Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs

May 30, 2014
ACKNOWLEDGMENTS

The authors wish to thank the University of Michigan Transportation Research Institute for their support in conducting this research and preparing this report. The authors also acknowledge the contributions of various organizations involved in connected vehicle test programs around the country and wish to thank the following contributors:

- Matt Smith, Michigan Department of Transportation
- Collin Castle, Michigan Department of Transportation
- Rick McDonough, New York State Department of Transportation
- Danielle Daneau, Road Commission for Oakland County Michigan
- Glen Davies, Road Commission for Oakland County Michigan
- Faisal Saleem, Maricopa County Department of Transportation
- Les Sipowski, City of Ann Arbor Michigan
- Russ Hanshue, City of Ann Arbor Michigan
- Craig Hupy, City of Ann Arbor Michigan
- Scott Shogan, Parsons Brinckerhoff
- Anthony Gasiorowski, Parsons Brinckerhoff
- Greg Krueger, Leidos
- Frank Perry, Leidos
- George Gilhooley, HNTB Corporation
- Debby Bezzina, University of Michigan Transportation Research Institute
This report describes deployment considerations for connected vehicle infrastructure by state and local transportation agencies in light of a 2014 U.S. DOT decision regarding the future of connected vehicle safety and based on lessons learned from the Safety Pilot Connected Vehicle Model Deployment. A literature review was performed to capture background information and lessons learned from Safety Pilot and other connected vehicle test programs. Interviews were conducted with Safety Pilot team members and affiliated test bed participants to obtain additional, practical lessons learned regarding connected vehicle deployment.
CONTENTS

INTRODUCTION..............................................................................................................1

BACKGROUND .......................................................................................................2
Description of the Safety Pilot Model Deployment and Infrastructure ..........3
Safety Pilot Model Deployment Vehicle-to-Infrastructure Applications ....4

STUDY APPROACH ...............................................................................................6

CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT NEEDS .................6
Value of the Basic Safety Message ....................................................................7
Safety and Mobility Needs ...............................................................................8
V2I Applications ..............................................................................................8
Connected Vehicle Data Needs ........................................................................11

CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT CHALLENGES ....11
Technical Challenges to Connected Vehicle Infrastructure Deployment ....12
  Technical Maturity, Interoperability and Standards ......................................12
  Technical Obsolescence and Changing Requirements ...............................14
  Application Support Considerations .............................................................15
  Data Management Considerations .................................................................16
  Communications ............................................................................................17
  Security Considerations ................................................................................18
Institutional Challenges to Connected Vehicle Infrastructure Deployment 19
  Resource Requirements ................................................................................20
  Technical Skills and Experience ....................................................................20
  Benefit and Cost Information .........................................................................20
  Data Access and Ownership ..........................................................................21
  Standards and Stability of the Environment ..................................................22
  Planning for the Connected Vehicle Environment – Institutional Issues ......22

CONCLUSION .........................................................................................................23

REFERENCES .........................................................................................................25

APPENDIX A .........................................................................................................A-1
APPENDIX B .........................................................................................................B-1
FIGURES

FIGURE 1: The Safety Pilot Model Deployment Area in Ann Arbor, Mich., included both arterial streets and freeways. ................................................................. 2

FIGURE 2: Typical installation of connected vehicle roadside equipment at a signalized intersection ........................................................................................................... 3

FIGURE 3: Intersection controller. ................................................................................................................................. 3

FIGURE 4: Pedestrian detectors for transit safety application. ...................................................................................... 4

FIGURE 5: Connected Vehicle Infrastructure Communications Block Diagram ...................................................... 5

TABLES

TABLE 1: Connected Vehicle Infrastructure Needs for Public Agencies Involved in the Study .............................. 9

TABLE 2: V2I Applications Cited by Respondents ........................................................................................................... 10
INTRODUCTION

The University of Michigan Transportation Research Institute (UMTRI) and the United States Department of Transportation (U.S. DOT) are conducting a model deployment of connected vehicles, called Safety Pilot, in Ann Arbor, Michigan. The purpose of the model deployment is to test the effectiveness of connected vehicle safety applications for reducing crashes, to show how drivers respond to these technologies while operating a vehicle in a real-world, multimodal environment, and to evaluate the feasibility, scalability, security, and interoperability of Dedicated Short Range Communications (DSRC) technology.

Empirical data collected during Safety Pilot has been evaluated to present a more accurate, detailed understanding of the potential safety benefits of connected vehicle technologies. In fact, these data provided a basis for a National Highway Traffic Safety Administration (NHTSA) agency decision regarding connected vehicle safety on February 3, 2014. This decision sent a signal to automakers and government agencies that the implementation of connected vehicle technology is highly probable within the next few years.

The U.S. DOT is preparing for such implementation by seeking input from stakeholders regarding deployment considerations. At the U.S. DOT External Stakeholders Outreach Meeting, held on January 16, 2014 in Washington, D.C., the Federal Highway Administration (FHWA) presented the following connected vehicle deployment expectations from the American Association of State Highway and Transportation Officials (AASHTO) Field Infrastructure Footprint Analysis:

- DSRC will be available in new vehicles by 2020.
- A minimal amount of connected vehicle infrastructure would be in place by 2020, with a 25% build-out by 2025.

- Major commercial and interstate highway corridors will be among the first highway segments to be equipped within this timeframe.
- By 2040, 80% of all signalized intersections and 25,000 other roadside units would be available nationwide.

The realization of these expectations will have an impact on the auto industry, but also on state and local road agencies.

The purpose of this report is to summarize connected vehicle deployment considerations from a practitioner’s perspective, applying lessons learned from Safety Pilot and other connected vehicle test bed programs around the country. It will offer realistic guidance to practitioners in light of the 2014 NHTSA decision. Infrastructure considerations related to roadside equipment, communications, head-end hardware, and software are emphasized in this report. Policy and other institutional considerations are also addressed.

The information contained in this report will supplement other initiatives related to connected vehicle infrastructure considerations, including:

- The Field Infrastructure Footprint Analysis being conducted by AASHTO.
- The Cooperative Transportation Systems Pooled Fund Study led by the Virginia DOT with technical support from the University of Virginia Center for Transportation Studies.

This report addresses the infrastructure deployment challenges faced during Safety Pilot, but also provides a general discussion of infrastructure deployment considerations that will face public agencies and other practitioners as they face the opportunity for connected vehicle infrastructure deployment.
BACKGROUND

The Safety Pilot Model Deployment is the primary basis for the findings in this report. As the largest and most recent deployment of connected vehicle technology in the United States, Safety Pilot provides the opportunity for learning from practitioners and consultants involved in the project. Practitioners and project participants from other connected vehicle test projects were included in this study to obtain information about the challenges they faced also. Among the other contributors were the Road Commission for Oakland County Michigan, the Maricopa County Arizona DOT, the New York State DOT, and the Florida DOT.

