle manufacturers include DSRC radios in all new models by 2020. The Michigan testbed is currently being expanded to include the City of Detroit, which is scheduled to host the 2014 ITS World Congress.

New York's testbed was deployed on Long Island to support a demonstration of the Commercial Vehicle Infrastructure Integration project that sought to use vehicle-to-infrastructure communication to verify and authenticate commercial vehicle driver authentication, roadside inspection and screening across a wireless platform to improve operations. The testbed also evaluate communication of safety and grade crossing warnings using commercial and maintenance vehicles (plow trucks). The original infrastructure included 32 roadside equipment devices along the interstate and 8 more at signalized intersections on adjacent arterials. No updates have been completed since the demonstration for the 2008 ITS World Congress and representatives from the New York State DOT have confirmed that no additions or expansions will be installed until the technology is fully mature.

The Intelligent Intersection at Turner-Fairbank Highway Research Center (TFHRC) has been retrofit with the Sensys wireless vehicle detectors, various equipped vehicles and roadside equipment devices from various vendors to support ongoing testing and development of technologies and applications of the Connected Vehicle program. TFHRC was used to evaluate the second-generation RSEs in advance of the Safety Pilot Model Deployment kick-off and will be used for application testing of the next generation as well. Furthermore, the Saxton Lab at TFHRC has been used for remote, end-to-end testing of the Security Certificate Management System that is being used to support the Safety Pilot Model Deployment communications. The TFHRC testbed is currently being expanded to support testing of up to six different RSEs at a time and enable more advanced testing of applications in a sheltered environment before deployment at the live testbeds.

The Northern Virginia testbed is one of the newest deployments and is designed to evaluate connected vehicle technologies in congested, urban areas and is operated by a partnership of several local universities and the Virginia DOT, called the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC). This testbed includes 45 RSEs along major corridors and is supported by a fleet of ten light-vehicles, one motorcoach and one semi-truck, as well as more than 200 portable systems for use in personal vehicles. Development of this testbed is ongoing and updates are available through the CVI-UTC website.

The general conclusion drawn from this information is that the existing deployments are relatively small-scale and targeted toward research rather than operations. Problems that have affected multiple deployments

include interference from line-of-sight barriers and interrupted operations from loss of power, and some deployments have noticed a failure to generate relevant message sets and outages in backhaul communication. None of the deployments have suffered from attempted vandalism or operational security interference; however, testing and development of the Security Certificate Management System is ongoing.

AASHTO Deployment Scenarios

Introduction

AASHTO developed a DSRC Infrastructure Deployment Scenario document containing several scenarios for deploying Connected Vehicle systems. The scenarios describe the beginning stages of deployment up through advanced, mature deployments. This document describes the DSRC field equipment required to support the scenarios described in the AASHTO Deployment Scenario document.

Overview of the AASHTO Infrastructure Deployment Analysis Scenarios

This section provides a brief overview of each Scenario described in the AASHTO Infrastructure Deployment Analysis and provides a list of DSRC Site Equipment required to support each.

2011 Setting the Direction-The Early Years

The rollout of DSRC infrastructure will begin slowly due to the limited availability of DSRC equipped devices and vehicles. According to the AASHTO Infrastructure Deployment Analysis, the following 3 areas of focus have been identified for initial deployments:

1. **"Commercial vehicles applications where DSRC can be used as a replacement or enhancement to the communications mechanism in existing systems (such as transponders used for roadside screening or through the Commercial Vehicle Information Systems and Networks (CVISN) program"**

To support Commercial Vehicle applications, DSRC will need to be integrated with the Commercial Vehicle Check Roadside subsystem within the CVISN field subsystem. Currently the Society of Automotive Engineers (SAE) DSRC Data Dictionary, J2735, does not define messages that specifically support Commercial Vehicle applications such as driver credential management\verification, Weight in Motion, etc.; however, some messages have been developed in the spirit of J2735 by several organizations for specific projects. These messages should be reviewed by the SAE DSRC Committee for inclusion in J2735 to provide a consistent and interoperable functionality. Interfaces will also need to be developed between the RSU and the Commercial Vehicle Check Roadside subsystem to support the DSRC messages, once defined.

2. **"Research and implementation of methods that use DSRC for emergency vehicle pre-emption (EVP) and transit signal priority (TSP) systems that would replace existing systems."**

To support Emergency Vehicle pre-emption (EVP) and Transit Signal Priority (TSP) DSRC will need to be integrated with existing Signal Controllers. SAE J2735 defines two (2) messages for pre-emption and priority requests and acknowledgements between authorized vehicles and signal controllers. Vehicles send a SignalReqestMessage (SRM) to the Signal Controller to request pre-emption\priority and the Signal Controller acknowledges the request with a SignalStatusMessage (SSM). Signal Controllers must be able to process SRMs and generate SSMs, for the system to provide the desired functionality. Current (09/13) generation Signal Controllers do not support either the SRM or the SSM. A dedicated device could be installed between the RSU and the controller to decode SRMs and encode SSM, but the Signal controller must still be able to process and generate the appropriate data elements. Several controller manufacturers

are currently evaluating supporting the SRM and SSM functionality, however, AASHTO, or the USDOT should oversee and coordinate the activities to ensure a common data set and interoperability among the controller and RSU manufactures.

3. The identification and deployment of DSRC-based safety applications at isolated high volume, high accident locations where they will provide demonstrable benefits

DSRC will need to be integrated with Signal Controllers to support DSRC-based safety applications in addition to the Emergency Vehicle pre-emption\priority functionality. In this scenario, Signal Controllers send Signal Phase and Timing (SPaT) information an RSU and the RSU broadcast SPaT and Map Messages to approaching vehicles. SAE J2735 defines both a SPaT and Map message. The SPaT message contains the current Phase of the controller and a countdown timer until the next Phase. The Map message defines all approaches and ingress and egress lanes of the intersection. The Intersection ID and Lane ID in the Map message correspond to the Intersection ID and Lane Set in the SPaT message. The FHWA has refined the SAE messages to reduce the overall message size and account for actuated and adaptive controller timing. J2735_SPATblob_MAPblob_ RevC_20120217 contains the updated messages as well as NCTIP data objects for signal controllers to support the SPaT message. To date (September 2013) 2 Signal Controller manufactures support these objects, however, the data must be encoded for over-the-air broadcast by an RSU. Current generation RSUs, based on USDOT RSE Specification 3.0; used for the Safety Pilot, do not encode or decode DSRC messages, therefore to broadcast SPaT, an additional device, a local DSRC message processor, is required to encode the data objects sent by the Signal Controller and send the encoded messages to the RSU for broadcast.

Signal Controllers should also incorporate the Map message and vehicle Basic Safety Message (BSM) to add additional capability. Knowing where vehicles are in relation to the intersection and each other would enable Signal Controllers to a) improve the overall throughput of the intersection and b) provide additional information to vehicles for threat (collision) assessment.

Table 5-3 contains a summary of the initial applications discussed above.

Table 5-3. Initial DSRC Applications

Initial Applications	Legacy Device	DSRC Device	Integration
Commercial Vehicles	Commercial Vehicle Check Roadside (CVCR) subsystem, within the CVISN field subsystem	RSU and local DSRC message processor	Official Commercial Vehicle SAE DSRC Messages need to be defined and incorporated into J2735. Interfaces also need to be developed between the RSU and the CVCR subsystem
Emergency Vehicle pre-emption\priority	Signal Controller	RSU and local DSRC message processor	Signal Controllers will need to process Signal Request Messages (SRM) from authorized Emergency Vehicles and respond with the appropriate Signal Status Message (SSM)

Initial Applications	Legacy Device	DSRC Device	Integration
Safety	Signal Controller	RSU and local DSRC message processor	2 Signal Controller manufactures provide Signal Time and Phase information for encoding and broadcast by RSUs. Process Map and vehicle Basic Safety Messages

2012 Showing Success – Model Deployments

In this scenario, in addition to supporting the applications described in the previous section, RSUs will be deployed along interstate corridors to support freight management and other strategic locations to enable vehicle devices to request and download security credentials.

To support freight management, RSUs will require a backhaul connection to a management center to enable data exchanges between vehicles and the management center.

To facilitate the downloading security credentials through an RSU, the installation site will require an Internet Protocol version 6 (IPv6) internet connection or a device connected to the RSU that can translate between IPv6 and IPv4, (the legacy Internet Protocol). To date (September 2013) IPv6 networks are limited in availability; only large service providers support IPv6 and even then it is a special request.

As the number of RSUs deployed increases, agencies should consider deploying an RSE management and monitoring system in which the devices can be accessed remotely from a Traffic Management Center (TCM) or other central location. This will enable the operations staff to constantly monitor the devices as well as save time and money in responding to outages.

Table 5-4 contains a summary of the Model Deployment applications discussed above.

Table 5-4. Model Deployment Applications

Model Deployments	DSRC Device	Integration
Interstate Corridors	RSU with backhaul	RSUs require a backhaul connection to a freight management center
Security Credential Management	RSU with backhaul	RSUs require an IPv6 connection to the Security Credential Management Center
Monitoring System	RSU with backhaul	RSUs should connect to the TMC or other central location for remote monitoring and management

2013-2014 Jump Starting Deployment – System Ramp-Up

In this scenario, the DSRC Footprint expands to arterials and low usage roadways. Both Roadside Units (RSU) and vehicle devices are maturing into reliable, robust, and stable devices. DSRC message encoding\decoding capabilities could begin moving into legacy roadside appliances, such as the Signal Controllers and Commercial Vehicle Check Roadside subsystem discussed above.

DSRC Field Equipment

For current (2013) Connected Vehicle system to support various V2I applications and services, several devices are required to be installed at DSRC field sites. This section provides a brief overview of the devices and the applications\services they will support.

A DSRC RSU facilitates communication between vehicles and local and\or remote hosts. The RSU acts as the gateway between the vehicles and the applications and\or services provided by the location. Depending on the applications and services provided, several supplemental devices may be required to be installed in conjunction with the RSU at a given site. Some of the most common field devices used in support of connected vehicle applications and\services are described below.

<u>Backhaul Router</u>

The backhaul router provides connectivity between the RSU and other site equipment and a back office facility (e.g. Traffic Management Center, connected vehicle application provider, connected vehicle service provider, etc.). The connection between the back office and the router can be either wired (T1, Fiber, etc.) or wireless (cellular 4G, WiMAX, Wi-Fi, etc.). Device mounting is system dependent. The router connects to the RSU and other local connected vehicle equipment as required. Backhaul enables the RSUs to be remotely managed and monitored; enables centralized applications to send\receive data from multiple RSEs, as well as can facility IP based services to\from vehicles. Most routers support Power-over-Ethernet (PoE) to minimize the cabling requirements.

<u>Ethernet Switch</u>

In the event there are multiple Ethernet based connected vehicle devices installed at the site, an Ethernet Switch will connect the devices to a single local IP network to facilitate communications among the devices. The size (number of ports) of the switch will depend on the number of devices deployed at the location.

<u>Local DSRC Message Processor</u>

The 3rd generation RSU does not support DSRC message encoding or decoding; only store and repeat or pass through. To provide local real-time content, such as Signal Phase and Timing, Signal Status, etc., a Local DSRC Message Processor is required. The Message Processor connects between the local legacy transportation equipment (i.e. Signal Controller) and the RSU and encodes local data into DSRC messages for broadcast over-the-air by the RSU and\or decodes DSRC messages received by the RSU into data usable by the local equipment.

<u>NEMA Enclosure</u>

To protect the DSRC Site equipment from the elements (i.e. heat, cold, rain, snow, slat, etc.) the devices can be located in a NEMA 4 rated out door enclosure. Typically, the enclosure mounts on the same pole as the RSU at approximately 10ft above the ground. This reduces the cable length required between the RSU and the equipment as well as helps to protect the equipment from vandalism. Additionally, a circuit breaker can be installed in the enclosure along with enough AC outlets to support all installed equipment. The circuit breaker is powered from the site power source.

<u>GPS Receiver with Antenna</u>

RSUs have built in GPS receivers and antennas; however, in the event other connected vehicle equipment installed at the site require positioning and timing information, an additional external GPS receiver and antenna may be required. The Antenna should be mounted with a clear view of the sky such that the receiver can obtain the appropriate Satellite lock. The antenna can be mounted on the outside of the NEMA Enclosure described above.

<u>Signal Controller</u>

In order for the RSU to send Signal Phase and Timing information to passing vehicles, the local Signal Controller must have an Ethernet interface and either encode DSRC messages and send them to the RSU or support the FHWA defined SPaT NTCIP data objects that can be encoded be a Local DSRC Massage Processor and sent to the RSU.

Remote Power Unit

If backhaul is available at a DSRC site, a Remote Power Unit (RPU) will provide the ability to remotely power cycle connected equipment, eliminating the need to send a maintenance crew to a site that may be experiencing a hardware or software problem. The RPU connects to the local power source through a standard 120v 3 prong plug with all supported equipment plugging into the RPU. In the event of an equipment outage and as long as the backhaul is available, an operator can long into the RPU remotely and turn off and on the power port for the problem device.

Table 5-5 contains a summary of the components discussed above.