FIGURE 1: The Safety Pilot Model Deployment Area in Ann Arbor, Mich., included both arterial streets and freeways.
Description of the Safety Pilot Model Deployment and Infrastructure

Safety Pilot involved installing connected vehicle technology in approximately 2,800 cars, trucks, buses, motorcycles and bicycles; deploying roadside equipment along 73 lane-miles of arterial streets and limited access highways; and equipping facilities to process the resulting data used to evaluate connected vehicle safety benefits and to support the U.S. DOT decision to proceed with the regulatory process to mandate connected vehicle safety equipment in light vehicles.

UMTRI recruited and prepared volunteers to participate in the model deployment. Drivers were recruited primarily from areas east and northeast of downtown Ann Arbor, Michigan. The model deployment required high concentrations of drivers along the outfitted routes as shown in Figure 1. The primary routes covered include U.S. 23, M-14, Plymouth Road, Washtenaw Avenue, and the Fuller/Geddes corridor in the Ann Arbor area. These routes were selected to capture the majority of test participant drivers during their daily commutes. The mix of freeways and city streets allowed researchers to evaluate the effectiveness of the technology on different road types and driving conditions.

Dedicated short-range communications were installed along these routes at:

- 21 signalized intersections,
- 3 curve locations, and
- 3 freeway sites.

All sites included a secure communication link for collection of the study data. A typical intersection installation is shown in Figure 2. Figure 3 shows the inside of a traffic signal controller cabinet with the traffic signal controller, detector track, and switch for the connected vehicle equipment. This controller configuration includes pedestrian detection which is used for alerting turning buses about the presence of pedestrians in the crosswalk.
The pedestrian detectors are shown in Figure 4. Figure 5 brings all of the elements at a typical intersection together. This diagram demonstrates the communications linkages between various elements in the system, from the connected vehicle to the RSU and intersection controller to the back office. Security management is accommodated by an enterprise level security management system, but also through network security appliances where subsystems intersect.

A set of plan sheets showing typical freeway RSU installations is shown in Appendix B. The configuration for freeway sites is similar to that for intersections, especially where the RSU is collocated with other freeway management system equipment, where a device control cabinet is required. For the freeway sites in Ann Arbor, wireless backhaul communications with relays link the sites to the City of Ann Arbor fiber optic communications network.

**Safety Pilot Model Deployment Vehicle-to-Infrastructure Applications**

The primary intent of Safety Pilot was to evaluate vehicle-to-vehicle (V2V) safety applications although vehicle-to-infrastructure (V2I) applications were also deployed as part of the program. The Safety Pilot roadside equipment was primarily used for data collection and for distribution of security certificates to support the V2V applications. V2I applications included curve speed warning at three locations and Signal Phase and Timing (SPaT) applications at twelve intersections along the Fuller/Geddes and Plymouth Road corridors. Because the traffic signals along Plymouth Road operate adaptive control (Split Cycle Offset Optimization Technique - SCOOT), SPaT implementation was more challenging than with fixed time signal plans. The issue regarding use of SPaT at adaptive traffic signals is addressed more fully later in this report. Additionally, pedestrian detection was deployed at one intersection on the Fuller corridor to alert drivers of turning transit vehicles to the presence of pedestrians in the crosswalk, and an ice warning system was installed at one location along Plymouth Road.

Safety Pilot was not intended to be a large scale test of V2I applications. Instead, it was intended to provide a basis for the evaluation of V2V applications in a real-world environment in support of the NHTSA decision related to V2V safety. The experimental design and concept of operations for Safety Pilot included, but did not emphasize, infrastructure and V2I applications to the same extent as V2V applications. Nevertheless, certain deployment and operations issues related to the connected vehicle infrastructure were manifested during the project.

While Safety Pilot provided a couple of typical V2I applications, other test programs around the country included other V2I applications that may be of interest to practitioners, including emergency and transit vehicle priority and freight applications. Therefore, this report includes lessons learned from other test programs in addition to Safety Pilot.
FIGURE 5: Connected Vehicle Infrastructure Communications Block Diagram.
STUDY APPROACH

The study approach involved two elements. The first element included a literature review to identify information that might be helpful to practitioners in light of the U.S. DOT decision on connected vehicle safety. The documents reviewed included:

1. Safety Pilot documentation
   a. Requirements
   b. Plans and specifications
2. AASHTO Connected Vehicle Field Infrastructure Footprint Analysis documents
3. U.S. DOT documentation, including presentations, reports and web pages

The second element of the study approach involved interviews with members of the Safety Pilot infrastructure team and other agency representatives involved in connected vehicle test projects. Interviews were conducted via telephone or in person. A questionnaire, employing open-ended questions, was used to capture the information. The discussions with practitioners were most often “free-ranging” as the interviewees became engaged. Copies of the questionnaires used for practitioners and for consultant team members are included in Appendix A.

Safety Pilot team members included in the interview process came from the following organizations:
- Test conductor team members
- City of Ann Arbor
- Michigan DOT

In addition to the Safety Pilot team members, others at the following organizations were interviewed:
- Road Commission for Oakland County (RCOC) Michigan
- Maricopa County Department of Transportation (MCDOT) Arizona
- Florida DOT
- New York State DOT

The interview process involved both practitioners and consultants. This framework was intended to elicit practitioner concerns related to connected vehicle infrastructure deployment, but also to obtain the input of experts from the consulting community related to those concerns.

The remainder of this report outlines the current state of research regarding connected vehicle infrastructure deployment considerations and how the practitioner community views their readiness for potential deployment. The findings of this research are anecdotal in nature due to the structure of the research process. However, the lessons learned by the practitioner community and their consultants on various test projects will provide important insights for public agencies as connected vehicle technology is implemented. These findings will also provide insights to support the FHWA in development of their guidance documents in 2015.

CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT NEEDS

The primary emphasis of the connected vehicle program thus far has been on V2V safety. However, most public agencies are uncertain about the role of infrastructure in a connected vehicle environment. Questions abound about how much infrastructure is needed, where it should be located, what will the public agency be responsible for, what skills will be needed, what data will be available, what benefits will be realized, how much it will cost, and what business models will be in place to support application development, security management, data management, and user privacy.

Infrastructure deployment needs of public agencies have been addressed primarily by AASHTO, which has been working with the U.S. DOT, Transport Canada, and the Institute
of Transportation Engineers (ITE) on connected vehicle infrastructure deployment research. AASHTO’s emphasis has been to establish a national “footprint” for field infrastructure deployment. This represents a set of broad research objectives related to the scale of a national deployment and the costs of such deployment. These are important considerations for national policy and funding support. AASHTO also engaged the practitioner community to assess priority applications, and identify workforce, training, policy and guidance needs. AASHTO’s Applications Analysis includes a good summary of V2I applications that will form the basis of most connected vehicle infrastructure programs at the state and local levels. The application groups and bundles identified by AASHTO provide a useful framework for understanding deployment needs and considerations. However, many of the applications identified in the AASHTO report were not identified as priorities among the respondents in this study. This demonstrates that most local agencies, even those involved in connected vehicle test programs, may not have a good understanding of the range of applications that will be available in the future.

Value of the Basic Safety Message
At the most basic level, public agencies want access to the Basic Safety Message (BSM Part 1) data to monitor and measure the performance of their transportation systems. Above all other applications, performance measurement represented the most fundamental need of the agencies involved in this study. Simple probe data, comprising vehicle location, speed and heading, can be used by public agencies for traffic monitoring, Advanced Traveler Information Systems (ATIS), traffic signal timing analyses, and planning purposes. The public agencies do not require real-time data for many of these basic needs, with the exception of ATIS applications. However, they expressed the need for near real-time data in the future as probe data may be used for new traffic signal control strategies, corridor management, and other active traffic management purposes.

Additional data available from the BSM Part 2, such as precipitation, air temperature, wiper status, light status, road coefficient of friction, Antilock Brake System (ABS) activation, Traction Control System (TCS) activation, and vehicle type, will support road surface condition monitoring, ATIS, enhanced maintenance decision support systems, and asset management related applications. The value of these data can be enhanced through aggregation with data from other sources, such as stationary sensor systems (Environmental Sensing Stations, Road-Weather Information Systems, CCTV cameras, traffic sensors). The need for near real-time data for road surface condition monitoring and road-weather applications is important in the short term to support maintenance decision support and response strategies.

As reported by McGurrin, the BSM is useful for a limited number of the more sophisticated V2I applications, especially with limited roadway coverage. However, it appears that many public agency needs can be addressed by BSM data in the short term based on the findings of this study. The penetration rate of probe vehicles is another consideration for public agencies seeking to install connected vehicle infrastructure. Rehborn et al. found that a two percent penetration rate of connected vehicle probes would provide “premium quality” data for basic applications. The findings of Zou et al. differed significantly from Rehborn but still demonstrated that benefits from probe vehicles
can be achieved with only a small penetration rate. Zou developed a travel time algorithm using simulated connected vehicle probes. With a probe vehicle penetration rate of 5%, a 12.5% average error rate was found. The error rate dropped below 10% only when the probe penetration rate exceeded 10%.

These studies indicate that reliable data can be collected even with a 5-10% penetration rate for connected vehicle probes. With a small number of roadside units strategically located on state and local road networks, many of the basic needs expressed by practitioners could be met with minor vehicle penetration rates, especially if the probe data is fused with data from other sources to increase its reliability.

Safety and Mobility Needs

Safety improvements and crash reduction needs were mentioned by all of the respondents during this study. However, the City of Ann Arbor reported no significant change in crash frequency on any of the streets in Ann Arbor equipped with connected vehicle infrastructure. They also noted that the City did not have access to Safety Pilot data that might reveal useful surrogate safety measures, such as the number of conflicts. They are anxious to obtain the results of the U.S. DOT evaluation on the safety impacts of the technology.

The importance of infrastructure to provide incremental safety benefits should not be overlooked, but other needs were weighed equally or even higher by many of the practitioners. All respondents certainly recognized the value of connected vehicle technology for safety, but also recognized that V2V applications would provide many of the gains in safety benefits. They also stated that safety benefits would increase as the number of connected vehicles increases. Until there is a scaled growth of equipped vehicles, the need for connected vehicle infrastructure will be low.

In the short term, most of the public agency practitioners placed more emphasis on mobility, traffic operations and traffic signal timing improvement, road condition assessment, performance management and asset maintenance/management. These applications do not rely on all vehicles being equipped. Table 1 summarizes the needs expressed by public agency practitioners involved in this study. These needs do not necessarily represent the needs of the entire user community.

V2I Applications

The needs expressed by the practitioners in this study tell only part of the story. The applications that will be developed to support these needs are equally important. Table 2 is derived from the AASHTO National Connected Vehicle Field Infrastructure Footprint Analysis – Applications Analysis. This table summarizes the V2I applications envisioned for various application bundles and cited as most needed by respondents. Many of these applications are also the subject of U.S. DOT connected vehicle research programs.

Four application areas were mentioned as priorities by practitioners:

- Agency data applications
- Mobility applications
- Road-Weather applications
- Safety applications
TABLE 1: Connected Vehicle Infrastructure Needs for Public Agencies Involved in the Study

<table>
<thead>
<tr>
<th>Connected Vehicle Infrastructure Needs</th>
<th>Public Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>City of Ann Arbor</td>
</tr>
<tr>
<td><strong>Short Term</strong></td>
<td></td>
</tr>
<tr>
<td>Data Capture for Improved Traffic Signal Operations (Signal Phase and Timing)</td>
<td>X</td>
</tr>
<tr>
<td>Data Capture for Winter Maintenance or Asset Management</td>
<td>X</td>
</tr>
<tr>
<td>Data Capture for Planning</td>
<td>X</td>
</tr>
<tr>
<td>Data Capture for Performance Measurement</td>
<td>X</td>
</tr>
<tr>
<td><strong>Long Term</strong></td>
<td></td>
</tr>
<tr>
<td>Crash Reduction</td>
<td>X</td>
</tr>
<tr>
<td>Reduce Other Infrastructure Needs</td>
<td>X</td>
</tr>
</tbody>
</table>

As mentioned above, agency data applications are short term priorities for public agencies. This is based on their need to monitor and improve the performance of their street and highway systems. Mobility applications are also very important for state and local agencies. In the short term, they see benefits from improved traveler information as data from various sources, including connected vehicles, is aggregated to provide a richer data set and more reliable information. As the number of connected vehicles increases and as the technology matures, public agencies perceive an opportunity to implement corridor management and multimodal intelligent traffic signal system applications. Ultimately, they believe that new traffic signal control strategies will be developed to replace current fixed time, traffic responsive and adaptive control algorithms.

Road weather applications were also considered important to public agency respondents. The purpose of these applications would be for internal operational and maintenance enhancements, but also to alert motorists to road surface and driving conditions.
## TABLE 2: V2I Applications Cited by Respondents

<table>
<thead>
<tr>
<th>Connected Vehicle Infrastructure Needs</th>
<th>City of Ann Arbor</th>
<th>Michigan DOT</th>
<th>Maricopa County DOT</th>
<th>Road Commission for Oakland County</th>
<th>New York State DOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agency Data Applications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe Based Traffic Monitoring</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Probe Based Pavement Condition Monitoring</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Performance Measures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Mobility Applications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable ATIS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Freight ATIS (FRATIS)</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Corridor Management</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Transit Vehicle Priority</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multimodal Intelligent Traffic Signal Systems</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Road Weather Applications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorist Advisories and Warnings</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Information for Maintenance and Fleet Management Systems</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maintenance Decision Support Systems</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>V2I Safety Applications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersection Collision Warning</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Emergency Vehicle Pre-emption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work Zone Alerts</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Curve Speed Warning</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Railroad Crossing Violation Warning</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Finally, safety was certainly a priority for all of the public agencies included in this study. However, the timeframe for V2I and I2V safety applications was viewed as lagging behind other applications since they depend on a growing number of equipped vehicles to be effective. Agency data applications, mobility applications and road weather applications only require a small percentage of the overall fleet to be equipped, whereas safety applications will require the vast majority of vehicles to be equipped for optimum effectiveness.