Table 5-5. High-Level Overview of DSRC Site Equipment

Item	Device	Purpose	Connections
1	DSRC RSE	Facilitates data exchange over DSRC between vehicles and local and\or remote hosts	Connects to vehicles (via DSRC) and backhaul and\or other Ethernet devices (via IP), if equipped
2	Backhaul router	Required for remote management\monitoring of the RSE as well as facilitating IP services for vehicles	Connects to RSE and other equipment to provide connection to the back office
3	Ethernet Switch	Required if more than 1 local Ethernet device will be connected to the RSE	Connects to local Ethernet devices to form a local network to facilitate communications among devices
4	Local DSRC Message Processor	Encodes and decode DSRC messages locally. Can also run local applications	Connects to the RSE and other devices as required
5	NEMA Enclosure	Protect local connected vehicle devices from the environment	Houses all local equipment, with the exception of the RSE, as required
6	GPS Receiver with Antenna	Provides position and timing information to local devices, as required	Connects to local connected vehicle devices, with the expectation of the RSE
7	Signal Controller	Provides local Signal Phase and Timing information to encode and broadcast SPaT to vehicles over DSRC	Connects to the RSE or Local DSRC Message processor
8	Remote Power Switch	Provides the ability to remotely power cycle devices (if backhaul is present)	Connects to local devices to be managed remotely

The diagram below is an example of how the devices mentioned above would be installed and connected at a given DSRC Site.

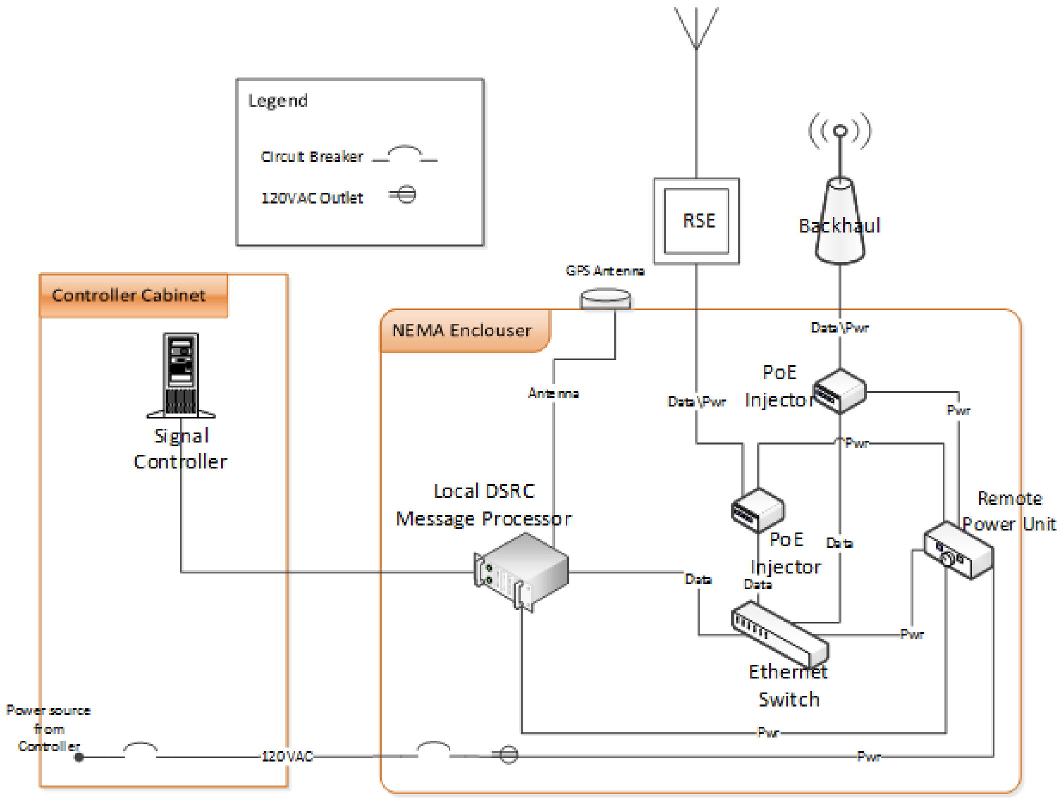


Figure 5-1. Example DSRC Site

FCC Licensing

FCC radio license

DSRC operates in a protected frequency band (i.e. 5.850 – 5.925 GHz), which means operators must obtain a license from the FCC in order to legally operate DSRC based devices. Typically, a FCC license is issued for a specific frequency range in a specific geographic area. This ensures the license holder is the only operator allowed to deploy devices in the given area, protecting the system against interference. In the case of the RSE, the operating agency must apply for a DSRC license for their territory and each RSE must also be registered with the FCC such that other operators are aware of their existence. More information and the DSRC FCC License application can be found at:

http://wireless.fcc.gov/services/index.htm?job=licensing&id=dedicated_src.

The following information is a summary of the RSE Effective Radiated (Transmit) Power and antenna height limitations described in FCC 47 CFR Part 90.377.

The maxim Effective Radiated Power (ERP) for DSRC RSEs are channel dependent as indicated in the table below:

Table 5-6. DSRC Max ERP by Channel

Channel No.	Frequency range (MHz)	Max. EIRP (dBm)	Channel use
170	5850–5855	----	*Reserved.*
172	5855–5865	33	Service Channel.
174	5865–5875	33	Service Channel.
175	5865–5885	23	Service Channel.
176	5875–5885	33	Service Channel.
178	5885–5895	33/44 .8	**Control channel.**
180	5895–5905	23	Service Channel.
181	5895–5915	23	Service Channel.
182	5905–5915	23	Service Channel.
184	5915–5925	33/40	Service Channel.

The higher ERP listed for channel 178 and 184 are only permitted for government agencies. With the exception of channels 175 and 181, all DSRC channels have a 10 MHz bandwidth. Channels 174 and 176 can be combined to form the 20 MHz channel 175 and channels 180 and 182 can be combined to form the 20 MHz channel 181.

RSEs transmitting at the maximum ERP listed in Table 1 have an antennas height limit of 6m above the roadway. For RSE antennas that must be installed at heights greater than 6m to meet coverage objectives, the maximum ERP is reduced by a factor of 20Log(ht/8), where ht is the height of the center of the antenna in meters. RSE antennas cannot exceed 15m above the roadway.

Site Survey

As part of the communications evaluation, a wireless spectrum analysis should be performed to identify relevant wireless communication systems in use in the area. The DSRC spectrum (5.850 – 5.925 GHz) specifically should be evaluated as well as any spectrum intended for wireless backhaul. DSRC requires an FCC license/approval much like other commercial wireless systems, such as 3G/4G cellular, satellite, and some microwave systems, which provides protection from interference. However, some systems suitable for backhaul operate in the Industrial, Scientific and Medical (ISM) band which does not require a license or FCC approval. Wi-Fi is one the popular systems that operate in the ISM band (2.4 GHz and 5.8GHz), however, other equipment is available that operate in the band that is not Wi-Fi. If a planned wireless system is already in use in the area, an alternative network should be considered, as the potential interference could render both networks unusable.

DSRC Technology Conclusions

The findings of this section demonstrate the need for ongoing research and development. The applications and deployments that have been completed as part of the Connected Vehicle program to-date are still relying on research-grade equipment and have not been fully integrated with live traffic operations. Truly operational deployments may not be feasible until the equipment components, network architecture, and supporting security systems are more mature, and the cost-benefit analysis of the existing testbeds demonstrates that heavy capital investments are necessary for initial deployment.

In the interim, there is much more research to be completed, including the development, simulation, evaluation, installation and testing of new applications. This activity is being led by the U.S. DOT with

support from the affiliated testbeds and a number of universities. New testbeds can be created to support the development of additional applications and to evaluate interoperability of

For States interested in participating in the research-phase of the Connected Vehicle program, the cost-benefit analysis highlighted that these deployments will impact State DOT business practices and operations. This indicates that early-adopters will be better equipped to transition to the operational-phase and can realize the safety and mobility benefits sooner than States that have not worked with the equipment and applications prior to operational deployment.

CHAPTER 6

Cellular Network Considerations

Elective New Section Add --- In-Process

CHAPTER 7

Conclusions

Connected vehicle technology represents a both a significant investment for public agencies, as well as an opportunity to provide a higher level of service to the agencies' customers – the traveling public. Findings presented in this report highlight the major components of a connected vehicle deployment, current and potential future costs, and how these components will impact public sector agencies. Decision makers should understand that because other research efforts have been investigating the societal impacts associated with connect vehicle technology, this research focused solely on the impacts of connect vehicle technology directly to a transportation agency's budget. While this approach provides decision makers with a clearer understanding on how these deployments may change agency budgets, it also illustrated the difficulty assessing direct benefits to the agency due to the lack of available data. As agencies continue to deploy connected vehicle technologies, it is assumed that these data would become more assessable and can be included in future, similar analyses.

For the quantitative analysis, the following benefits were quantified as data was available. A major outcome of this study was the conclusion that data required to make to quantify benefits are generally not available. Benefits included in this study are based upon available and adequate data, including:

- Crash response and cleanup cost reduction;
- Reduced need for traveler information infrastructure;
- Reduction of infrastructure required to monitor traffic;
- Lower cost of pavement condition detection; and
- Adaptive lighting energy savings.

For future investment decisions, agencies may need to take into account new data collection methods and metrics to support connected vehicle investment decisions.

Key findings explained in the previous sections demonstrate that the benefits derived from these deployments will gradually offset a significant portion of the annual cost of connected vehicle technology, although the deployment will may not produce a positive net present value due to high initial costs. The variables with the greatest impact on the analysis are:

- Accident Response Cost;
- Accident Rate Reduction;
- RSE Unit Cost;
- RSE Maintenance Cost; and
- Recurring Backhaul Cost.

Connected vehicle deployments over time have the ability to produce savings to the DOT that outweigh annual operations and maintenance costs. It is difficult to generate a net-positive cost-benefit ratio based solely on direct impacts to the agency; however, most transportation infrastructure projects are not profitable, so evaluating returns on investment may not be the best method for determining the value of the technology. Benefits will also vary greatly on the location of the deployment, as urban and suburban

corridors will likely see greater benefits than rural areas due to the availability of ITS and energy infrastructure, increased interactions between vehicles and infrastructure, and richer concentration of data. Also, traffic incident rates and hence the cost avoidance associated with a reduction in accidents due to connected vehicle technology will likely be higher in urban areas. DOTs should further investigate the levels of cost avoidance associated with connected vehicle technology in specific locations prior to making connected vehicle technology deployment decisions in order to maximize the benefits.

Key findings explained in the previous sections demonstrate that the benefits derived from these deployments will gradually offset a significant portion of the annual cost of connected vehicle technology, although the deployment may not produce a positive net present value due to high initial costs. The level of benefits will depend on the location of the deployment as urban and suburban corridors will likely see greater benefits than rural areas due to cost avoidance in areas such as adaptive lighting and traffic monitoring infrastructure. Also, traffic accident rates and hence the cost avoidance associated with a reduction in accidents due to DSRC technology will likely be higher in urban areas. DOTs should further investigate the levels of cost avoidance associated with DSRC technology in specific locations prior to making decisions in what area to start deployment of RSEs to facilitate DSRC technology in order to maximize the benefits. In addition, the costs considered in this analysis were drawn from actual research deployments and will likely decrease as the technology matures and the market becomes more competitive. The recurring backhaul costs associated with connected vehicle deployments represent a major component of the investment and will not likely decrease at the same rate as the equipment costs, but it is difficult to quantify that cost as it varies on a case by case basis. Some factors that influence this cost include deployment size, scope, proposed applications, and existing infrastructure.

Connected vehicle technology may also have the ability to improve agency business practices by creating data rich environments which provide new, additional sources of information and data on asset condition for monitoring and maintenance. The technology also can provide agencies with the ability to proactively reach a wider audience of drivers than available with traditional methods (e.g.., geotracking, cellular crowd-sourcing, etc.) by providing a dedicated communication and data stream to government agencies. Introduction of the technology also has the ability to add new roles for traditional transportation management agencies, including information technology-related fields, automotive engineering, application development, among many other potential roles.

This analysis shows that there are benefits that can be derived from connected vehicle deployments. One could consider that as these technologies mature, more benefits will be discovered. At the same time, this technology will allow practitioners to provide a higher level of service to the traveling public. Finally, the findings presented in this report can inform DOT decision making makers of the impacts of a connected vehicle deployment. With the exception of tolling, transportation investments are not generally executed with the aim of generating revenue to recuperate investment costs, but rather to promote the safety and mobility of the traveling public. Connected vehicle technology has significant potential to allow DOTs with an ability to generate revenue and serve these interests.

References

Arizona Department of Transportation (AZDOT). 2013. Arizona Motor Vehicle Crash Facts 2012. Last accessed September 20, 2013. Available at: http://www.azdot.gov/docs/default-source/mvd-services/12crashfacts.pdf?sfvrsn=2

Ahn, S., Kandala, S., and Gettman, D. 2010. Arizona Emergency Vehicle Infrastructure Integration: Field Demonstration Evaluation and Benefit-Cost Analysis.

Bai.Y, 2007. Determining the Major Causes of Highway Work Zone Accidents in Kansas. Lawrence, KS: University of Kansas.