Many agencies envision a time in the future when stationary sensors will not be needed. Instead, connected vehicles and other mobile devices will provide the data they will need to manage their systems. This could potentially result in large savings for traditional infrastructure deployment and maintenance, but may have impacts on staffing requirements and information technology (IT) resources.

While the interviews with public agency staff involved primarily DSRC technology, some respondents noted that DSRC is only needed for safety-critical, low-latency applications. They suggested that cellular technology may provide an alternative for many mobility and traveler information applications that do not require V2V communications. This may relieve public agencies of the cost burden anticipated with the installation, maintenance and operation of connected vehicle infrastructure while also providing a more ubiquitous solution during the transition period as connected vehicle penetration increases. As connected vehicle penetration rates increase, then the number of V2I applications and the perceived value of connected vehicle infrastructure will increase.

**Connected Vehicle Data Needs**

While not related to a specific application, practitioners expressed a general concern about their ability to obtain, share, store, aggregate, process, and analyze the vast amount of data generated by connected vehicles and from other sources in the future. This seemed to be a theme related to the Agency Data Applications cited by the practitioners and a concern for public agencies. Data management, including data collection, filtering, aggregation, storage and analysis, at the local level was identified as a critical need as connected vehicles enter the market. While some public agencies may have resources to facilitate these activities, it was clear from the interview process that staffing and information technology resources were woefully lacking in most agencies due to wage rates and funding constraints. Also, most agencies do not have a clear understanding of what physical resources (communications and head-end storage capacity) may be required. This issue has implications for training, organizational requirements, contracting and business models for public agencies in the future.

**CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT CHALLENGES**

Public agency practitioners identified numerous connected vehicle infrastructure deployment challenges during the next decade. They recognize that V2I applications will lag behind V2V deployment for a variety of reasons, both technical and institutional, and that a scaled deployment of connected vehicles is required to achieve most of their safety and mobility goals.
They feel that the federal research focus has been primarily on V2V applications and testing. While the federal research focus will likely shift to implementation of V2I applications over the next decade, an infrastructure lag will exist.

The technical and institutional challenges facing public agencies are summarized below.

**Technical Challenges to Connected Vehicle Infrastructure Deployment**

All of the practitioners and contractors involved in this study have experience in the deployment of connected vehicle infrastructure as part of Safety Pilot or other test programs. Most feel that the technical issues will be addressed over the next five years to correspond with the U.S. DOT timeline for connected vehicle implementation.

The practitioners involved in this study felt that the physical installation of the DSRC equipment was relatively straightforward and does not pose much concern. Most of the practitioners are accustomed to working with radio equipment in conjunction with other traffic control devices. Therefore, they are familiar with techniques for assessing line of sight, calibration of the equipment, and hanging such devices on poles and mast-arms. They seem to understand range limitations for Power over Ethernet (POE) cabling, lightning/surge protection, and other routine matters related to installation and maintenance of the connected vehicle equipment. Most agencies view connected vehicle infrastructure as an extension of their current traffic control equipment.

The technical challenges they face do not pertain to the physical installation of the equipment. Rather, they see challenges related to the maturity level of connected vehicle equipment, interoperability and standards, the implementation of specific applications, application support, data management, communications and network management, local network security, and network optimization. These topics are addressed below.

**Technical Maturity, Interoperability and Standards**

The technical challenges experienced by the respondents were related mostly to the maturity of the connected vehicle equipment and other technologies required for implementation. The respondents unanimously agreed that the currently deployed Roadside Units (RSU) are prototypes and are not “street-ready.” For example, practitioners feel that connected vehicle infrastructure components lack the technical maturity of other traffic control devices they typically deploy. Most public agencies are risk averse when it comes to deployment of technology solutions, especially related to traffic signal systems and other safety-critical infrastructure. Consequently, the public agencies involved in this study expressed their concerns about the robustness of the equipment, interoperability, technology obsolescence, and changing requirements.

The environment is viewed as unstable at this time. This poses some discomfort among public agencies, seeking stability and solid, long-lasting solutions that they can deploy on an affordable
basis. Therefore, most of them stated that they will proceed cautiously with deployment. A certification process and entity was mentioned by almost all of the respondents as a requirement to provide standard, robust solutions in the future. They felt that the U.S. DOT should play a role in defining the certification process.

All of the public agencies expressed concern regarding the robustness of the currently available roadside equipment. Device failures have been common with the current RSUs. During test projects, equipment instability strained the staff resources of the agencies involved. They cited the time and effort required for bench testing prior to installation of the equipment. Once installed, they all mentioned the need for frequent maintenance of the equipment. They expressed a desire for specialized diagnostic tools, remote management capabilities, and the ability to reset the RSUs remotely to reduce recurring trips to the field to meet maintenance requirements.

Practitioners also expressed the need for standardization among traffic signal control equipment. The use of different control equipment by adjacent highway departments should not impact regional deployment efforts. Connected vehicles must work identically across jurisdictional boundaries. This interoperability issue was addressed to some extent on Safety Pilot. However, each traffic signal controller manufacturer has proprietary elements that limit complete interoperability. The use of Model 2070 Advanced Traffic Controllers (ATC) provides a more universal hardware platform for interoperability. Safety Pilot included two different traffic signal controller manufacturers to test interoperability across controller platforms. The National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) was employed to enable use of data from differing controller manufacturers. However, the City of Ann Arbor found that their central control software was unable to obtain some data from field controllers from a different manufacturer despite the use of NTCIP. This indicates that more work is needed to provide the seamless solutions being sought by local agencies.

State and local agencies are also seeking a fully integrated solution. Current device specifications do not provide such a solution. A “black box” solution was introduced during Safety Pilot as the interface between the RSU and the traffic controllers. The “black box” solution was implemented to translate SPaT messages sent from the traffic controller to the RSU and to enable IPv6 communications. The practitioners view this current interface solution as a low-risk, temporary, yet cumbersome, “work-around.” They are seeking a standard solution, where the connected vehicle equipment will operate...
seamlessly with any brand or model of traffic control equipment. They look forward to a more robust and integrated solution from traffic controller manufacturers. Future implementation will require a more integrated solution.

Some agencies would like to see the RSU placed in the cabinet (with the antenna on a pole or mast-arm) for ease of maintenance. However, some traffic control cabinets are already packed with equipment. This may require new specifications for traffic signal controllers, cabinets and other enclosures. One manufacturer has introduced a new controller cabinet design with a separate compartment and doors for ITS-related equipment. This not only would address the space issue, but could also address the concern expressed by some agencies about allowing third parties to maintain DSRC equipment in the future. The practitioners expressed the need to work with traffic controller manufacturers to achieve an integrated solution. They also expressed a desire for detailed documentation on how to wire, configure, and integrate the equipment.

Agencies identified a concern about the need to upgrade their existing traffic signal control equipment to accommodate connected vehicle technology. Controller manufacturers have been working on solutions where their traffic signal control equipment can be updated to provide SPaT data with simple software and firmware retrofits. While this may address some of the cost issues involved in upgrading traffic controllers, space needs still could be an issue.

A more comprehensive solution to connected vehicle infrastructure needs at signalized intersections is expected within the next year. U.S. DOT efforts to update the specification for the roadside unit will eliminate some of the ambiguity in the current specification and improve the robustness of the equipment. The new specification (Specification 4.0) will be more of a preproduction unit specification than current prototype versions of the equipment. Key changes will include integrated Global Positioning System (GPS), POE capability that supports IPv4 and IPv6, a NEMA-grade enclosure, and mean-time-between-failures (MTBF) that is typical for carrier-grade communications equipment. These new features will address many of the concerns expressed by practitioners, but may still may fall short of what agencies are typically accustomed to deploying.

As with most technologies in their infancy, other technical issues will manifest as the deployment scale increases. Experienced practitioners mentioned this risk as part of the normal product maturity cycle. Product updates and new versions will certainly be needed to mitigate issues that are introduced with scale. Much of this is outside the control of the public agencies, since the auto manufacturers will likely drive the standards during the next decade. Consequently, many public agencies will wait until the environment is more stable before they enter the connected vehicle market.

**Technical Obsolescence and Changing Requirements**

All of the practitioners expressed concern about technical obsolescence. The current timeframe for implementation of DSRC technology is lengthy enough to suggest that other, more robust or advanced technologies will be introduced to render DSRC obsolete before it is fully
deployed. The likelihood of such disruption may create inertia among public agencies.

The DSRC manufacturers are small companies, and the market is very immature at this time. Consequently, market forces will likely drive some of the current equipment providers out of business. This is a risk for public agencies that enter this arena as early adopters. This risk is compounded if other technologies, such as cellular, grab larger market shares.

All of the respondents indicated a need for standards that would account for disruptive changes. The standards would allow forward and backward compatibility. Most agencies would be satisfied with a 10 year life from the equipment they install based on the benefits they feel would be achieved.

**Application Support Considerations**

As outlined previously, local agencies will seek support from the U.S. DOT or from the private sector to develop other needed applications. Most agencies do not have internal capabilities to develop connected vehicle applications.

SPaT data is critical for most applications sought by agencies. The acquisition and use of SPaT data have proven to be more difficult than originally envisioned by the public agencies. They are anxious to obtain the results of the Integrated V2I Prototype research efforts underway by the U.S. DOT, where the SPaT interface will be improved. That research project will more clearly define the interface specification and standards for two-way communication (information exchange and data flows) between traffic signals and vehicles.

Currently, SPaT has been implemented at twelve intersections for the Safety Pilot Model Deployment and at twenty-two locations along Telegraph Road in Oakland County, Michigan. The traffic signals at which SPaT has been implemented on Telegraph Road are operating very simple, two-phase timing plans. This has allowed testing of SPaT capabilities in a simple signal timing environment, but the agencies noted that they want to expand research efforts to more complex traffic signals and intersection configurations.

Safety Pilot offered a more complex environment for SPaT implementation, where different traffic controller manufacturers would be involved along with more complex signal timing plans and intersection configurations. SPaT was implemented on both the Fuller/Geddes Road corridor and the Plymouth Road corridor during Safety Pilot. Each of these corridors offered unique characteristics for testing SPaT. Six traffic signals along the Fuller/Geddes corridor used EconoliteTM traffic signal control equipment. The City of Ann Arbor had no experience with this brand of traffic control equipment in the past. An additional six intersections along Plymouth Road were SPaT-enabled. These signals were operating the SCOOT adaptive traffic signal control system.

The intersections along Fuller Road are operating fixed-time traffic signal timing plans. This means that the signal phases do not vary on a cycle-
by-cycle basis. This situation allows SPaT to provide “countdown” data at traffic signals along Fuller Road. The intersection of Fuller Road and Maiden Drive also includes pedestrian detection for transit operations. When a pedestrian is present in the crosswalk at this intersection, buses involved in the Safety Pilot Model Deployment receive warning messages to facilitate safe turning movements. This information is sent along with SPaT data to the approaching buses, thus adding some complexity to the SPaT application.

The traffic signals along Plymouth Road in Ann Arbor are operating the SCOOT adaptive traffic signal control system. The challenge with adaptive traffic control is how to reliably broadcast SPaT messages when phase lengths are not predictable. In Ann Arbor’s case, Siemens has determined that only the last five seconds of a phase would need to be broadcast in order to provide ample time for driver warnings at intersections. Siemens made some adjustments in the SCOOT central system to provide a 5-second countdown for signals along Plymouth Road. This technique offers a possible way to use SPaT applications at traffic signals operating in adaptive mode. However, it was noted that the “wait periods” for broadcast of the SPaT data along Plymouth Road introduced other impacts and the absence of SPaT data during those “wait periods” restricted the types of applications available.

Since many public road agencies have implemented or are evaluating deployment of adaptive traffic signal control strategies, the Plymouth Road experience offers important lessons regarding use of SPaT at such intersections. For example, Ann Arbor, Maricopa County and the Road Commission for Oakland County all currently operate adaptive traffic control systems. Each of these agencies recognize the weaknesses in the current SPaT solutions for adaptive control. In the future, it is likely that new adaptive control algorithms will be developed to leverage connected vehicle probe data. Many of the practitioners felt that this would be a good research topic.

**Data Management Considerations**

All agencies involved in this study expressed uncertainty about the availability and ownership of connected vehicle probe data. They also expressed an apparent need for data management resources, including storage capabilities, staffing to analyze the data, and new ways to present the data in useful forms.

The amount of data captured during Safety Pilot was overwhelming, even on a model deployment level and without collecting the full BSM message set. How to manage connected vehicle data on a larger scale will be a challenge for public agencies in the future.

The availability of probe data was expressed as a critical need of state and local agencies. If or when connected vehicle data becomes available, public agencies will need to store the data, aggregate the data with other similar data, and analyze the data to provide useful information. Currently, public agencies have limited capabilities to undertake these activities. They will need staff who are skilled in data management and analytics to assist with performance monitoring, measurement and decision support. It is likely that agencies will rely on the private sector for many of these services.