Booz Allen Hamilton. 2012. Draft Report: Modeling of Promising Options for Secure Communications Data Delivery Systems. Washington, DC: United States Department of Transportation

Bureau Of Labor Statistics. 2013. Average Energy Prices, Washington-Baltimore – August 2013. Last accessed September 20, 2013. Available at: http://www.bls.gov/ro3/apwb.htm

Commonwealth of Virginia Department of Motor Vehicles. (2013). 2012 Virginia Traffic Crash Facts. Last accessed September 20, 2013. Available at: www.dmv.state.va.us/safety/crash_data/crash_facts/crash_facts_12.pdf

Federal Highway Administration. Flexibility in Highway Design. Last accessed September 20, 2013. Available at: http://www.fhwa.dot.gov/environment/publications/flexibility/ch03.cfm

FMS Working Group MAG Intelligent Transportation Systems Committee. 2006. Current Status and Future Needs of the Metropolitan Phoenix Freeway Management System.

Hill, C.J. and Garret, K. J. 2011. AASHTO Connected Vehicle Infrastructure Deployment Analysis. Final report to FHWA.

McDaniel, W. 2010. Communication Strategies To Increase Understanding of Funding and Revenue Needs for the Nation's Transportation System. Last accessed September 20, 2013. Available at: www.transportation-finance.org/pdf/featured_documents/nchrp_20_24_62_Arizona-Maricopa.pdf

Medina, Alejandra. 2013. Connected Vehicle Applications for Adaptive Lighting. Blacksburg, VA: Virginia Tech Transportation Institute. Last accessed September 20, 2013. Available at: www.cvi-utc.org/?q=node/63

Michigan Department of Transportation (MDOT). 2013. Frequently Asked Questions. Last accessed September 20, 2013. Available at: http://www.michigan.gov/mdot/0,4616,7-151-52374-228674--F,00.html

Najm, W.G., Koopmann, J., Smith, J.D., & Brewer, J. 2010. Frequency of Target Crashes for IntelliDrive Safety Systems. Washington, DC: United States Department of Transportation.

NHTSA's National Center for Statistics and Analysis, Traffic Safety Facts: Rural/Urban Comparison, USDOT Report 811 395, 2009. Last accessed September 20, 2013. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/811395.pdf

Southeast Michigan Council of Governments (SEMCOG). 2011. Traffic Crash Facts for Southeast Michigan, 2011. Detroit, MI: SEMCOG. Last accessed September 20, 2013. Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/QuickFactsTrafficCrashes2011.pdf

Southeast Michigan Council of Governments (SEMCOG). 2013. Traffic Crashes. Detroit, MI: SEMCOG. Last accessed September 20, 2013. Available at: www.semcog.org/Data/Apps/crash.cfm

United States Department of Transportation Research and Innovative Technology Administration. Connected Vehicle Frequently Asked Questions. Last accessed September 20, 2013. Available at: http://www.its.dot.gov/connected_vehicle/connected_vehicles_FAQs.htm

Virginia Department of Transportation (VDOT). 2013. Work Zone Awareness. Last accessed September 20, 2013. Available at: http://www.virginiadot.org/programs/prog-wzsa-default.asp

Appendices

Appendix A: Interview Guides

Guide for Connected Vehicle Application Interviews
The SAIC Team will conduct interviews to gather information about the core state and local transportation agency business practices that could be affected by implementation of connected vehicle infrastructure. This effort will be a series of two interviews. The first interview will obtain high-level details on applicability and deployment possibilities of connect vehicle applications. The second interview will present hypothetical scenarios developed with information gathered in the first interview to obtain metrics directly related to a cost-benefit analysis. The intent of this series of interviews is to identify and quantify the impacts so as to support the subsequent cost-benefit analysis.

Identifying Transportation Agency Business Functions
A thorough review of the potential for connected vehicle applications needs to consider the complete range of agency functions. Interviews will therefore be scheduled with representatives from each of the key functions: Planning, Design, Construction/Deployment, Operations, and Maintenance. These functions may have different titles or be combined within any particular agency, and individuals may represent more than one function in interviews

Prioritizing Applications
The wide range of potential connected vehicle applications requires that the applications be prioritized for discussion in interviews. Representatives will be presented first with those applications that might most directly affect their area of responsibility and expertise. Discussions could expand to applications at their functional interfaces if time allows.

Selection and prioritization of applications for discussion is based on the application analyses performed earlier in this project and on the case study site profiles. The application groups generally are:

- Safety
- Mobility
- Agency Operations and Maintenance
    - Asset Condition
- Environment

Interview Guide

1. Describe the connected vehicle environment and programs. Reference the USDOT website: http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm
2. Describe the interview process (the major steps in this guide) as well as provide an introduction to the project.
3. Ask about their general interest in connected vehicles and the potential to improve agency operations. Typical questions may include:
    a. What information have they previously received about connected vehicle programs (or IntelliDrive/VII)?
    b. How have they participated in connected vehicle programs?
    c. What are their general impressions of the potential of connected vehicle systems to improve transportation?
    d. What are the areas where you see the greatest impact from connected vehicle technologies based on your specific areas of need?
4. Describe the types of impacts connected vehicle applications may have. Present examples in the following categories:
    a. Safety
    b. Mobility
    c. Agency Operations and Maintenance (i.e., real-time data collection, etc.)
    d. Environment
5. Ask how their organization would prioritize these impacts.
6. Using the Excel-based Relevant Application tool, enter the prioritization stated by the interviewee to determine a list of relevant connected vehicle applications.
7. For each relevant application:
    a. Describe the application.
    b. Confirm the interest in that type of application.
    c. Describe the potential impacts of the application on a typical agency.

   d. Solicit impressions of the potential impacts in their organization. For significant impacts, attempt to quantify impacts.
   e. Ask about factors that could affect the ability to implement or the effectiveness of the application for their agency.
8. Discuss their organization's decision making process for deploying connected vehicle applications.
9. Discuss possible funding opportunities to fund connected vehicle applications. Present pre-determined funding approaches to determine which, if any, is most relevant in their organization.
10. Present pre-determined deployment strategies to determine which, if any, is most applicable to their organization.
11. Ask about the likelihood, timing, and any limiting factors for implementing the application.
12. Ask for willingness to participate in a follow-up interview to present hypothetical scenarios developed from their responses in the first interview.

Documenting the Interview
Draft notes of the interview discussions will be prepared and provided to the interviewee for review and comment. Final versions of the notes will correct any errors and address any comments. Information gathered during the interviews will be used to update the application descriptions developed earlier in the project.

Appendix B: List of Applications

The following applications are considered in CVAST v1.0:

1. CICAS–Signalized Left Turn Assist (CICAS-SLTA)
2. CICAS–Traffic Signal Violation (CICAS-TSV)
3. CICAS–Traffic Signal Adaptation (CICAS-TSA)
4. CICAS–Stop Sign Assist (CICAS-SSA)
5. CICAS–Stop Sign Violation (CICAS-SSV)
6. Cooperative Curve Speed Warnings
7. Cooperative Speed Limit Zone Warnings
8. Cooperative School Speed Zone Warnings
9. Cooperative Work Zone Speed Warnings
10. VMT-based User Fees
11. HOT Lanes
12. Pothole (Pavement Defect) Detection
13. Pavement Condition Monitor
14. Traffic-responsive Adaptive Signal Control
15. Weather-responsive Adaptive Signal Control
16. Traffic Signal Prioritization for Transit Vehicles
17. Traffic Signal Preemption for Emergency Vehicles
18. Arterial Network Signal Coordination
19. Variable Speed Management (Speed Harmonization)
20. Cooperative Adaptive Cruise Control
21. Adaptive Ramp Metering
22. Adaptive Corridor Management
23. Real-Time Traveler Information
24. Real-Time Commercial Vehicle Data Exchange
25. Real-Time Emissions Reporting
26. Agency Data Applications (Trip-based Traffic Studies)

Appendix C: Cost-Benefit Analysis Information

Distributions of Input Variables for Sensitivity Analysis

Common Distributions

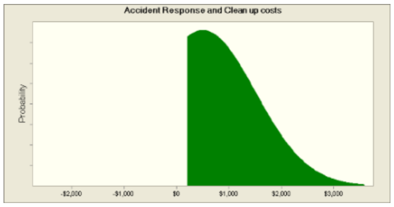


Figure C-1. Average Accident Response and Cleanup Costs

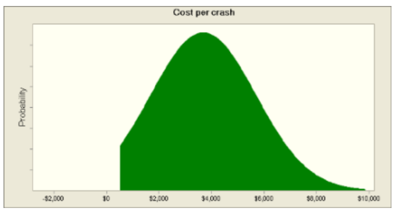


Figure C-2. Average Work Zone Accident Cost

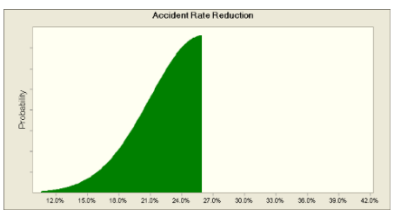


Figure C-3. Accident Rate Reduction

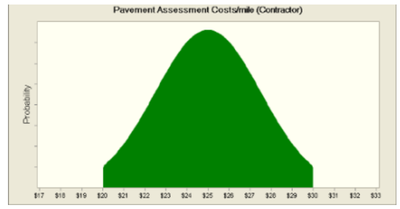


Figure C-4. Pavement Assessment Cost/mile (contractor)

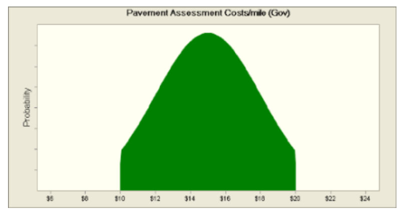


Figure C-5. Pavement Assessment Cost/mile (government)

Michigan Test Bed

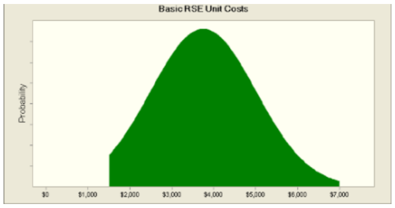


Figure C-6. Basic RSE Unit Costs

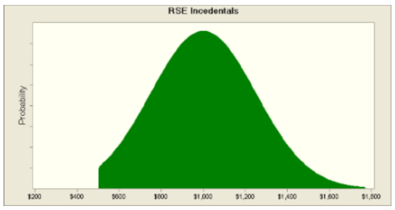


Figure C-7. RSE Incidentals

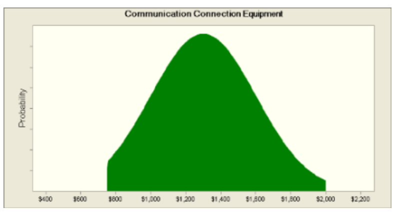


Figure C-8. Communication Connection Equipment

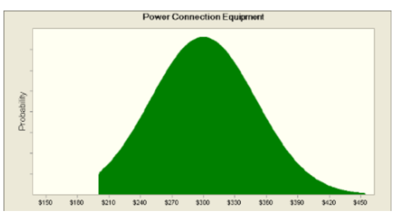


Figure C-9. Power Connection Equipment

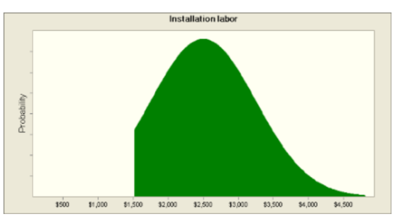


Figure C-11. Installation Labor

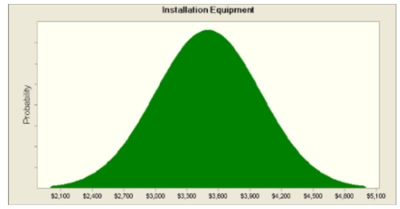


Figure C-12. Installation Equipment

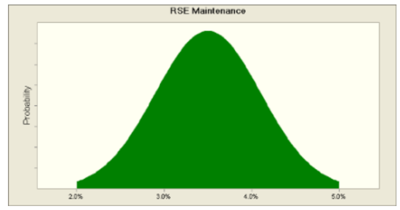


Figure C-13. RSE Maintenance

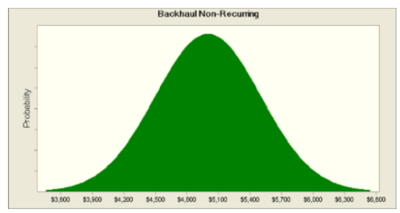


Figure C-14. Backhaul Non-Recurring

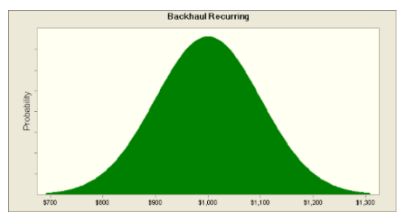


Figure C-15. Backhaul Recurring

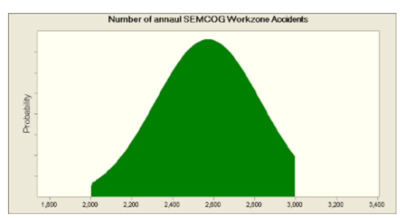


Figure C-16. Number of annual SEMCOG Work Zone Accidents

Figure C-17. Average cost per lane mile for winter maintenance (plowing and salting)

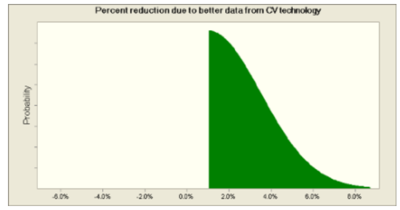


Figure C-18. Percent reduction due to better data from connected vehicles technology