**THE AVAILABILITY OF PROBE DATA WAS EXPRESSED AS A CRITICAL NEED OF STATE AND LOCAL AGENCIES.**

For some agencies, such as the Michigan DOT and the Road Commission for Oakland County, road weather information is critical for maintenance operations, especially during winter months. Access to BSM Part 2 data would give them an additional source of road weather data to support their maintenance decisions. Currently, they rely a great deal on weather
forecasting services, Road-Weather Information Systems and Environment Sensing Stations (RWIS/ESS), and specialized sensors installed on maintenance vehicles to help them make such decisions. It is unlikely they would abandon these other reliable sources of data, but the additional data from BSM Part 2 would supplement the current sources and increase the reliability of the information they use to make decisions.

One issue identified during the interview process is the limited involvement of public agencies in the development of the SAE J2735 standard message set. The J2735 standard was developed primarily by the auto industry for their purposes. Public agency data needs may not be fully addressed in the J2735 standard. A more robust dialogue between the auto industry and public agencies is needed to identify data elements of value to public agencies. Some of this work is being done through the V2I research currently underway by the U.S. DOT, but it is evident that a more inclusive discussion would be useful to help public agencies understand the data that will be available to them and to help the industry refine the standard to meet data capture requirements for public agencies.

The availability and possible expansion of BSM data, and the aggregation of those data with data from other sources will be important for maintenance decision support systems in the future. The agencies likely will need outside support from the U.S. DOT and consultants when or if these data become available to public agencies.

Communications

Communications requirements for connected vehicle implementation are certainly a concern for public agencies. While many agencies own their communications networks, some still rely on leased communications circuits. This poses concerns related to network capacities, maintenance priorities, technical capabilities of third party providers of communications services, and network security. For agencies that own their networks, uncertainty about network capacity is a concern.

The requirement for IPv6 became an issue on Safety Pilot. It was a challenge for the Safety Pilot Conductor to fully understand and deploy IPv6 on the City of Ann Arbor network. Nevertheless, IPv6 was successfully deployed and operational on the City’s network during Safety Pilot. This demonstrated that IPv6 may be more easily deployed on private networks than on commercial networks at this time.

For example, RSUs along U.S. 23 and M-14 were to be integrated with other field devices installed by the Michigan DOT. Cellular communications were to be deployed at those sites. While the cellular provider stated that they would be able to support IPv6 at those sites, it was determined that IPv6 could not be supported by the commercial carrier after months of delay. Another third party communications provider was brought in to remedy the situation. After many more months of delay, they too could not support this requirement. These freeway sites were not implemented during the deployment phase of Safety Pilot due to the delays that resulted. Ultimately, it was decided that three RSU sites along U.S. 23 and M-14 would be relayed via broadband wireless communications to a node on the City of Ann Arbor’s communications network at U.S. 23 and Plymouth Road.

The lesson learned is that IPv6 is not widely supported by commercial communications providers at this time. It is anticipated that IPv6 will be supported commercially within the next
five years. The current RSU specification assumes IPv6 and does not support IPv4 SIM tunneling. This required “work-arounds” on Safety Pilot. Therefore, initial deployments will likely depend on similar “work-arounds” using IPv4 tunneling or private closed network resources until IPv6 is commercially viable. The new RSU specification being developed by the U.S. DOT will include both IPv4 tunneling and IPv6 compatibility.

Backhaul communications also is a concern for rural deployments for the reasons mentioned above. Most rural deployments will rely on leased communications because publicly installed and owned communications networks in rural areas are costly to build and maintain. Consequently, communications capabilities pose a significant barrier to rural connected vehicle deployment. Connected vehicle deployment plans must take this into consideration.

**Security Considerations**

Security management was expressed as a concern by all respondents, who appear to see this issue as a barrier to deployment. Security is a critical need for all connected vehicle transactions to ensure that only information from trusted sources is sent, accepted and used.

Network security is currently being addressed on an enterprise level by issuing security certificates through the Security Certificate Management System (SCMS). The Public-Key Infrastructure (PKI) role for certificate authority will likely not be handled at the local level in the future. Instead, it is likely that regional servers or security management systems will be distributed across the country and coordinated on a national basis. This was identified by the study participants as a key need and role for the U.S. DOT or an independent third party.

Local agency staff still had questions about how the security management system would work. Are certificates delivered through the publicly owned infrastructure or at auto dealerships? Can the cellular network be used for delivery of the certificates rather than using RSUs? It was clear that the model for security management is yet unclear and needs to be defined prior to deployment.

Local agencies also expressed a different concern related to security of their local networks. If they receive data directly from connected vehicles, then they must open up their network firewalls to accept such data. This poses the risk of network vulnerability to malicious behavior or “bad players.”

Most of the public agencies involved in this study stated that some security concerns could be mitigated if third party data brokers collect, aggregate, analyze and configure connected vehicle data for public agencies in the future.

While this may simplify the security scenarios for local agencies in the future, it may also create latencies in the retrieval of information and may have implications for how public agencies collect and use traffic data.

**Planning for the Connected Vehicle Environment – Technical Issues**

Optimization of the RSU network is both a technical and practical concern for public agencies. It is clear that public agencies must plan for deployment, but they currently lack information about how many devices they will need, where they should be located for optimal benefit, and benefits and costs.
RSU coverage must be well-planned by local agencies to control costs, but also to avoid overlapping coverage areas that could lead to data management and interpretation issues. It was found that the range of DSRC radios varies considerably given terrain, vegetation, and other line-of-sight features. Nevertheless, it also appears that the range of the radios may be greater than the 300 meter distance generally assumed prior to Safety Pilot given clear line-of-sight. The extended range of the radios was unexpected on Safety Pilot and certainly poses interesting challenges for future deployment. At this point, the impacts of a vehicle communicating with multiple RSUs are not fully known. Siting criteria will be needed to assist local agencies in their planning.

Siting criteria must take into consideration the greater than expected broadcast range of the DSRC radios. It is possible that fewer RSUs may be needed along corridors or throughout a metropolitan area. Agencies must conduct analyses to determine coverage needs, tune radios to reduce coverage gaps or overlaps, and assess sight lines along corridors. All of these activities will have cost implications for agencies.

The location of the devices will be determined by state and local priorities. Local agencies stated that they will use crash and traffic data to determine locations where needs are greatest. They feel that this approach, which is already used for most investment decisions, will provide the greatest benefits from the onset of the program. All agencies expressed a need for benefit and cost information to justify the investment of public funds for connected vehicle technology. Most agencies indicated that they would proceed cautiously until they could demonstrate the value of deployment to the general public, especially in light of resource limitations.

**Institutional Challenges to Connected Vehicle Infrastructure Deployment**

Public agencies involved in this study reported six major institutional challenges related to connected vehicle infrastructure deployment. First, public agencies face funding shortfalls that will impact their ability to deploy connected vehicle infrastructure. This not only concerns capital costs for deployment, but also funding for operation and maintenance of the infrastructure. The second theme involves the need for more staff with new skills. The ability of public agencies to hire and retain staff with the technical skills required is a considerable challenge for local agencies. Third, public agencies currently lack the benefit and cost information they require to support deployment decisions. Fourth, they do not understand how to access the data, who will own the data, and what the institutional environment will be like to support their information needs. Fifth, public agencies have no control over what vehicle manufacturers will do. They envision a dynamic environment that is unstable and will require continuous enhancements to the infrastructure to stay current. Standards and backward compatibility were two issues that public agencies feel are needed. Finally, public agencies lack enough information about the business model for connected vehicle deployment to begin planning for a connected vehicle environment. Uncertainty instills inertia, and most local agencies will wait until the path is clear before they proceed with deployment.
**Resource Requirements**

Resource concerns dominate the institutional challenges expressed by public agencies. Their resources are already strained in deploying, operating and maintaining their current infrastructure. Adding more equipment with new maintenance requirements will exacerbate this issue.

Funding for deployment, operations and maintenance was mentioned as the top concern for state and local agencies. Agencies expressed uncertainty regarding future federal funding levels, competition for funding, and funding eligibility under current federal aid programs. While agency staff did not support a separate funding program for connected vehicle deployment, operations and maintenance, they did support eligibility under current or future categorical programs for such activities. They also indicated that incentives may be required to encourage use of funds for connected vehicle implementation over other purposes.

Agencies perceive a need for additional funding to upgrade traffic signal control equipment in order to accommodate connected vehicle infrastructure. Additionally, the cost of maintenance of additional equipment was cited by all agencies as a concern. This concern related to field equipment, communications infrastructure, and back office hardware and software systems.

The agencies also perceive an opportunity for public-public and public-private partnerships to support connected vehicle deployment, operations and maintenance. Most of the agencies cited the opportunity to form partnerships with local transit and public safety agencies. Others believe that private, third-party organizations will determine a viable business model to support deployment, maintenance and operations. Nevertheless, all agencies recognize that the viability of connected vehicle infrastructure will depend on partnerships that cover federal, state, regional and local governments along with the private sector.

**Technical Skills and Experience**

The interview respondents all consider themselves to be sophisticated users and pioneers in connected vehicle technology. Therefore, they are predisposed to technical challenges involved in deploying the technology and have staff with the technical skills required for implementation. However, they fear that staff retention will pose problems for them as deployment takes place. Wage rates for highly skilled technical staff are considerably lower at public agencies than in the private sector. They anticipate staff shortages for highly skilled technical resources required for back office support, network management and security, data management, testing and application development support. Consequently, most of the respondents believe that they will rely more on consultants and contractors to support these aspects of deployment, operations and maintenance of their systems in the future.

**Benefit and Cost Information**

Since connected vehicle technology has only been deployed in test beds, benefit and cost information is scarce. However, the U.S. DOT is expected to finalize its analysis of Safety

---

THE AVAILABILITY OF PROBE DATA WAS EXPRESSED AS A CRITICAL NEED OF STATE AND LOCAL AGENCIES.
Pilot data and release a report, including estimates of costs and benefits, in early 2014. Preliminary analyses indicated that connected vehicle technology could address more than 80 percent of vehicular crash scenarios involving unimpaired drivers. While public agencies do not question the potential safety benefits of V2V applications, they also do not understand the incremental safety benefits that can be achieved by the implementation of connected vehicle infrastructure and V2I safety applications. Continuing research and evaluation will be required, even after deep market penetration of connected vehicles, to understand the added benefits of V2I capabilities.

Data Access and Ownership

The public agencies involved in this study feel that the data from connected vehicles will yield the greatest benefits for their organizations in the short-term. However, they expressed frustration regarding limited access to the data from the connected vehicle test bed programs. Either the data is not yet available to the agencies in a usable format, or the data is proprietary and unavailable for public agency use. Some agencies are equipping their fleets with various sensors to obtain road and weather condition information, even though some of this information may already be available directly from BSM Part 2.

As mentioned previously, the respondents felt that greater public agency participation is needed to refine the J2735 standard to include data elements in a format that will be useful for public agency purposes. This will require greater public agency participation on standards committees and greater collaboration with private industry to define the data needs of public agencies.

In the short term, public agencies could use the data from connected vehicle test programs to help them:
- Understand the substance and format of the data
- Understand the benefits of the technology
- Identify ways to use the data to meet their operational needs
- Establish performance metrics or determine problem locations on their transportation networks
- Develop their connected vehicle infrastructure deployment site plans
- Educate their staff and decision-makers on data uses and the value of the technology

Longer term, as market penetration of connected vehicles increases and more data is available, public agencies will face different challenges. Data ownership issues must be addressed as part of future policy making. Is the data generated by connected vehicles part of the public domain? If so, which data? If not, then who owns the data and how can public agencies access that data?

Most of the public agencies expressed a concern that they could become overwhelmed with data. They stated that it may be more beneficial for a third party to collect, store, process, aggregate, and analyze the data for them. This will help them overcome challenges they envision related to skilled IT personnel and back office resource needs. It may also help them from a liability perspective. None of the agencies expressed a desired to respond to more requests under the Freedom of Information Act (FOIA). Many of the public agency representatives mentioned that they are already procuring information from third parties for performance measurement and decision support. This appears to be a preferred model for public agencies.
Standards and Stability of the Environment

Most public agencies recognize that currently installed connected vehicle infrastructure represents a prototype version and that additional development is required. They also recognize that much of this development is out of their control. They identified a need for public agencies to work in concert with traffic control equipment manufacturers, connected vehicle equipment suppliers, and automakers to provide a more stable environment for connected vehicle deployment. Until they sense stability in the environment, most agencies will lack sufficient confidence to move into the connected vehicle space.

Some of the agencies offered an interesting perspective that the environment may never become stable – that technological advances will make it increasingly difficult for them to settle on a technology. They fear obsolescence will render their infrastructure obsolete too quickly to realize a satisfactory return on investment. They emphasized the need for technology-agnostic solutions that facilitate forward and backward compatibility.

A couple of agency representatives stated that “the sooner the technology is in the hands of practitioners, the sooner it will evolve.” There is anecdotal evidence that this might be the case. For example, video detection technology was introduced for traffic control purposes in the early 1990’s. Initial devices lacked technical maturity, and problems became evident only after sufficient numbers of the devices were deployed. Soon, shadow processing and directional detection capabilities were introduced, and local agencies gained greater confidence in the technology. However, if the initial users of the technology did not take those first steps, it is possible that technical maturation and adoption rates would have been much slower.

The stability of the environment is based on many factors, but having a set of mature standards is the key to technology adoption.

Planning for the Connected Vehicle Environment – Institutional Issues

Planning of connected vehicle infrastructure will take place at the state, regional and local levels, not at the federal level. This will require an understanding of the technology, the benefits, the costs, the uses for the data, and the applications. It will also require funding availability.