VDOT Test Bed

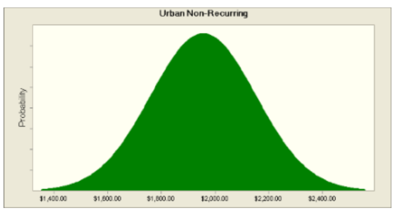


Figure C-19. Backhaul Set up Costs

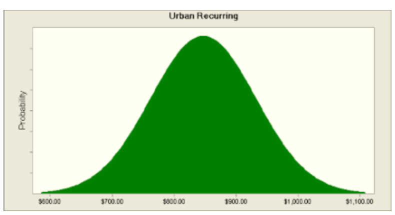


Figure C-20. Backhaul Annual Recurring Costs

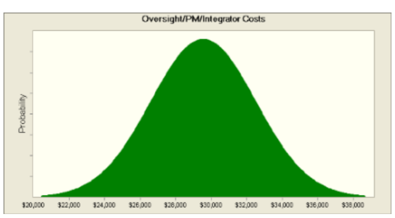


Figure C-21. Oversight/PM/Integrator Costs

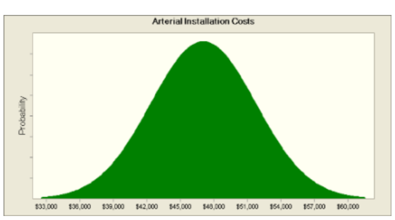


Figure C-22. Arterial Installation Costs

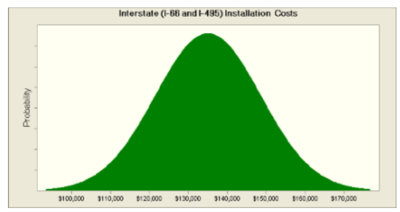


Figure C-23. Interstate (I-66 and I-495) Installation Costs

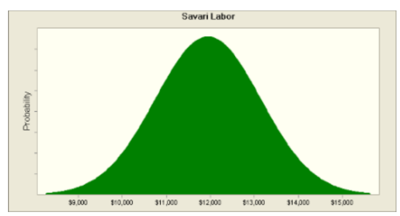


Figure C-24. Savari Labor

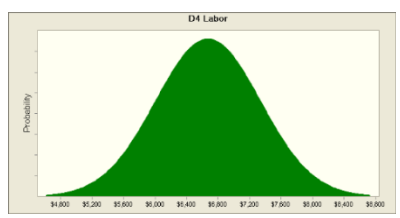


Figure C-25. D4 Labor

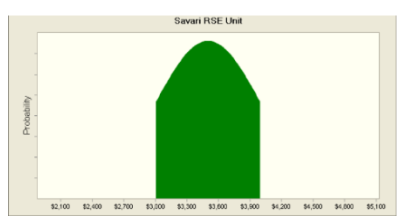


Figure C-26. Savari RSE Unit

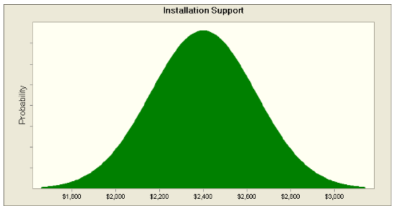


Figure C-27. Installation Support

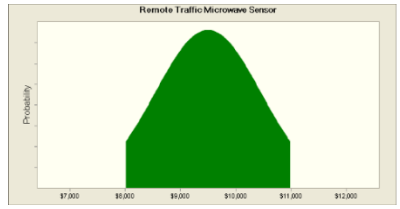


Figure C-30. Remote Traffic Microwave Sensor Cost

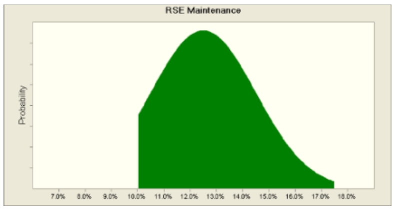


Figure C-28. RSE Maintenance

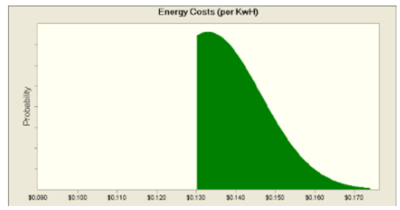


Figure C-31. Energy Costs (per KwH)

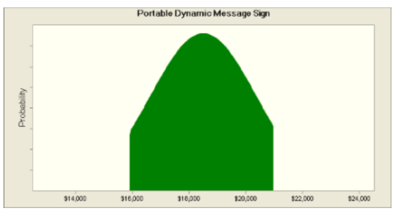


Figure C-29. Portable Dynamic Message Sign Cost

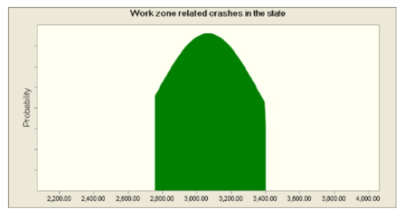


Figure C-32. Work zone related crashes in Virginia

Arizona-Maricopa County Regional Deployment

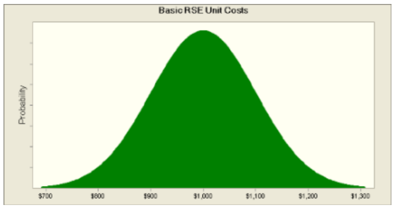


Figure C-33. Basic RSE Unit Costs

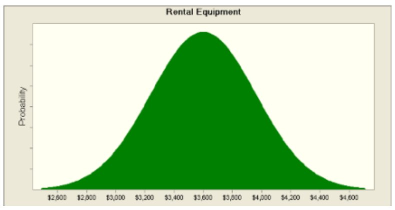


Figure C-34. RSE Incidentals

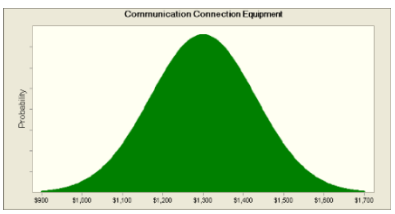


Figure C-35. Communication Connection Equipment

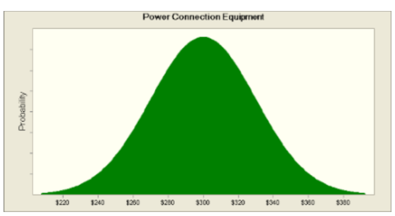


Figure C-36. Power Connection Equipment

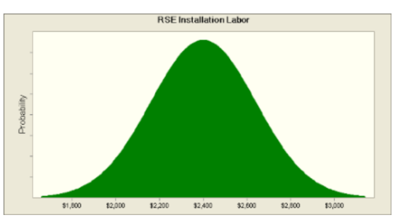


Figure C-37. RSE Installation Labor Costs

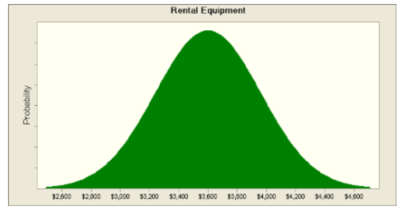


Figure C-38. RSE Installation Rental Equipment Costs

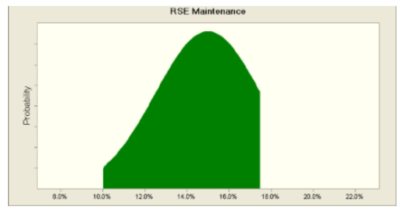


Figure C-39. RSE Maintenance

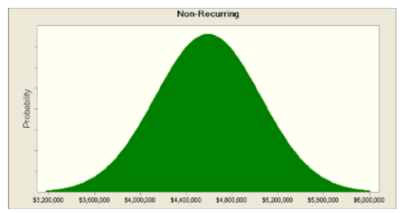


Figure C-40. Backhaul Set up Costs

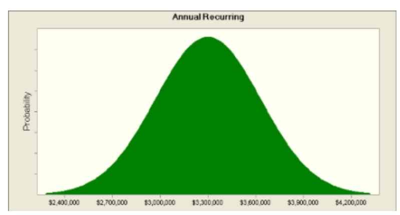


Figure C-41. Backhaul Annual Recurring Costs

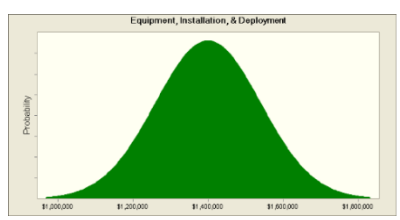


Figure C-42. Equipment, Installation, & Deployment

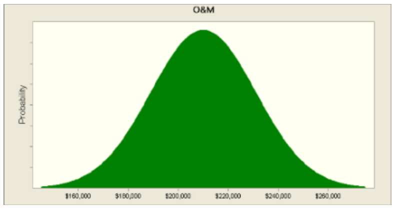


Figure C-43. O&M

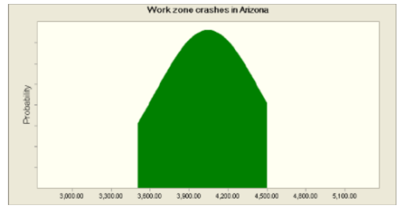


Figure C-45. Work zone crashes in Arizona

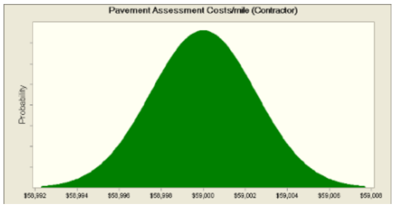


Figure C-44. Pavement Assessment Costs

Cost-Benefit Tables

Table C-1: Michigan Cost-Benefit Results ($000)

Costs	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Non-Recurring	868	0	0	0	0	0	0	0	0	0	0	868
Recurring	0	80	80	80	80	80	80	80	80	80	80	804
Total	**868**	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**1,671**

Benefits	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Increased Revenue												0
Cost Savings	0	11	11	12	14	16	21	30	44	61	77	299
Total	**0**	**11**	**11**	**12**	**14**	**16**	**21**	**30**	**44**	**61**	**77**	**299**

Net Benefit/Cost	-868	-69	-69	-68	-67	-64	-59	-50	-36	-19	-3	-1,372

Table C-2: Arizona-Maricopa County Region Cost-Benefit Results ($000)

Costs	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Non-Recurring	31,718	0	0	0	0	0	0	0	0	0	0	31,718
Recurring	0	4,957	4,957	4,957	4,957	4,957	4,957	4,957	4,957	4,957	4,957	49,572
Total	**31,718**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**4,957**	**81,290**

Benefits	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Cost Savings	0	363	695	1,348	2,526	4,346	6,585	9,208	10,769	11,724	12,261	59,823
Total	**0**	**363**	**695**	**1,348**	**2,526**	**4,346**	**6,585**	**9,208**	**10,769**	**11,724**	**12,261**	**59,823**

Net Benefit/Cost	-31,718	-4,594	-4,262	-3,609	-2,432	-611	1,627	4,250	5,811	6,766	7,304	-21,467

Table C-3. Table of Assumptions

Assumption	Value	Reference
Accident Rate Reduction	Up to 26%	Najm, W.G., Koopmann, J., Smith, J.D., & Brewer, J. (2010). Frequency of Target Crashes for IntelliDrive Safety Systems. Washington, DC: United States Department of Transportation.
Accident Response and Cleanup costs	Crash requiring a single police officer generally costs $200 for the officer while a crash that requires fire/EMS costs an average of $800. Assume each occur with equal frequencies.	The Florida Senate Issue Brief 2009-303: Cities and Counties Charging "Accident Responses" Fees to Drivers and Insurers.
Average Cost of Work Zone Accidents	$3,687	Determining the major causes of highway work zone accidents in Kansas, Yong Bai, Ph.D., University of Kansas, October 2007.
Market Penetration Curve		This is based conversations with AASHTO members at the November 19th 2012 meeting in Pittsburgh, PA on the potential of a mandate for DSRC technology in new vehicles, and on the rate of new vehicle replacements derived from NADA data.
Virginia I-66 Connected-Vehicle Test Bed Backhaul Costs	Backhaul setup costs: $1,956 Annual recurring backhaul costs: $846	U.S. Department of Transportation, Research and Innovative Technology Administration, Task 3 Draft Report: Modeling of Promising Options for Secure Communications Data Delivery Systems, Booz Allen Hamilton, September 2012.
Arizona-Maricopa County RSE Installation and Backhaul Costs	Various	Arizona Emergency Vehicle Infrastructure Integration: Field Demonstration Evaluation and Benefit-Cost Analysis; Soyoung Ahn, Ph.D., Srivatsav Kandala, and Douglas Gettman; January 21, 2010.

Appendix D: Instructions for CVAST v1.0: Connected Vehicle Application Selection Tool

Introduction

To begin, open the macro-enabled Microsoft Excel file titled "**CVAST_v1.0.xlsm**". Once opened, enable macros by selecting the icon in the top-center of the worksheet, shown in Figure D-1.

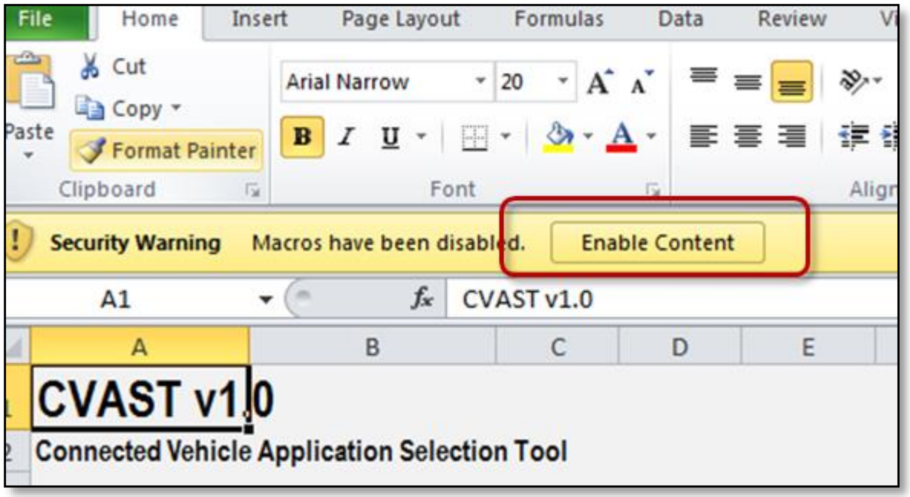


Figure D-1. Enabling Macros

Once macros are enabled, the user will be able to enter their agency as well as name to be included in the report produced from this tool. Next, select the relevant characteristics for the deployment scenario by selecting the check boxes shown in Figure D-2. At least one deployment characteristic must be selected for the *Deployment Type* and *Roadway Types* in order to prevent an error message from occurring.

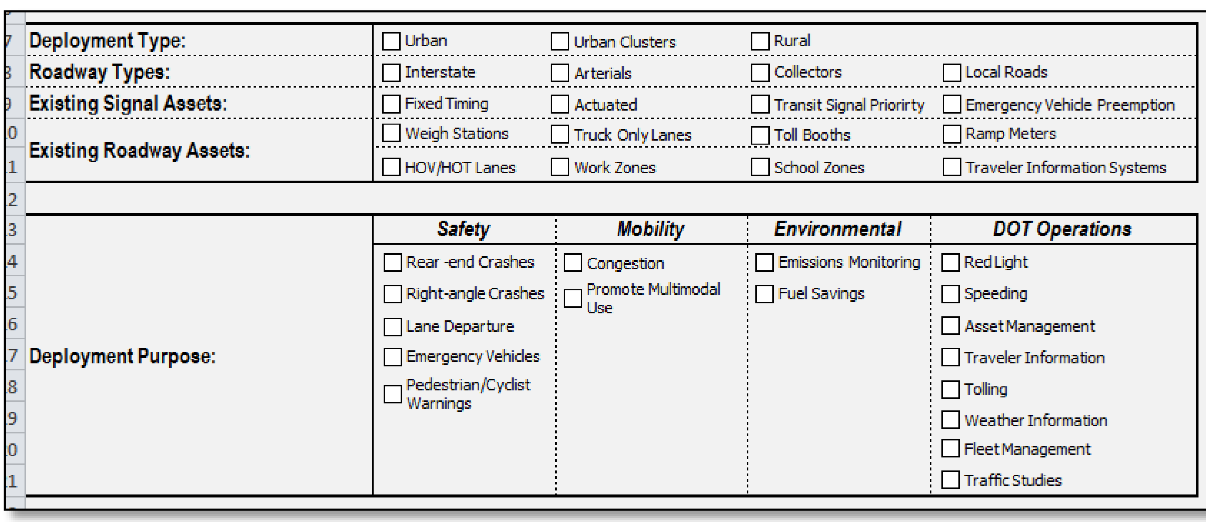


Figure D-2. Deployment Characteristics

Once all relevant deployment characteristics are selected, click on the *Run Analysis* button in the middle of the screen to generate a report, shown in Figure D-3.

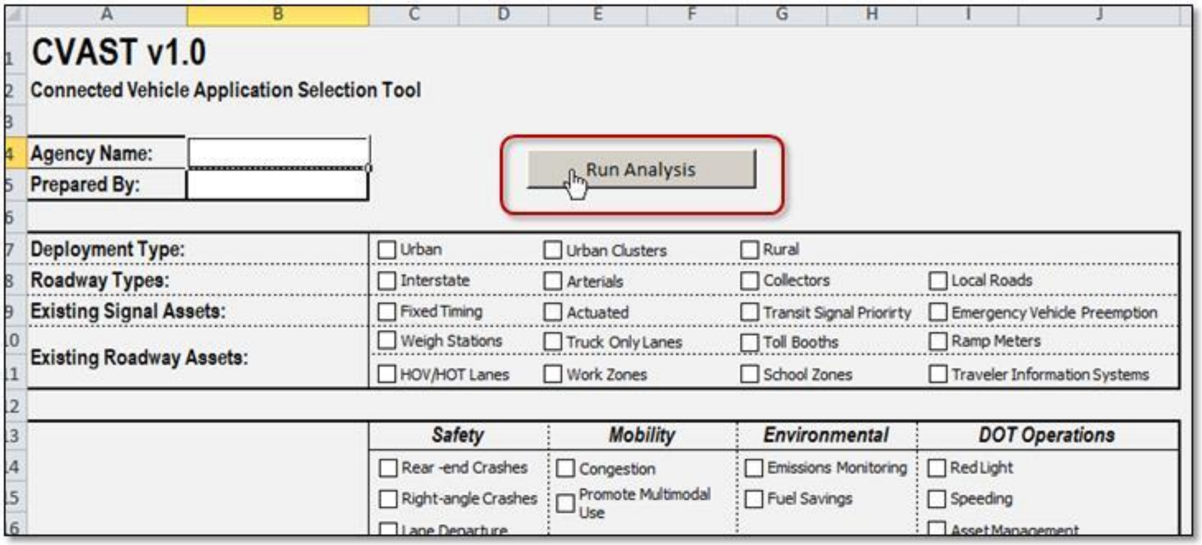
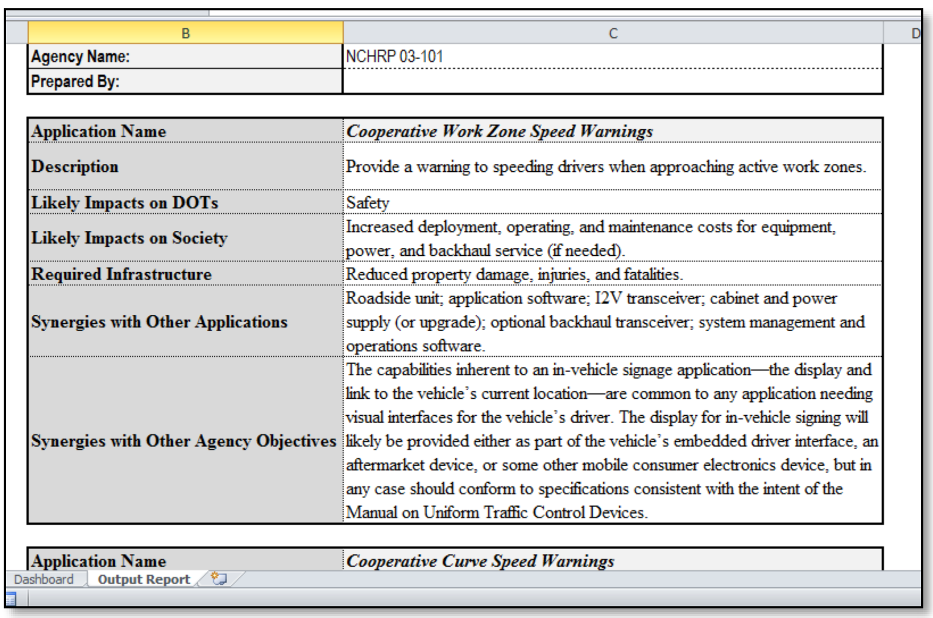


Figure D-3. Run Analysis Button

The report will be generated in a worksheet format entitled "Output Report". Figure D-4 below shows an example output report.



Agency Name:	NCHRP 03-101
Prepared By:	

Application Name	***Cooperative Work Zone Speed Warnings***
Description	Provide a warning to speeding drivers when approaching active work zones.
Likely Impacts on DOTs	Safety
Likely Impacts on Society	Increased deployment, operating, and maintenance costs for equipment, power, and backhaul service (if needed).
Required Infrastructure	Reduced property damage, injuries, and fatalities.
Synergies with Other Applications	Roadside unit; application software; I2V transceiver; cabinet and power supply (or upgrade); optional backhaul transceiver; system management and operations software.
Synergies with Other Agency Objectives	The capabilities inherent to an in-vehicle signage application—the display and link to the vehicle's current location—are common to any application needing visual interfaces for the vehicle's driver. The display for in-vehicle signing will likely be provided either as part of the vehicle's embedded driver interface, an aftermarket device, or some other mobile consumer electronics device, but in any case should conform to specifications consistent with the intent of the Manual on Uniform Traffic Control Devices.

Application Name	***Cooperative Curve Speed Warnings***

Figure D-4. Sample Output Report

The Output Report will provide a "menu" of applications from to choose for an agency's deployment scenario. The report includes:

- The application name,
- A short description of the application,
- The benefits for deploying the application to both agency operations and to society at-large,
- Synergies the applications affords when combined with other applications, and
- Indirect benefits from deployment that may help meet other agency goals.

The Output Report is intended to allow decision-makers to view a catered list of applications that suit their deployment needs without having to research each potential application individually. The logic form used to populate these applications can be found

Table D-1. CVAST Logic Form

Application Name:	*[Name]*
Description:	*[Description]*

	Characteristic	*Applicable?*
Deployment Type	**Urban**	
	Urban Clusters	
	Rural	
Roadway Types	**Interstate**	
	Arterials	
	Collectors	
	Local Roads	
Signal Assets	**Fixed Signal Timing**	
	Actuated Signals	
	Transit Signal Priority	
	Emergency Vehicle Preemption	
Existing Roadway Assets	**Weigh Stations**	
	Truck Only Lanes	
	Tolling Facilities	
	Ramp Meters	
	HOV/HOT Lanes	
	Work Zones	
	Schools Zones	
	Traveler Information Systems	
Deployment Purpose: Safety	**Rear End Crashes**	
	Right Angle Crashes	
	Lane Departure Crashes	
	Emergency Vehicles	
	Pedestrian and Bicyclists	
Deployment Purpose: Mobility	**Congestion Management**	
	Promote Multimodal Use	
Deployment Purpose: Environment	**Emissions Monitoring**	
	Fuel Savings	
Deployment Purpose: DOT Operations	**Red Light Running**	
	Speeding	
	Asset Management	
	Traveler Information	
	Tolling	

Application Name:	*[Name]*	
Description:	*[Description]*	
	Weather Information	
	Fleet Management	
	Traffic Studies	

Appendix E: Deployment Plan Template

Notes to the Author

[This document is a template of a Deployment Plan Template document for a project. The template includes instructions to the author, boilerplate text, and fields that should be replaced with the values specific to the project.

- *Blue italicized text enclosed in square brackets ([text]) provides instructions to the document author, or describes the intent, assumptions and context for content included in this document.*
- *Blue italicized text enclosed in angle brackets (<text>) indicates a field that should be replaced with information specific to a particular project.*
- *Text and tables in black are provided as boilerplate examples of wording and formats that may be used or modified as appropriate to a specific project. These are offered only as suggestions to assist in developing project documents; they are not mandatory formats.*

When using this template, the following steps are recommended:

1. *Replace all text enclosed in angle brackets (e.g., <Project Name>) with the correct field document values. These angle brackets appear in both the body of the document and in headers and footers. To customize fields in Microsoft Word (which display a gray background when selected) select File->Properties->Summary and fill in the appropriate fields within the Summary and Custom tabs.*

   After clicking OK to close the dialog box, update all fields throughout the document selecting Edit>Select All (or Ctrl-A) and pressing F9. Or you can update each field individually by clicking on it and pressing F9.

   These actions must be done separately for any fields contained with the document's Header and Footer.

2. *Modify boilerplate text as appropriate for the specific project.*
3. *To add any new sections to the document, ensure that the appropriate header and body text styles are maintained. Styles used for the Section Headings are Heading 1, Heading 2 and Heading 3. Style used for boilerplate text is Body Text.*
4. *To update the Table of Contents, right-click on it and select "Update field" and choose the option - "Update entire table".*
5. *Before submission of the first draft of this document, delete this instruction section "Notes to the Author" and all instructions to the author throughout the entire document.*

1 Introduction

1.1 Purpose

[This subsection of the Project Deployment Plan describes the purpose of the plan and identifies the system to be implemented.]

1.2 System Overview

[This subsection of the Project Deployment Plan provides a description of the system to be implemented and its organization.]

1.2.1 System Description

[This subsection of the Project Deployment Plan provides an overview of the processes the system is intended to support. Provide a description of the type of equipment and data maintained, sources and uses of that equipment and data. Include any identification numbers, titles, abbreviations, version numbers and release numbers to describe the system.]

1.2.2 Assumptions and Constraints

[This subsection of the Project Deployment Plan describes the assumptions made regarding the development and execution of this document as well as the applicable constraints. Some items to consider when identifying the assumptions and constraints are:

- *Schedule*
- *Budget*
- *Resource availability and skill sets,*
- *Software and other technology to be reused or purchased,*
- *Constraints associated with product interfaces]*

1.2.3 System Organization

[This subsection of the Project Deployment Plan provides a description of the system structure and the major system components essential to its implementation. It should describe both hardware and software, as appropriate. Charts, diagrams, and graphics may be included as necessary to provide a clear picture of the system.]

2 Management Overview

[This section of the Project Deployment Plan provides a description of how the implementation will be managed and identifies the major tasks involved.]

2.1 Description of Implementation

[This subsection of the Project Deployment Plan provides a description of the planned deployment, installation, and implementation approach. Include whether the system will be implemented using a phased approach or an "instant-on" approach.]

2.2 Points-of-Contact

[This subsection of the Project Deployment Plan identifies the System Proponent, the name of the responsible organization(s), titles, and telephone numbers of the staff who serve as points of contact for the system implementation. These points-of-contact should include the Business Sponsor, Program Manager, Project Manager, Quality Assurance Manager, Configuration Management Manager, Security Officer, Database Administrator, or other managers and representatives with responsibilities relating to the system implementation. The site implementation representative for each field installation or implementation site should also be included, if appropriate.]

Add additional lines as needed to the table. If the applicable team members are listed in the Project Management Plan, reference the appropriate section within that document.]

Table 2.2 – Points-of-Contact

Role	**Name**	**Contact Number**
Business Sponsor		
Project/Program Manager		
Government Project Officer		
System Developer or System Maintainer		
Quality Assurance Manager		
Configuration Management Manager		
Security Officer		
Database Administrator		
Site Implementation Representative		

2.3 Major Tasks

[This subsection of the Project Deployment Plan provides descriptions of the major system implementation tasks. Add as many subsections as necessary to this subsection to describe all the major tasks. The tasks described in this subsection are not site-specific, but generic or overall project tasks that are required to install hardware, software, and databases, prepare data, and validate the system

If several implementation approaches are being reviewed, then identify the advantages, disadvantages, risks, issues, estimated time frames, and estimated resource requirements for each option considered. These options could include:

- *Pilot approach,*
- *Isolated approach,*
- *Local approach,*
- *Area approach,*
- *Regional approach, or*
- *Private sector investment approach*

Include the following information for the description of each major task, if appropriate:

- *What the task will accomplish*
- *Resources required to accomplish the task*
- *Key person(s) responsible for the task*
- *Criteria for successful completion of the task (e.g., "user acceptance")*

Examples of major tasks are the following:

- *Provide overall planning and coordination for the implementation*
- *Provide appropriate training for personnel*
- *Ensure that all manuals applicable to the implementation effort are available when needed*
- *Provide all needed technical assistance*
- *Schedule any special computer processing required for the implementation*
- *Perform site surveys before implementation*
- *Ensure that all prerequisites have been fulfilled before the implementation date*
- *Provide personnel for the implementation team*
- *Acquire special hardware or software*
- *Perform data conversion before loading data into the system*
- *Prepare site facilities for implementation*

Consider addressing the changes that may be necessary once the system has been implemented. These changes may include, but are not limited to, personnel and technology equipment alignment, and contractor support.]

2.4 Implementation Schedule

[This subsection of the Project Deployment Plan provides a schedule of activities to be accomplished. Show the required tasks (described in Subsection 2.3, Major Tasks) in chronological order, with the beginning and end dates of each task. If MS Project is used to plan the implementation, include the project Gantt chart. Include any milestones from the projects that are dependent on this project and vice-versa.]

2.5 Security and Privacy

[This subsection of the Project Deployment Plan includes an overview of the system security and requirements that must be followed during implementation. If the system contains personal data, describe how Privacy Act concerns will be addressed.]

2.5.1 System Security Features

[This subsection of the Project Deployment Plan provides an overview and discussion of the security features that must be addressed when it is implemented. It should include the determination of system sensitivity and the actions necessary to ensure that the system meets all the criteria. Reference the applicable security guidance documents.]

2.5.2 Security Set Up During Implementation

[This subsection of the Project Deployment Plan addresses security issues specifically related to the implementation effort, if any.]

3 Implementation Support

[This section of the Project Deployment Plan describes the support hardware, software, facilities, and materials required for the implementation, as well as the documentation, necessary personnel and training requirements, outstanding issues and implementation impacts to the current environment. The information provided in this section is not site-specific. If there are additional support requirements not covered by the subsequent sections, others may be added as needed.]

3.1 Hardware, Software, Facilities, and Materials

[This subsection of the Project Deployment Plan lists all support hardware, software, facilities, and materials required for the implementation.]

3.1.1 Hardware

[This subsection of the Project Deployment Plan provides a list of support equipment and includes all hardware used for installing and testing. This hardware may include computers, servers, peripheral equipment, simulators, emulators, diagnostic equipment, other non-computer equipment as well as any network and data communication requirements. The description should include the specific models, versions, configuration settings, and the equipment owner. Also include information about manufacturer support, licensing, and usage and ownership rights, and maintenance agreement details.]

If this information is recorded in another document or system, such as the Configuration Management Plan or tool, identify that item here. Otherwise, refer to the Hardware Inventory table in Appendix D.

For example, if a web-enabled database is to be implemented, identify the application and web servers that will provide network access. If the hardware is site-specific, list it in Section 4, Implementation Requirements by Site.]

3.1.2 Software

[This subsection of the Project Deployment Plan provides a list of non-hardware components (software, databases, and compilers, operating systems, utilities, etc.) required to support the implementation. Identify the component by specific name, code, or acronym, identification numbers, version numbers, release numbers, and applicable configuration settings. Also, include information about vendor support, licensing, usage, and ownership rights, as well as any required service and/or maintenance contract costs and associated payment responsibility. Identify whether the component is commercial off-the-shelf, custom developed or legacy. Identify any component used to facilitate the implementation process.

If this information is recorded in another document or system, such as the Configuration Management Plan or tool, identify that item here. Otherwise, refer to the Software Inventory table in Appendix E.

If the component is site-specific, list it in Section 4, Implementation Requirements by Site.]

3.1.3 Facilities

[This subsection of the Project Deployment Plan identifies the physical facilities, accommodations and their location(s) required during implementation. Examples include physical work space for assembling and testing hardware components, desk space for software installers, floor space for equipment, and classroom space for training the implementation staff. Specify the hours per day needed, number of days, and anticipated dates.

If the facilities needed are site-specific, provide this information in Section 4, Implementation Requirements by Site.]

3.1.4 Materials

[This subsection of the Project Deployment Plan identifies any other consumables (i.e. technology, supplies, and materials) required to support the system. Provide the names, identification numbers, version numbers, release numbers, owners, and any associated maintenance or operational costs.

If the materials needed are site-specific, provide this information in Section 4, Implementation Requirements by Site.]

3.2 Documentation

[This subsection of the Project Deployment Plan lists any additional documentation needed to support the deliverable system. Include any security or privacy protection considerations associated with the systems use. If created, make reference to the Software User Documentation Guide for user documentation.]

3.3 Personnel

[This subsection of the Project Deployment Plan describes committed and proposed staffing requirements. Describe the training, if any, to be provided for the implementation staff.]

3.3.1 Staffing Requirements

[This subsection of the Project Deployment Plan describes the number of personnel, length of time needed, types of skills, skill levels, expertise, and any necessary security clearances for the staff required during the implementation period. If particular staff members have been selected or proposed for the implementation, identify their roles and responsibilities.]

3.3.2 Training of Implementation Staff

[This subsection of the Project Deployment Plan addresses the training, if any, necessary to prepare staff for implementing the system; it does not address user training, which is the subject of the Software Training Plan.

Describe the type and amount of training required for each of the following areas, if appropriate, for the system:

- *System hardware/software installation*
- *System support*
- *System maintenance and modification*

List the courses that will be provided, a course sequence, and a proposed schedule. If appropriate, identify which courses particular types of staff should attend by job position description.

If one or more commercial vendors will provide training, identify them, the course name(s), and a description of the course content.

If Center staff will provide the training, provide the course name(s) and an outline of the content of each course. Identify the resources, support materials, and proposed instructors required to teach the course(s).]

3.4 Outstanding Issues

[This subsection of the Project Deployment Plan states any known issues or problems relevant to implementation planning. This section answers the question, "Are there any specific issues, restrictions, or limitations that must be considered as a part of the deployment?"

If issues are site-specific, provide this information in Section 4, Implementation Requirements by Site.]

3.5 Implementation Impact

[This subsection of the Project Deployment Plan describes how the system's implementation is expected to impact the network infrastructure, support staff, user community, etc. Include any references to Service Level Agreements which describe the performance requirements, availability, security requirements, expected response times, system backups, expected transaction rates, initial storage requirements with expected growth rate, as well as help desk support requirements.

If impacts are site-specific, provide this information in Section 4, Implementation Requirements by Site.]

3.6 Performance Monitoring

[This subsection of the Project Deployment Plan describes the performance monitoring tool, techniques and how it will be used to help determine if the implementation is successful.]

3.7 Configuration Management Interface

[This subsection of the Project Deployment Plan describes Configuration Management, such as when versions will be distributed. Reference the Configuration Management Plan.]

4 Implementation Requirements by Site

[This section of the Project Deployment Plan describes site-specific implementation requirements and procedures. If requirements and procedures differ by site, provide this information in an appendix and reference it here.

The "X" in the subsection number should be replaced with a sequenced number beginning with 1. Each subsection with the same value of "X" is associated with the same implementation site. If a complete set of subsections will be associated with each implementation site, then "X" is assigned a new value for each site.]

4.1 Site Name or Identification for Site X

[This subsection of the Project Deployment Plan identifies the site by name, location and ownership.]

4.1.1 Site Requirements

[This subsection of the Project Deployment Plan defines the requirements that must be met for the orderly implementation of the system and describes the hardware, software, and facilities requirements for this site.

Any site requirements that do not fall into the following three categories and were not described in Section 3, Implementation Support, may be described in this subsection, or other subsections may be added following Facilities Requirements below:

- *Hardware Requirements -- Describe the hardware requirements necessary to support the implementation (such as, workstations that will run on a LAN).*
- *Software Requirements -- Describe any software required to implement the system (such as, software specifically designed for automating the installation process).*
- *Database Requirements – Describe any databases that are required to implement this system and their contents.*
- *Data Requirements -- Describe any specific data preparation requirements and data that must be available for the system implementation. An example would be the assignment of individual IDs associated with data preparation.*
- *Facilities Requirements -- Describe the physical facilities and accommodations required during the system implementation period. Some examples of this type of information are provided in Section 3, Implementation Support.]*

4.1.2 Site Implementation Details

[This subsection of the Project Deployment Plan addresses the specifics of the implementation for this site. Include a description of the implementation team, schedule, procedures, and database and data updates. This subsection should also provide information on the following:

- *Team -- If an implementation team is required, describe its composition and the tasks to be performed at this site by each team member.*
- *Schedule -- Provide the subsection of the master implementation schedule described in paragraph 2.4, Implementation Schedule, above that applies to this site.*
- *Procedures -- Provide the detailed procedures required to accomplish the implementation at this site. If necessary, other documents may be referenced. If appropriate, include a step-by-step sequence of the detailed procedures. A checklist of the installation events may be provided to record the results of the process.*
    - *If the site operations startup is an important factor in the implementation, then address startup procedures in some detail.*
    - *If the system will replace an already operating system, then address the startup and cutover processes in detail.*
    - *If there is a period of parallel operations with an existing system, then address the startup procedures that include technical and operations support during the parallel cycle and the consistency of data within the databases of the two systems.*

- *Database -- Describe the environment where the system and the database(s) will be installed. Include a description of the different types of databases and library environments (such as, production, test, and training databases).*
    - *Reference database operating procedures, database file and library naming conventions, database system generation parameters, and any other information needed to effectively establish the database.*
    - *Reference the database administration testing procedures to be used before the system implementation.*
- *Data Update -- If data update procedures are described in another document, such as the operations manual or conversion plan, that document may be referenced here. The following are examples of information to be included:*
    - *Control inputs*
    - *Operating instructions*
    - *Database data sources and inputs*
    - *Output reports*
    - *Restart and recovery procedures]*

4.1.3 Risks and Contingencies

[This subsection of the Project Deployment Plan identifies the risks and specific actions to be taken in the event the implementation fails or needs to be altered at any point and includes the factors to be used for making the decision. Refer to the Project's Contingency Plan, Risk Management Plan and the Risk Management Process for additional guidance.]

4.1.4 Implementation Verification and Validation

[This subsection of the Project Deployment Plan describes the process for ensuring that the implementation was not poorly executed. It describes how any noted discrepancies will be rectified. It also references the system Contingency Plan, if, as a result of the discrepancies, a no-go decision is made to implement the system.]

4.2 Acceptance Criteria

[This subsection of the Project Deployment Plan establishes the ***exit or acceptance criteria*** *for the system. Identify the criteria that will be used to determine the acceptability of the deliverables as well as any required technical processes, methods, tools, and/ or performance benchmarks required for acceptance.]*

Template APPENDIX A: Project Deployment Plan Approval

The undersigned acknowledge that they have reviewed the ***Project Name*** **Deployment Plan** and agree with the information presented within this document. Changes to this **Project Deployment Plan** will be coordinated with, and approved by, the undersigned, or their designated representatives.

Signature: ______________________________ Date: ____________

Print Name: ______________________________

____

Title: ______________________________

Role: Project Manager

Template APPENDIX B: REFERENCES

[Insert the name, version number, description, and physical location of any documents referenced in this document. Add rows to the table as necessary.]

The following table summarizes the documents referenced in this document.

Document Name	Description	Location
<Document Name and Version Number>	*<Document description>*	*<URL or location where document is located>*

Template APPENDIX C: GLOSSARY

The following table provides definitions and explanations for terms and acronyms relevant to the content presented within this document.

Term	**Definition**
[Insert Term]	*<Provide definition of term and acronyms used in this document.>*

Template APPENDIX D: System Hardware Inventory

Name/ ID	Type	Model/ Version	Physical Location	Equipment Owner (Person or Dept)	Maintenance Contract? Y/N	Maintenance Contact Point	Maintenance Type/ Level of Coverage	Maintenance Period Expiration Date	Required Licenses

Template APPENDIX E: System Software Inventory

Name/ ID	Type	Model/ Version	Physical Location	Equipment Owner (Person or Dept)	Maintenance Contract? Y/N	Maintenance Contact Point	Maintenance Type/ Level of Coverage	Maintenance Period Expiration Date	Required Licenses

Appendix F: State-of-Deployment Surveys

Arizona-Maricopa County, Arizona

Part I. Infrastructure Deployed

1. Please confirm which of the following technologies have been deployed in your state:

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	6	Traffic Signal Priority Applications (Emergency Vehicle, Transit, Pedestrian) and Traveler Information
Black Box (Traffic Controller Interface)		
In-Vehicle Devices (ASD/VADs in instrumented vehicles)	5	
Security Certificate Management		
Fiber Optic Connectivity	✓	
OTHER_______________		

2. Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:

- Signal Controller – Econolite ASC3
- Fiber Optic Network
- CCTV
- Loop Detectors

3. What new infrastructure has been deployed to support the implementation of DSRC equipment?
None

4. How are roadside systems connected to a backend network and managed?
Backend connection from the test bed to the TMC is through T1 leased circuit.

5. What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?
Local bandwidth is 1 Gbs on fiber optic LAN network. Backhaul network connection bandwidth is 1.5 Mbs. Local bandwidth usage does not exceed the threshold of the T1 circuit.

Part II. Deployment/Operational Strategies and Challenges

1. What criteria were used to select sites to deploy DSRC infrastructure?

- Urban environment
- Traffic equipment
- Roadway geometry
- Minimum impact to traffic and existing infrastructure
- Proximity to Freeway for Future Expansion
- Agreement with Fire Department

- Local Community Outreach

2. **What software applications reside on the roadside systems?**

Traffic signal priority processing algorithm

3. **Has the performance of these applications been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions.**
    - Communications Performance:
        - Line-of-sight interference
    - Hardware Performance:
        - Normal maintenance and reboot
    - Application Performance:
        - Performance improved after each iteration

4. **How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)**
    - Priority Based Traffic Signal Control for EV and Transit (MCDOT/UA)
    - InFusion: Performance improvements of traffic controllers by means of data fusion and analysis (SBIR Phase I – Savari, UA, SCSC)
    - SmartCross: Smartphone Signal Alert Status (SBIR Phase I – Savari, UA, SCSC)
    - In-vehicle traveler information alerts

5. **Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?**

No

6. **Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

No

Part III. Security Considerations

1. **What security standards and requirements have been incorporated into the system?**

All deployed RSEs are consistent with the DSRC RSE Specification v3.0

2. **Have there been any operational security problems?**

Zero failed attempts and zero successes. No vandalism observed.

California

Part I. Infrastructure Deployed

1. **Please confirm which of the following technologies have been deployed in your state:**

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	10-operational	Interactive Transit Station Information System (ITSIS); Cooperative Intersection Collision Avoidance Systems

Technology	Quantity	What application does this system support?
	30- additional stock	(CICAS-SLTA); 511; Tolling; Ramp Metering; Curve Over-Speed Warning
Black Box (Traffic Controller Interface)		
In-Vehicle Devices (ASD/VADs in instrumented vehicles)		
Security Certificate Management		
Fiber Optic Connectivity	✓	Remote health monitoring; Signage
OTHER_______________		

2. **Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:**
    - Signal Controller
    - Transit Dispatch Center/Traffic Management Center/Passenger Information Server

3. **What new infrastructure has been deployed to support the implementation of DSRC equipment?**
    - Upgraded Signal Controllers – being upgraded from 170 to 2070 ATSC Controllers
    - Backhaul Network – remote health monitoring and management, and signage servers
    - Signal Sniffers

4. **How are roadside systems connected to a backend network and managed?**

T1/DSL Wireless and 3G/4G Cellular Wireless.

5. **What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?**

~7-12Mbps – Download, ~4-6.2Mbps Upload; currently only 10%-15% is being used, would increase when MMITSS apps are active.

Part II. Deployment/Operational Strategies and Challenges

1. **What criteria were used to select sites to deploy DSRC infrastructure?**
    - Urban environment
    - Traffic equipment
    - Roadway geometry
    - Proximity to car OEMs

2. **What software applications reside on the roadside systems?**

Tentative List:
- SPaT, BSM forwarder
- Multi-Modal Intelligent Traffic Signal System Apps: ISIG, TSP, PED-SIG, PREEMPT, FSP
- Curve Over-Speed Warning and CICAS-SLTA (both at RFS)

3. **Has the performance of these applications been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions.**

Most applications are now in a pre-deployment stage. However, all criteria below are considered in the system plan:

- Communications Performance:
  - Line-of-sight interference
  - Insufficient bandwidth
- Hardware Performance:
  - Loss of Power
- Application Performance:
  - Failure to generate relevant message sets

4. What is the cost of data communication from deployment sites to backend systems?
ISP charges of $42.55 per month per site for unlimited 4G Mobile Broadband data plan.

5. How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)

- Cooperative Intersection Collision Avoidance Systems (CICAS-SLTA)
- Ramp Metering - Tolling as part of VII POC
- Curve Over-Speed Warning
- Augmented Speed Enforcement

6. Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?
No

7. Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?
No

Part III. Security Considerations

1. What security standards and requirements have been incorporated into the system?
All deployed RSEs are consistent with the DSRC RSE Specification v3.0

2. Have there been any operational security problems?
None encountered or registered yet.

Florida

Part I. Infrastructure Deployed

1. Please confirm which of the following technologies have been deployed in your state:

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	24	SunGuide Software Connected Vehicle module
Black Box (Traffic Controller Interface)		

Technology	Quantity	What application does this system support?
In-Vehicle Devices (ASD/VADs in instrumented vehicles)		
Security Certificate Management		
Fiber Optic Connectivity	✓	District 5 RTMC SunGuide Production Servers
OTHER_______________		

2. **Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:**
   - Signal Controller
   - Fiber Optic Network
   - Other_____________________

   [*no further response*]

3. **What new infrastructure has been deployed to support the implementation of DSRC equipment?**
   - Research Vehicles (Road Rangers, Lynx Buses, I-Ride Trolleys)
   - Other _____________________

   [no further response]

4. **What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?**

   [no response]

Part II. Deployment/Operational Strategies and Challenges

1. **What criteria were used to select sites to deploy DSRC infrastructure?**
   - Urban environment
   - Conference location – 18th ITS World Congress, Orlando
   - Other _______________________

   [no further response]

2. **Has the performance of these applications been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions.**

   [no response]

3. **How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)**

   [no response]

4. **Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?**

   [no response]

5. **Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

[no response]

Part III. Security Considerations

1. **What security standards and requirements have been incorporated into the system?**
All deployed RSEs are consistent with the DSRC RSE Specification v3.0

2. **Have there been any operational security problems?**
[no response]

Michigan

Part I. Infrastructure Deployed

1. **Please confirm which of the following technologies have been deployed in your state:**

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	78	Signal Phase and Timing (29 for Safety Pilot)
Black Box (Traffic Controller Interface)	0	
In-Vehicle Devices (ASD/VADs in instrumented vehicles)	2850	Mix of ASDs and VADs in passenger vehicles, transit busses and trucks
Security Certificate Management	✓	
Fiber Optic Connectivity		
OTHER_______________		

2. **Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:**
   - Signal Controller 22 units connected
   - Other 8 connected to 3G, 22 connected to 5.8 GHz wireless, 10 connected to AT&T T-1 lines, 8 connected to Wimax.

3. **What new infrastructure has been deployed to support the implementation of DSRC equipment?**
   - <u>Upgraded Signal Controllers</u> – SCOOT Adaptive Traffic Signal System in Ann Arbor, SCATS adaptive traffic signal system in Oakland County at 675 signals
   - <u>Fiber Optic Network</u> – State-wide initiative to add 2300 miles of new fiber optic connectivity, 10 miles in Grand Rapids for a VMS project
   - <u>Research Vehicles</u> - The Connected Vehicle Test bed has 9 vehicles available for testing with connected vehicle applications. They currently do not have DSRC communications equipment installed.

4. **What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?**

This varies by site. 3G sites have ~700Kbps, T-1 Sites ~ 1.5 MBps, 5.8GHZ has ~54Mbps shared amongst 22 road side units, and Wimax has about 54Mbps shared among the 8 sites. Utilization is < 5% since they are not actively in use.

Part II. Deployment/Operational Strategies and Challenges

1. **What criteria were used to select sites to deploy DSRC infrastructure?**
    - Urban environment
    - Traffic equipment
    - Proximity to research lab (UMTRI)

2. **What software applications reside on the roadside systems?**

During legacy RSE operation, it was typical for 1-2 sites out of 50 to fail per week, for various reasons.

- Communications Performance:
    - Other -Backhaul communication outages, various reasons
- Hardware Performance:
    - Loss of Power – Power loss outages have occurred
- Application Performance:
    - Power loss can prevent SPAT from restarting

3. **What is the cost of data communication from deployment sites to backend systems?**

T-1 sites cost close to $1000 per month. 3G sites are ~ $60 per month. Wimax and 5.8 GHz backhaul only have the initial deployment cost, which I do not have information on.

4. **How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)**
    - Signal Phase and Timing (SPaT)
    - Curve Speed Warning
    - Traveler Information Message

5. **Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?**

No

6. **Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

No

Part III. Security Considerations

1. **What security standards and requirements have been incorporated into the system?**

All deployed RSEs are consistent with the DSRC RSE Specification v3.0 and the system is linked to the Security Certificate Management System (SCMS) in Oak Ridge, TN.

2. **Have there been any operational security problems?**

The development and testing of the SCMS is ongoing, and has been subjected to the hacker community to discover any serious

New York

Part I. Infrastructure Deployed

1. **Please confirm which of the following technologies have been deployed in your state:**

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	41	Connected Vehicle Driver ID and Verification Wireless Vehicle Safety Inspection Inspection Information Maintenance V2V Communication (Plows to Trucks)
Black Box (Traffic Controller Interface)		
In-Vehicle Devices (ASD/VADs in instrumented vehicles)	21	Connected Vehicle Driver ID and Verification
Security Certificate Management		
Fiber Optic Connectivity	✓	
OTHER_______________		

2. **Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:**
   - The deployed RSEs are connected to the regional TMC for communication with vehicles to support the applications listed above.

3. **What new infrastructure has been deployed to support the implementation of DSRC equipment?**
   - Research Vehicles – 4 plow trucks
   - After-market Safety Devices – 20 Kapsch ASDs

4. **How are roadside systems connected to a backend network and managed?**

The RSEs are connected to the Long Island TMC across the existing fiber network, and in selected places, using cellular modems.

5. **What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?**

The RSEs tie into the same backhaul as the rest of the traffic control systems and the dedicated network use has not been evaluated.

Part II. Deployment/Operational Strategies and Challenges

1. **What criteria were used to select sites to deploy DSRC infrastructure?**
   - Traffic equipment– e-screening site
   - Conference location – 2008 ITS World Congress, Manhattan

2. **Has application performance been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions.**

Yes – device/application performance has been stable. Because the deployment of the devices was concentrated along the interstate, there weren’t any issues with range or line-of-site, and there were no recorded problems with power outages or hardware failures.

3. **How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)**
   - CVII DSRC applications:

    - Driver ID and Verification
    - Wireless Vehicle Safety Inspection
    - CV to maintenance vehicles communication
- Grade Crossing Driver Warnings (In-vehicle signage & crossing signal activation)
- Heavy Vehicle to Light Vehicle Driver Safety Warnings

4. Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?

None have been observed or recorded.

5. Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?

No

Part III. Security Considerations

1. What security standards and requirements have been incorporated into the system?

All deployed RSEs are consistent with the DSRC RSE Specification v3.0.

2. Have there been any operational security problems?

No

Turner Fairbank Highway Research Center

Part I. Infrastructure Deployed

1. Please confirm which of the following technologies have been deployed in your state:

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	1	Signal Phase and Timing, Dilemma Zone Warning, AERIS: Eco-Drive, Wireless Signal Actuation
Black Box (Traffic Controller Interface)	1	Signal Phase and Timing
In-Vehicle Devices (ASD/VADs in instrumented vehicles)	1	Dilemma Zone Warning, AERIS: Eco-Drive, Wireless Signal Actuation
Security Certificate Management	✓	
Fiber Optic Connectivity		
OTHER_______________		

2. Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:

- Signal Controller
- Backend Connectivity to the Saxton Lab

3. What new infrastructure has been deployed to support the implementation of DSRC equipment?

- Upgraded Signal Controllers
- Black Box (Traffic Controller Interface)

- Research Vehicles – 2 Jeep Grand Cherokees, 5 Cadillac SRXs
- Denso After-Market Safety Device
- WiMAX Connectivity
- PTZ Cameras

4. How are roadside systems connected to a backend network and managed?

The equipment at the intersection is connected via Cat5e cable as well as across a locally managed WiMAX network.

5. What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?

1Gb of bandwidth on Internet-2, with 45Mb allocated for internet use which can be utilized for communication with backend servers.

Part II. Deployment/Operational Strategies and Challenges

1. What criteria were used to select sites to deploy DSRC infrastructure?

- Proximity to research lab – Saxton Transportation Operations Laboratory
- Proximity to government facility – FHWA Research Center

2. Has the performance of these applications been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions

Communications Performance – Line-of-sight interference due to roadway curvature and grade, as well as foliage from adjacent trees.

3. How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)

- Signal Phase and Timing (SPaT)

4. Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?

No

5. Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?

No

Part III. Security Considerations

1. What security standards and requirements have been incorporated into the system?

All deployed RSEs are consistent with the DSRC RSE Specification v3.0.

2. Have there been any operational security problems?

No

Fairfax, Virginia

Part I. Infrastructure Deployed

1. **Please confirm which of the following technologies have been deployed in your state:**

Technology	Quantity	What application does this system support?
Roadside Equipment devices (RSEs)	45	Eco-Speed Control, Pavement Assessment and Management, Transit Signal Priority, Adaptive Lighting, Freeway Merge management, Cooperative Intersection Control, etc.
Black Box (Traffic Controller Interface)		
In-Vehicle Devices (ASD/VADs in instrumented vehicles)		
Security Certificate Management		
Fiber Optic Connectivity		
OTHER________________		

2. **Please indicate whether the roadside equipment is connected to other existing infrastructure in the options below:**
   - Signal Controller
   - Camera and Radar Units
   - Other ___________________

3. **What new infrastructure has been deployed to support the implementation of DSRC equipment?**
   - Research Vehicles (automobiles, motorcycles, a motor coach and a semi-truck)

4. **What is the network bandwidth availability and how much of the bandwidth is currently being utilized by the system?**

Part II. Deployment/Operational Strategies and Challenges

1. **What criteria were used to select sites to deploy DSRC infrastructure?**
   - Urban environment with significant transportation system deficiencies (congestion, high crash rates, air quality non-attainment)
   - Major merge/diverge locations
   - Two metro stations/public transport and commuter routs
   - HOT and HOV lanes
   - Proximity to a large county hospital, fire station, multiple schools and pedestrian trails and a major roadway construction site

2. **Has application performance been stable since deployment? Please describe any operational problems that have been encountered and subsequently implemented solutions.**

   [no response to date]

3. **How are DSRC systems used to enable communication between vehicles and the infrastructure? In other words, what applications are currently supported/enabled by DSRC equipment?)**

- Adaptive Lighting
- Freeway Merge Management – Field Test
- Safety and Congestion Issues Related to Public Transportation, Pedestrians, and Bicyclists
- Cooperative Intersection Control
- Freeway Speed Harmonization
- Freeway Cooperative Adaptive Cruise Control Systems
- Emergency V2V Communication
- Eco-Speed Control using V2I Communication
- "Intelligent" Awareness System for Roadside Workers
- Pavement Condition Measures and Utility Assessment
- Adaptive Stop/Yield Signs

4. Have there been any problems with conflicting frequencies (between 5.9 GHz and others) or degraded signal strength? If so, what has been done to mitigate these problems?

[no response]

5. Has the state evaluated the ruggedness of the deployed systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?

No individual evaluations were completed, but all deployed equipment has been evaluated as part of the product testing to meet USDOT acceptance criteria.

Part III. Security Considerations

1. What security standards and requirements have been incorporated into the system?

All deployed RSEs are consistent with the DSRC RSE Specification v3.0.

2. Have there been any operational security problems?

None have been observed or reported to date.

Appendix G: State-of-Readiness Surveys

Sensys VDS240 Wireless Vehicle Detectors

Part I. System Components and Design

1. **Please identify all system components and interfaces that have been integrated as part of the design:**
    - Microstrip patch antenna (mounted below top surface of the sensor)
    - Low-power radio
    - Magnetometer
    - Battery pack

2. **Please explain which industry standards or requirements were incorporated into the design of the device or application.**
    - Plastic casing is a NEMA Type 6P-compliant enclosure
    - Physical layer protocol uses IEEE 802.15.4 Standard
    - Compliant with Part 15 of FCC rules
    - Compliant with the European Commission Low Voltage Directive (2006/95/EC)

Kapsch Roadside Equipment

Part I. System Components and Design

1. **Please identify all system components and interfaces that have been integrated as part of the design:**
    - MTX-9450 (5.9 DSRC Radio)
    - Two separated 5.9 radios (e.g. for CCH and SCH)
    - Ethernet IF
    - GPS receiver and GPS antenna connector
    - External antenna connectors for both radios
    - One TRC industrial PC – Roadside Unit Controller
    - Protective circuitry including surge protection for device voltage supply and Ethernet connection

2. **Please explain which industry standards or requirements were incorporated into the design of the device or application.**
    - FCC
    - NEMA 4X
    - MIL-STD 810F
    - IP67 protection class standard
    - IEC 60068-2-56 Cb/30Db
    - IEEE 1609.2, 1609.3, 1609.4
    - IEEE 802.11 p
    - USDoT Safety Pilot Requirements
    - SAE J2735

Part II. Proof-of-Concept and Existing Deployments

1. **Was a proof-of-concept test conducted to evaluate the general use case of the system? Are there any use cases that have not been evaluated?**
   - USDOT Safety
   - Testfeld Telematik (Austrian FoT)
   - ECo-AT (Austrian part of an European C-ITS corridor project)
   - I-94 truck parking
   - NYSDOT NYSERDA (Commercial vehicle inspection)
   - HELP Inc. (CVO trial) 5 sites, 9 gantries across three states along US I-70
   - SunPass Florida Turnpike in Orlando, FL
   - Port of Hood river
   - Lee County pilot in Tampa, FL
   - Volvo Trucks CVII
   - Singapore parking demo
   - Auburn University research project

2. **Please describe any subsequent deployments of the device or application and any broad system functionality that was enabled or supported by the device or application.**

Applications which have been tested are (see also section 3):

- Curve speed warning
- SPaT (green light speed advisory)
- Traffic information – in-vehicle signage (DMS content, static traffic signs, traveler information)
- Public transport information incl. park and ride facilities
- Cooperative Intersection Collision Avoidance System
- Weather warning
- Road works warning
- Truck parking (I-94)

Part III. Evaluation of Reliability, Durability, Interoperability and Security

1. **Have the availability and reliability of the system been evaluated by any independent organization? If so, please provide the specifications.**

USDOT tests and qualifications leading to listing on the USDOT Research Qualified Products List (rQPL).

Detailed MTBF calculation has shown that a reliable operation for 10 years may be expected. Additionally, stability and reliability are under permanent evaluation, e.g. in FoT Testfeld Telematik and other currently running and past FoTs.

2. **For physical equipment, has any independent evaluation of the ruggedness of the systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

Cetecom tests have been conducted:

- Salt mist
- Shock
- Vibrations
- Operating temperature range
- ESD
- IP 67

No problems recognized during certification phases.

3. **What security standards and requirements have been incorporated into the system design?**

Radio security standards according to IEEE 1609.2 have been incorporated. (ECC signing provided by ESCRYPT, 3DES and AES SSH connections available for back-office and supervisory connections as required by USDOT RSE specs. IPTABLES used to secure ports and packet capture.

Raw UDP packets (IPV6) as required by the USDOT RSE spec.
Connection from/to BO is done via SSL; device monitoring utilizes SNMPv3 and HTTPS.

4. **Please discuss the level of interoperability with related software and hardware. Can the device or application function properly as part of a system with components from different vendors? If so, has any independent interoperability evaluation been conducted?**

During Testfeld Telematik project in Austria the interoperability between several vendors (Siemens, Swarco, C2C-CC,…) of 5.9 HW and SW have been successfully tested. The system has been demonstrated during the ITS WC 2012 in Vienna.

SNMPv3 integration with umbrella network management system.

During the USDOT Safety Pilot project, interoperability was implemented.

Savari Roadside Equipment

Part I. System Components and Design

1. **Please identify all system components and interfaces that have been integrated as part of the design:**
   - The system components integrated are 1609.2 security stack, DSRC WAVE stack.
   - Our RSEs are capable of supporting wireless radio standards like WiFi, DSRC, GPS, 3G & Bluetooth.
   - RSE is integrated with Ethernet, USB and Serial ports for management access.
   - We have integrated support powering the devices using both Power Over Ethernet as well as 110v AC power mechanisms.

2. **Please explain which industry standards or requirements were incorporated into the design of the device or application.**
   - NEMA certified enclosure
   - IEEE 802.11p, IEEE 1609.x
   - FCC Class 90 certified
   - SAE J1455, SAE J1113-11, IEC61000-4-2, MIL-STD-810G
   - USDOT RSE 3.0 Specification

Part II. Proof-of-Concept and Existing Deployments

1. **Was a proof-of-concept test conducted to evaluate the general use case of the system? Are there any use cases that have not been evaluated?**

Savari RSEs apart from various transportation test beds throughout the country have been extensively used in the year long, UMTRI Safety Pilot Study. The RSE was tested as per the DOT RSE 3.0 specification.

2. **Please describe any subsequent deployments of the device or application and any broad system functionality that was enabled or supported by the device or application.**

Savari RSEs are deployed at the following locations

- Forty RSE's deployed at Safety Pilot test bed managed by Parsons Brinckerhoff & UMTRI.
- Hundred RSEs deployed in three different test beds in Virginia maintained by VTTI & VDOT.
- Six RSEs Anthem (Arizona-Maricopa County) test bed maintained by Arizona-Maricopa County & University of Arizona.
- Ten RSEs Palo Alto test bed maintained by PATH & Caltrans.
- Two RSEs deployed at the Turner Fairbank Highway Research Center in McLean, VA.

Our RSE is fully compliant to RSE specification 3.0. We have made several improvements and developed various tools to simplify the deployment and management of Road Side Equipment.

Part III. Evaluation of Reliability, Durability, Interoperability and Security

1. **Have the availability and reliability of the system been evaluated by any independent organization? If so, please provide the specifications.**

Our equipment has been evaluated by MET labs as part of the USDOT QPL program.

2. **For physical equipment, has any independent evaluation of the ruggedness of the systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

Independent evaluation of the ruggedness of the system was conducted by MET labs for extreme temperatures, vibration, wind loads and precipitation. Environmental tests were carried out as per MIL-STD-810G for rain, temperature, salt fog and humidity tests.

3. **What security standards and requirements have been incorporated into the system design?**

It is fully compliant to IEEE 1609.2 security for data communication. Furthermore, the RSE supports SSH, ACLs and firewalls as part of the security for its management interface.

4. **Please discuss the level of interoperability with related software and hardware. Can the device or application function properly as part of a system with components from different vendors? If so, has any independent interoperability evaluation been conducted?**

Interoperability of the RSEs with other RSE vendors like ITRI, Arada, Cohda was tested by OmniAir consortium. During the course of our Safety Pilot deployment, we have verified interoperability of Vehicle Awareness Devices and After Market Safety device vendors like Savari, Cohda Wireless and Denso.

Savari Vehicle Awareness Device

Part I. System Components and Design

1. **Please identify all system components and interfaces that have been integrated as part of the design:**
   - The system components integrated are 1609.2 security stack, DSRC WAVE stack.
   - VAD supports DSRC and GPS radios.
   - VAD is integrated with Ethernet, USB and Serial ports for management access.
   - We have integrated support powering the devices using a 12v DC line.

2. **Please explain which industry standards or requirements were incorporated into the design of the device or application.**

We followed the IEEE, SAE standards for the design of the VAD application according to the USDOT specification for Vehicle Awareness Device Ver 3.6.

Part II. Proof-of-Concept and Existing Deployments

1. **Was a proof-of-concept test conducted to evaluate the general use case of the system? Are there any use cases that have not been evaluated?**

It has been certified by MET labs for the purposes of the VAD functionality.

2. **Please describe any subsequent deployments of the device or application and any broad system functionality that was enabled or supported by the device or application.**

Savari's VADs were used in the National UMTRI Safety Pilot test bed apart from their subsequent use in many other test beds. We are also designing variations of our VAD platform for the purposes of taxi management systems in controlled deployments like airports.

Part III. Evaluation of Reliability, Durability, Interoperability and Security

1. **Have the availability and reliability of the system been evaluated by any independent organization? If so, please provide the specifications.**

Savari's VAD was selected as part of the research Qualified Program List by USDOT. Our VAD device was evaluated by MET labs as part of the QPL program. The relevant specs were defined in the USDOT VAD specification (version 3.6).

2. **For physical equipment, has any independent evaluation of the ruggedness of the systems to withstand extreme environmental conditions? (for example: temperatures, shock, vibration, wind loads, precipitation) If so, were any problems identified or new solutions implemented?**

Our VAD device was evaluated by MET labs as part of the VAD QPL program. A series of environmental tests have been conducted and the Savari VAD has successfully passed all of them. Some of the tests conducted are Operating Temperature Range from -40 to + 80 C, Shock & Vibration tests, SAE J1211.

3. **What security standards and requirements have been incorporated into the system design?**

No physical tamper proof requirements were incorporated in designing the VAD device.

4. **Please discuss the level of interoperability with related software and hardware. Can the device or application function properly as part of a system with components from different vendors? If so, has any independent interoperability evaluation been conducted?**

Our VAD device was deployed at the Safety Pilot program conducted by USDOT with UMTRI as the test conductor. Our VAD is known to interoperate with the following RSE device vendors, such as Savari, ITRI and Cohda Wireless.