Most of the public agencies feel they have time to plan for a connected vehicle environment. They understand that connected vehicle infrastructure will likely lag behind connected vehicle penetration for a variety of reasons, already mentioned in this report. However, continued uncertainty about the business model for connected vehicle deployment, operation and maintenance is creating inertia among public agencies seeking answers about how they must adjust. While most agencies do not envision radical changes in the structure of their organizations because of connected vehicles, they do envision changes in various functions within their organizations, such as data management. Public agencies already contract many functions previously performed internally, so this is common practice in today’s environment. While more functions may be contracted out, the public agencies still will need skilled contract managers who understand those functions and the technologies they are based upon.

Public agencies all envision greater efficiency in their business operations with improved information in the future. They will be able to more quickly pinpoint traffic problems, vehicle maintenance issues, or poor road surface conditions. They may need to adjust current processes to take advantage of more and faster
information. Decision-support systems may need to be revamped as a result. Nevertheless, without knowledge of how the technology will be rolled out or who will own the data, most public agencies will sit on the sidelines.

Greater public awareness will be required to overcome misconceptions about connected vehicle technology. Even within public agencies involved in connected vehicle test programs, misinformation is common. Communications and outreach will be needed to educate the public about the benefits and costs of connected vehicle technology, especially when public funds are used for deployment.

GREATER PUBLIC AWARENESS WILL BE REQUIRED TO OVERCOME MISCONCEPTIONS ABOUT CONNECTED VEHICLE TECHNOLOGY.

CONCLUSION

Deployment of connected vehicle infrastructure will take place at the state and local level, but be guided by federal policy. A step in this direction was taken on February 3, 2014, when the U.S. DOT announced their intent to move forward with the regulatory process related to connected vehicle safety in light vehicles. According to the U.S. DOT press release regarding the agency announcement, the “DOT believes that the signal this announcement sends to the market will significantly enhance development of this technology and pave the way for market penetration of V2V safety applications.”

The agency decision sent a message to automakers, the supplier community, connected vehicle application developers, and government agencies that policy and guidance will be forthcoming at a future date. This decision has been expected for many months, but with the announcement comes a greater sense of confidence that connected vehicle technology will become a reality before the end of the decade.

Many challenges, both technical and institutional, must be overcome to realize the benefits of this promising technology. Technical challenges facing practitioners include the technical maturity and robustness of the equipment, interoperability, standards, application development, security, and communications. Public agencies will need to adapt to the changing technical environment by developing or hiring skilled professionals in information technology, networking, and data analytics.

On the institutional front, the challenges seem even more daunting. Uncertainty will instill a sense of inertia, and infrastructure deployment will lag without guidance on data management and ownership issues, standards, business models, and funding options. Information on benefits and costs will be needed to help state and local agencies justify their investment decisions. Communications and outreach will be needed to foster greater understanding of the technology and the value it offers to the public.

It is clear that the world is on the verge of a transformational era in transportation safety. It is highly probable that this transformation will create ancillary benefits in mobility, environmental sustainability, and even new funding mechanisms. The key to realizing this transformation is to systematically address the issues, both real and perceived, identified by the practitioner community. What will the business model for deployment look like? How will it be rolled out and when?

Public agencies must work with their stakeholders to understand their needs and fears, but also to establish realistic expectations about connected vehicle technology. While the nation may be on the verge of transformational changes in transportation, the program could be sidelined by technical failures or public misconceptions.

Ultimately, connected vehicle technology could
be the “game-changer” that was envisioned by the U.S. DOT and the automakers more than a decade ago. As the transformation occurs, new methods for traffic signal timing, traffic analyses, and roadway design criteria will need to adapt. Current engineering and operational concepts, algorithms, our transportation workforce, and traffic control systems will go through significant changes. Adaptation will be difficult, especially in an age of severely limited resources. However, as one responder pointed out, “The book is being rewritten.”
REFERENCES

9. “Link Travel Time Estimation Based on Vehicle Infrastructure Integration Probe Data,” Zhijun Zou, Meng Li, and Fanping Bu, Tenth International Conference of Chinese Transportation Professionals (ICCTP), Beijing, China, August 4-8, 2010, published by ASCE.


**General References**

- http://www.its.dot.gov/testbed.htm
APPENDIX A

Interview Questionnaires
PRACTITIONER QUESTIONNAIRE

1. What do you, as a practitioner, feel is the greatest benefit that will be derived from connected vehicle technology?
2. What specific applications of connected vehicle technology will help your agency achieve your organizational goals and the greatest benefits? Please describe.
3. What do you think are the greatest impediments to widespread deployment of connected vehicle technology?
4. What deployment challenges did you face on the Safety Pilot program?
5. What maintenance and operational challenges have you faced related to connected vehicle infrastructure?
6. What institutional challenges did you face during the deployment of connected vehicle technology?
7. Based on your experience, what technical challenges pose the greatest risk or barriers to future deployment?
8. Based on your experience, what institutional challenges pose the greatest risk or barriers to future deployment?
9. What skills, knowledge and experience are needed to successfully deploy and manage connected vehicle infrastructure?
   a. What skills, knowledge and experience would be needed by staff for deployment?
   b. What skills, knowledge and experience would be needed by staff for operations and maintenance?
10. What other resources do you have available to support this report (e.g., wiring diagrams, intersection plan sheets, technical specifications, special provisions, technical documentation, etc.)?
11. Who else should we meet with to obtain information for this report?

CONSULTANT QUESTIONNAIRE

1. What do you, as a consultant expert, feel is the greatest benefit that will be derived from connected vehicle technology?
2. What specific applications of connected vehicle technology will help public agencies achieve their organizational goals and the greatest benefits? Please describe.
3. What do you think are the greatest impediments to widespread deployment of connected vehicle technology?
4. What deployment challenges did you face on the Safety Pilot program?
5. What maintenance and operational challenges have you faced related to connected vehicle infrastructure?
6. What institutional challenges did you face during the deployment of connected vehicle technology?
7. Based on your experience, what technical challenges pose the greatest risk or barriers to future deployment?
8. Based on your experience, what institutional challenges pose the greatest risk or barriers to future deployment?
9. What skills, knowledge and experience are needed to successfully deploy and manage connected vehicle infrastructure?
   a. What skills, knowledge and experience would be needed by staff for deployment?
   b. What skills, knowledge and experience would be needed by staff for operations and maintenance?
10. What other resources do you have available to support this report (e.g., wiring diagrams, intersection plan sheets, technical specifications, special provisions, technical documentation, etc.)?
11. Who else should we meet with to obtain information for this report?
APPENDIX B

Typical Highway RSU Installation Plans
CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT CONSIDERATIONS:
Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs

---

**LEGEN**

**TABLE OF CONTENTS**

- Title Page
- Table of Contents
- Acknowledgments
- Executive Summary
- Introduction
  - Background
  - Objectives
  - Scope
- Literature Review
- Methodology
- Results
  - Preliminary Analysis
  - Detailed Analysis
- Discussion
- Conclusion
- Recommendations
- Appendix
- References

---

**ANN ARBOR DSRC VICINITY MAP**

**SHEET**: B-3

---
CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT CONSIDERATIONS:
Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs
CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT CONSIDERATIONS:
Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs