Lessons Learned: Deployment of Public Sector Infrastructure for VII/IntelliDrive℠

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Lessons Learned: Deployment of Public Sector Infrastructure for VII/IntelliDrive℠

1.0 Task Introduction
Parsons Brinckerhoff (PB) was tasked by the Michigan Department of Transportation (MDOT) to compile this document detailing the lessons learned by various individuals and organizations who have been involved in VII/IntelliDrive℠ infrastructure installations, operations, and maintenance. This document captures both the detailed and general lessons learned from early deployments of roadside infrastructure, but it does not cover on-board vehicle installations nor does it venture into the applications realm.

1.1 Interviews
As part of the evaluation, PB interviewed individuals across the spectrum of VII/IntelliDrive℠ deployments, including those involved with the U.S. Department of Transportation (US DOT) Proof of Concept Project, various state demonstration projects, and the New York World Congress deployment. Table 1 shows the participants interviewed, their employers, and the projects they helped deploy.

<table>
<thead>
<tr>
<th>Name</th>
<th>Employer</th>
<th>Deployments</th>
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<tr>
<td>Glen Davies</td>
<td>Road Commission Oakland County</td>
<td>POC and Oakland County, MI</td>
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<td>Walton Fehr</td>
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<td>Steve Galgano and John Onis</td>
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<tr>
<td>Frank Perry</td>
<td>Booz Allen Hamilton</td>
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<td>Emilio Sosa and Richard Lockwood</td>
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<td>Jeris White</td>
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Some interviews were conducted in person, and some were conducted via telephone. In all instances, a general introduction of the task was provided verbally to the interviewee at the onset of the interview, providing them with an overview of our scope and allowing them to focus their answers. Specific questions within the interviews were targeted toward that individual candidate’s experiences, although the comments in this report are an assemblage and not attributed to any one individual.
1.2 Document Organization

Section 2—IntelliDrive SM Background—Provides general information about IntelliDrive SM

Section 3—VII Deployment History—Discusses the most prominent deployments in brief detail

Section 4—Lessons Learned/Non-Technical—Reviews a variety of feedback related to non-technical issues, such as program management, concept of operations, and team communication

Section 5—Lessons Learned/Technical—Includes knowledge gained in the field and issues related to backhaul/back office

Section 6—Conclusion—Presents a closing summary of the lessons learned.

2.0 IntelliDrive SM Background

IntelliDrive SM is a suite of technologies and applications that use wireless communication standards to provide connectivity that can deliver transformational safety, mobility, and environmental improvements in surface transportation (Figure 1). The US DOT and private and public corporations have researched IntelliDrive SM to determine its potential benefits and costs of deployment. This multimodal initiative focuses on three main aspects of connectivity:

- Among vehicles—emphasizes applications to enable crash prevention among traveling vehicles
- Between vehicles and infrastructure—focuses on enabling safety, mobility, and environmental benefits
- Among vehicles, infrastructure, and wireless devices—provides continuous real-time connectivity to all system users

IntelliDrive SM safety applications can enable vehicles to be connected to a traffic operations center through a range of roadside devices and on-board units. These connected vehicles can use IntelliDrive SM safety applications to have 360-degree awareness of incidents and hazards that are out of their visible range. These types of applications can potentially reduce crashes in common trouble areas, such as sharp ramp curves and roadways up ahead that are affected by weather conditions. Vehicle-to-vehicle communications can also enable data sharing between connected vehicles and provide information about vehicle surroundings, such as the presence of bicyclists and pedestrians in the corridor. Warnings could be provided in more imminent crash situations, such as when a vehicle stops abruptly.

IntelliDrive SM mobility applications can provide a connected, data-rich environment based on information transmitted anonymously from thousands of vehicles connected to the transportation system. Transportation operation centers and DOT agencies can use the data from vehicles to better manage the roadway, including optimizing traffic signals and transit operations and more efficiently dispatch maintenance crews or emergency services.

IntelliDrive SM environmental applications include providing travelers with real-time information about traffic congestion and other travel conditions so that motorists can make informed decisions to reduce
their impact to the environment. Travelers may opt to avoid congested corridors and use arterial routes, take public transit, or cancel their trip altogether to be more fuel efficient and eco-friendly.

The US DOT IntelliDrive™ research program fosters advancements in transportation system connectivity in both the public and private sectors. The research focuses on refining the technologies that support systems and applications, testing their use in surface transportation, determining actual benefits in the field, and developing consensus standards that will ensure the interoperability of IntelliDrive™ applications and system components.

Figure 1: IntelliDrive™ Network

A major set of applications—active safety systems—detect potential hazards in a vehicle's path, even hazards that the driver does not see. The connected vehicle provides enhanced awareness at potentially reduced cost and offers additional functionality over autonomous sensor systems available on some vehicles today.

The unique characteristics of these applications demand a unique communications solution between vehicles and between vehicles and the roadside. Dedicated Short Range Communications (DSRC) is the medium of choice for communications-based active safety systems research based on the following:

- It operates in a licensed frequency band
- It is primarily allocated for vehicle safety applications by FCC Report & Order – Feb. 2004 (75 MHz of spectrum)
- Active safety applications require a secure wireless interface that can be developed for DSRC communications
- DSRC supports high speed, low latency, short range wireless communications
The IntelliDrive℠ system contains devices that can communicate from equipment located within participating vehicles to roadside equipment (RSE). From that point, data are communicated to several locations, including the Network Operations Center through preconfigured networking schemes. At the Network Operations Center, Advanced Transportation Management Systems (ATMS) and other types of 511 traveler information platforms are integrated into a main back office system. A method of data sharing between the vehicle and operations center is thus opened through this communication process.

3.0 VII Deployment History

Over the past five years there have been a number of laboratory research projects involving VII/IntelliDrive℠ and at least three major deployments. A brief overview of these is provided below. The lessons learned from these deployments, which are the primary focus of this evaluation, have been combined and are presented in the subsequent sections.

3.1 USDOT Proof of Concept

In 2005, the US DOT commissioned a program to test 5.9GHz-based DSRC communications between the roadside and vehicles called the US DOT Proof of Concept (POC). The intent of the POC was to verify that data can be shared to and from connected vehicles and across an infrastructure of roadside devices and traffic operations centers in an accurate, timely, and useful manner.

The POC was located in the cities of Novi and Farmington Hills within Oakland County, Michigan (the northwest suburbs of the Detroit metropolitan area). In total, 55 RSEs were installed within the two cities covering a 45-square-mile area. A communications network was established with 27 vehicles configured with on-board equipment (OBEs). A small number of applications were also developed and used to test the functionality and performance of the VII communication system. A visual of the POC locations in Michigan is shown in Figure 2.

Several key players were involved in the POC project. Booz Allen Hamilton was the project manager and was responsible for the design and build of the infrastructure, as well as development of the network services. The Road Commission for Oakland County (RCOC) was selected to install the roadside devices for 3G and WiMax-enabled back-haul devices, as well as provide the power necessary for the RSEs on county-owned traffic signal poles. RCOC also provided personnel to coordinate technical support for the service providers. Booz Allen Hamilton performed the integration, configuration, and testing of the roadside devices and backhaul methods setup by RCOC. AT&T installed T1s for back-haul at those intersections not covered by RCOC. The Michigan Department of Transportation provided contractual services, coordination, and data exchange.

Two additional parties, Kapsch TrafficCom and Raytheon, were also involved in the POC. Kapsch TrafficCom (at the time of installation called Technocomm) provided the hardware platform for Raytheon and Booz Allen Hamilton to integrate. Finally, Noblis is now under contract with the US DOT to facilitate transition of the POC to a permanent operations and maintenance contractor. Once this contractor is in place, Noblis will remain involved in an advisory capacity.
3.2 New York World Congress

In November 2008, the New York State Department of Transportation (NYSDOT), New York City Department of Transportation (NYCDOT), Kapsch TrafficCom, Delphi, and other public and private entities teamed together to demonstrate the capabilities of IntelliDrive™ at the annual ITS World Congress conference, which was held in New York that year. Two separate demonstrations were developed, one in Manhattan and one on Long Island. Twenty-five unique arterial and freeway locations were sited for RSE deployment by the team to demonstrate comprehensive DSRC applications, including, but not limited to, the following:

- Intersection Safety
- Travel Time Information
- Incident/Construction Information
- Parking Information
- Multimodal Information—Transportation System Warning
- Real-Time Flight Updates
- Transit Signal Priority
- Congestion Pricing, Toll Collection
- Off-Board Navigation
- Electronic Payment
- Emergency Vehicle Preemption
- Data Transfer (Video, Map Updates)
- Real-Time Weather Updates

Each member of the team had specific roles and, in some cases, overlapping responsibilities:
- NYSDOT — Procurement of RSE radios; software development and installation of Service Delivery Node (SDN) in back office; procurement of equipment for backhaul; and coordination and oversight of ATMS server integration and probe data testing
- NYCDOT — Identification and installation of RSE radios; procurement of equipment for backhaul; and coordination and oversight of ATMS server integration and probe data testing
- Kapsch TrafficCom — Provision of RSE equipment; oversight of RSE software development; and guidance regarding RSE installation to installers
- Delphi — Responsible for OBE system functionality, design, software development, and interoperability

### 3.2.1 Long Island Deployment

The DSRC deployment in Long Island was led by the NYSDOT. Emilio Sosa and his team were responsible for the Long Island demonstrations, which included 22 RSE DSRC radios. The team chose nine RSEs to be integrated with existing traffic signals to demonstrate several arterial applications (signal connectivity facilitated by Naztec’s Apogee software and its compliance with NTICP 1202 version 2). The remaining 13 RSEs were deployed on the Long Island Expressway. Locations on the expressway were selected based on power availability.

All sites were integrated to have some backhaul method, either through a Code Division Multiple Access (CDMA) 3G data network or through NYSDOT backbone fiber connections. In locations where there was no available fiber backbone, new conduit and fiber were laid in the ground and necessary interconnections were made with existing infrastructure. Signal Phase and Timing (SPaT) details were collected and distributed across the developed network from the nine locations integrated with existing traffic signals. The system deployed in Long Island was stable, and all of the devices and core infrastructure are still in place today. The NYSDOT developed the service delivery node (SDN) for deployment in Long Island & Manhattan, which integrated into their existing INFORM system (Figure 3).

![NYSDOT INFORM VII System Architecture](image-url)
3.2.2 Manhattan Deployment
The deployment in Manhattan was led by the NYCDOT. Steve Galgano and his team were responsible for the Manhattan demonstrations. The deployment included 20 controllers that were installed in a continuous route around the ITS World Congress conference centre. The team developed applications that demonstrated all of the similar features from the Long Island demonstration, including travel time, multimodal information, over height/overweight warning, and in-vehicle variable message signs, among others.

A primary difference in how the information in Manhattan was distributed to the head office compared to the Long Island deployment was the use of backhaul methods. The NYCDOT team used the state-owned network that runs on a 3G cellular network similar to that of EVDO (evolution data optimized).

The installation and integration were primarily done by the NYCDOT with help from Kapsch TrafficCom to troubleshoot the first few installations.

3.3 Northern California Deployment
In 2004, Partners for Advanced Transit and Highways (PATH), part of the University of California, Berkeley, worked under contract to the California Department of Transportation (Caltrans), along with other public and private universities and agencies, to design a DSRC deployment and test the applications of VII in the San Francisco Bay Area and the development of software interfaces between the OBE, RSE, and 511 Message servers.

The partners for the VII deployment in California each had specific roles and, in some cases, overlapping responsibilities:

- PATH—RSE radio identification, software development, and installation
- MTC—Procurement of communications equipment for backhaul, coordination and oversight of 511 message server integration, and probe data testing
- Caltrans—RSE procurement, coordination, and oversight of RSE software development and RSE installation
- Telvent Farradyne—Backhaul communications, 511 message server integration, and probe data testing
- Daimler Chrysler—OBE system functionality, design, software development, and interoperability
- Volkswagen of America—OBE system functionality, design, software development, and interoperability
- Navteq—Integration and interoperability with the Innovative Mobility Showcase (IMS)
The first system came online in District 4 (US-101/Ontario). The University of California, Berkley co-installed all of the equipment in partnership with Caltrans staff. The team developed applications for the deployment to showcase capabilities within VII, such as tolling and integrated transit applications, Cell Phone Automatic Vehicle Locator (AVL), integration with AC Transit (serves the Bay Area), Signal Priority Applications, and the use of SPAT. Mercedes Benz and other auto manufacturers funded these applications.

Originally more than 40 RSE devices were procured for this project, but only five are working today in the field. Many of the RSEs remain in the lab, new and unused. Funding resources for the advancement of IntelliDrive℠ in California has come to a halt. Federally funded options are being considered, but they will require additional stakeholder support to jump start the program in California.

3.4 Road Commission for Oakland County DSRC Deployments
The Road Commission for Oakland County (RCOC) has completed several DSRC deployments. The largest was a deployment between M-102 (8 Mile Road) and 14 Mile Road along US-24 (Telegraph) in Oakland County. In addition, there were earlier deployments of VII for Chrysler World Headquarters in Auburn Hills, Michigan, and a small deployment along I-696 between US-24 (Telegraph) and I-275. The I-696 deployment is not currently operational.

4.0 Lessons Learned/Non-Technical
The biggest lesson from this research effort is that the non-technical issues of a project or program often dictate its outcome. The following section is focused on issues and lessons learned that did not occur while crawling inside a cabinet, up a pole, or inside a computer at an operations center—but nevertheless had a direct impact in many instances on the success or failure of a particular aspect of the deployment.

Summary of Non-Technical Lessons

- Use the Systems Engineering “Vee”
- Determine requirements of the entire system prior to deployment
- Make sure the project’s scope is clear and consistent over the life of the project
- Use the scope to identify appropriate resources needed and roles/responsibilities
- Develop project management and controls to mitigate funding issues
- Understand the differences between DSRC deployment inspection and traditional highway design and construction
- Choose a project team carefully
- Include a good communication plan as part of the project plans
- Clearly identify key program champions
4.1 Follow the Systems Engineering Process

Systems engineering reduces the risk of schedule and cost overruns and increases the likelihood that an implementation will meet the users' needs. Other benefits include the following:

- Improved stakeholder participation
- More adaptable, resilient systems
- Verified functionality and fewer defects
- Higher level of reuse from one project to the next
- Better documentation

These assertions have been supported by several studies that show good systems engineering can result in better cost and schedule performance.

Use the Systems Engineering "Vee". When deploying any kind of transportation project, especially with technology involved, it is imperative that a defined process be followed throughout the project duration (see Figure 4). A lack of rigor was a common issue for all of the VII/IntelliDrive\textsuperscript{SM} deployments, but especially in the case of the POC. Several interviewees mentioned a lack of rigor/process when it came to the POC as a reason why that project struggled at several points. Standard operating procedures were developed, but not all stakeholders were engaged in their development, such as would have been achieved with a Concept of Operations. Functional requirements were proposed, but performance metrics to evaluate whether the requirements were met were missing in many instances. At least one individual mentioned a lack of independent validation and verification (IV&V) at several important steps in the project.

The most common remark was that the many different parties involved in the project were not “reading from the same sheet of music,” thereby resulting in delays and missteps at several points in the effort.

The scope of the POC was broad and intended to test a wide number of variables. One individual made it clear that, “you can't test that many things without more rigors in the project management.” In fact, the authors of this report learned that performance requirements for the POC are just now being developed as part of the hand-off to a permanent contractor. This should have been done before the first RSE was deployed.

Determine requirements of the entire system prior to deployment. As IntelliDrive\textsuperscript{SM} deployments become more widespread, a determination must be made about who will operate and maintain the Service Delivery Node SDN. What are the procedures and plans for upgrading the system and performing routine checks for field equipment connections? Specifying procedures for security and reliability will be critical to the success of the deployment. Specific questions about who will manage the entire operation, the public sector or private sector, must be decided. All of this should be included in a well documented Concept of Operations and detailed requirements document.
A thorough Concept of Operations, as defined in the Vee, will force the development of collaborative requirements, helping reduce or even eliminate conflicts later in the deployment cycle.

Specific to DSRC deployments, one interviewee suggested that the OBE should not be identified as a critical link in the system because of the many variables beyond the control of a public agency. Instead, the government agency should focus its energy on building a robust RSE-SDN-ENOC system and the private sector should build OBEs that can work with this system (ENOC = enterprise network operations center). This is a common theme in the standards arena where the private sector often prefers that the government agency establish a benchmark or infrastructure system, stick to it, and let the private sector work with it. This is a proven and better method than a lengthy collaboration effort where everyone must agree on a benchmark.

4.2 Project Scope
A project’s scope is the total sum of all of its expected products with their requirements or features.

Make sure the project’s scope is clear and consistent over the life of the project. Throughout the interview process, several individuals mentioned that the POC, by its scope’s definition, was a research project. The original intent as discussed among VII Working Group Members and as presented during the early stages, was that the POC was going to be THE test and demonstration that ultimately led to full deployment. The expectations among participants were high, and communication with stakeholders did nothing to diminish that expectation. The reality, however, is that the scope evolved into more of a research program as it unfolded. And while the key players involved gathered a lot of information
throughout the POC deployment, it serves as a poor frame of reference for future deployments to depend upon. More than one individual stated, "the POC was a research project in which the team took on too much and too complex of a task for a first-time deployment."

The POC’s scope was also revised about half way through the project because of a personnel change at US DOT. According to one interviewee, in the end a commercial system was being developed based on the direction of stakeholders rather than the proof of concept that was originally intended. Another interviewee felt that the mindset for the entire POC was research, and there just wasn’t any long-term O&M vision behind it. Therefore decisions that were made during the design, development, and installation phases may not be representative of real-world conditions.

Alternatively, one individual cited that the POC, in its research capacity, provided “a great avenue for companies to break into the market and therefore consequent deployments have been more efficient and have gone much smoother.” For example, the New York World Congress deployment benefitted greatly from lessons learned during the POC, and it could follow that future deployments will continue to improve as a result of sharing lessons learned.

"Was it Research or Deployment? The POC was a research project in which the team took on too much and too complex of a task for a first-time deployment."

**Use the scope to identify appropriate resources needed and roles/responsibilities.** In the case of the POC, the project scope also defined roles and responsibilities for the individuals involved. The question arose in multiple interviews, “Were the correct parties involved in the deployment?” Many individuals had a similar take on this question, and one individual stated, “according to the definition of the system (POC) the correct parties were involved; but in hindsight the underlying premise used was wrong and thus more stakeholders should have been involved.” That individual was implying that public agencies as a whole need to be more involved in planning and developing the deployments and providing input regarding which systems and protocols should be in place for seamless integration.

**Develop project management and controls to mitigate funding issues.** Because the POC was federally funded, the money was distributed in a specific way. Because of some unfortunate procurement circumstances, it took more than six months for funding to be approved, which required vendors and suppliers to work at risk during that period. Despite procurement delays, the deployment schedule was not altered to account for the delayed budget approval. Some of the private companies struggled to stay within their given budget and ended up losing as much as $1 million on the project because of a lack of communication and providing support that was not originally within the scope. For VII California, funding (or lack thereof) has resulted in a temporary shut-down in new installations or maintenance of existing field devices. The program continues to develop, but a halt in expansion, according to one interviewee, could impact future initiatives.

**Understand the differences between DSRC deployment inspection and traditional highway design and construction.** Another interviewee pointed out that the traditional rule for transportation construction is that approximately 10 percent of the effort goes toward inspection; however, given the high-tech
nature of DSRC deployments, perhaps as much as 20 to 25 percent should be set aside for ample inspection, testing, and evaluation. This could require a culture shift for some agencies accustomed to setting aside a set portion of funding for different elements of a project or program.

4.3 The Team

A project team is more than a group of individuals assigned to work on one project. It is a group of interdependent individuals who work cooperatively to achieve common project objectives. The effectiveness of the project team can make the difference between project success and failure.

**Choose a project team carefully.** Specific to the POC, one individual stated, "it’s important to have the right team on board. Some of the players had never worked together before, and personalities might have gotten in the way of cooperation. Again, without a strong rigorous process, the personalities could affect the outcomes of efforts."

It was acknowledged that the POC integration went "okay but was laced with multiple difficulties due to the amount of companies and individuals involved in the efforts." Several individuals mentioned that their companies were sometimes forced to work together when in some cases they had competing agendas. The POC had an official integration contractor, but the process didn’t define a specific “integration team” that included all the stakeholders; therefore some key players felt left out of the integration effort. Individuals interviewed felt that if a team was more formally established, communication and coordination may have gone more smoothly.

One of the successful elements cited several times in regard to VII California was the strength of the team and how well everyone worked together. More than one individual noted that Caltrans district personnel allowed PATH personnel to have access to signal cabinets and perform installations, a practice unheard of prior to this effort.

**Include a good communication plan as part of the project plans.** One interviewee stated in regard to the POC and other various RCOC installations, “we need to keep the lines of communication open between vendor and the client through the installation process and engage stakeholders early on.” He felt that if the installer engaged the vendor early on, some installation issues may have been resolved prior to implementation and would not have required the replacement of the radios and the extended troubleshooting timeframes. It is also imperative that regular progress meetings be scheduled. The formation of an integration team might have fostered such a schedule. In many instances, items were not completed in a timely manner causing delays in other parts of the project because of the lack of communication and commitment.

The New York World Congress deployment benefitted from the presence of a strong project team that communicated often and effectively. Although multiple parties were involved, budgets were stretched, and timelines looming—just as with the POC—all parties indicated that the New York deployment went much more smoothly because each team member (and organization) had defined tasks assigned, open lines of communication, and a unified scope of work.

"The POC did not have an official integrator team defined...in some cases there were competing agendas among the companies working together."
Clearly identify key program champions. Multiple individuals stated the importance of having a program champion who leads the way at the state and national levels. Two specific individuals were mentioned as influencing progress: Kirk Steudle (Michigan DOT) and Randy Iwasaki (Caltrans). The strong support for VII/IntelliDrive\textsuperscript{SM} at higher levels can often push projects forward, obtain funding for additional research and development, and promote education on the subject. Strong champions at their level can also help provide much needed staff resources, buy-in from stakeholders less familiar with VII/IntelliDrive\textsuperscript{SM}, access to right of way and maintenance of traffic, etc.

Several individuals expressed the need to start educating local agencies now rather than later so they will be prepared when IntelliDrive\textsuperscript{SM} is ready for implementation on a larger scale. More champions at the state level should be cultivated. With the recent departure of Iwasaki, the urgency in California is ever present. Similarly, Michigan will soon hold a gubernatorial election that could result in the replacement of Steudle next year, thereby removing the second big champion. Once again the question of the Systems Engineering process came up in this regard—a rigorous process could go a long way toward withstanding a change in leadership, but a sloppy process will crumble in the face of champions being replaced.

"A rigorous process can withstand changes in leadership, but a sloppy process will crumble in the face of champions being replaced."
5.0 Lessons Learned/Technical

A number of technical issues related to DSRC deployment have been well documented in other reports, so the intent of this summary is to focus on those issues identified by the interviewees as “critical for the future” and, where applicable, to connect non-technical hurdles to technical hurdles.

5.1 In the Field

The RSE used in the various deployments is a critical element for communicating via DSRC. The RSE device is the primary component that sends and receives data from multiple devices within the IntelliDrive™ architecture. The RSE communicates with the OBE and sends and receives information about road conditions, traffic conditions, etc. The RSE, also through various backhaul network schemes, translates data to the Network Operations Center (NOC) for operational usage and various systems interconnections, thereby enabling the vehicle-to-infrastructure communication. It is intended for, but not restricted to, installation at a fixed location on the roadway. A majority of the lessons learned specific to the RSE can be directly related to a lack of a rigorous Concept of Operations and up-front process planning by all affected participants.

### Summary of Technical Lessons—In the Field

- Develop physical interface requirements to reduce installation complexity of the RSE
- Ensure ALL coupler/cable connections are weatherproofed and outdoor-rated
- Place serviceable parts of the RSE at a height that maintenance staff can reach without the need of a bucket truck
- Discuss design with local agency and installers to ensure it is appropriate for mounting and serviceability of devices unique to that location
- Install extra Ethernet connections to allow for maintenance and serviceability of field equipment
- Evaluate conduit capacity prior to installation
- Investigate conduit contents ahead of time
- Inventory of existing controller types before implementation
- Provide multiple recovery techniques for RSE designs to minimize down time
- Review overall design of RSE field deployment to reduce points of maintenance and failure

5.1.1 Cable and Connector Designs

**Develop physical interface requirements to reduce installation complexity of the RSE.** The Detroit POC team experienced problems when trying to use different cable types with the three backhaul types (3G, WiMax, and T1). Every backhaul method had a different pin-out on the cable side that required re-engineering the cable. The team eventually standardized the cable so that two of the backhaul methods
(3G and WiMax) used the same pin-out. At locations where T1 backhaul was used, a jumper connector cable was required to make the connection. The development of physical interface standards for the various communication alternatives can help reduce complexity during installation of the RSE, resulting in increased flexibility and interchangeability between sites.

**Ensure ALL coupler/cable connections are weatherproofed and outdoor-rated.** During the POC deployment, environmental protection of the RSE became a big issue. The RSEs were not tested in a lab to be environmentally hardened and to be able to withstand Michigan weather. The device’s manufacturer used a sun shade for the device in states where increased sunlight was present. This is generally not an issue for Michigan because it receives less sunlight in winter and would not require it year round. However, the RSE models that were used had sun shields that were manufactured on the radios, which caused more of a problem.

Unfortunately, snow would get packed in the sun shield, which sits directly above the exposed data connectors. A heating mechanism in the RSE would melt that snow and cause water to enter the case of the RSE via the data connections. Many problems arose as the RSE stopped working in its intended environment. Eventually a protective hood was created to cover the RSE to ensure water would not enter the equipment. For the New York World Congress deployment, installers wrapped all connections with weatherproofing tape and putty to increase the RSEs' resistance to environmental elements. As a result, no RSEs developed any major problems related to environmental protection and therefore did not require a special shield from adverse weather.

**5.1.2 Maintenance and Operational Need**

**Place serviceable parts of the RSE at a height that maintenance staff can reach without the need of a bucket truck.** The Detroit POC originally mounted the RSE at a height of 25 feet. This height was too high for maintenance workers to access the radios from a ladder; a bucket truck was therefore required. Further investigation determined that the RSE equipment could sit at a height that is acceptable for maintenance, such as 10 feet, and the antennae would sit at 25 feet. At the World Congress in New York, mounting heights were not a major concern for accessibility because the radios and antennas were installed at 14 feet and 17 feet, respectively.

Discuss design with local agency and installers to ensure it is appropriate for mounting and serviceability of devices unique to that location. During the World Congress deployment in New York, the integration and installation team found a problem with the mounting brackets that were shipped for the RSE. An incorrect size and material were provided for the brackets allowing the RSE to only be installed vertically. Some locations required a horizontal installation based on pre-existing conditions. Proper communication during the design stages could have prevented this situation.

"Sun shields on RSEs aren’t needed in Michigan—and instead they caused more problems than they prevented."

"If we had followed the Systems Engineering process and engaged all the stakeholders, we would have discovered early that some locations required a horizontal mounting and therefore different hardware to properly secure the RSE."

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Install extra Ethernet connections to allow for maintenance and serviceability of field equipment. When installing field equipment such as RSEs, extra Ethernet connections should be provided so maintenance workers have an easier way to test and resolve field issues. In the New York deployment, two Ethernet connections were installed at each location; three were installed for locations that were integrated with traffic signals. One connection was used for SPAT (traffic signal location); one location for network communication; and one was reserved for testing. Technicians did not need to climb up to conduct network/configuration testing at each location because of the Ethernet connection that is accessible from the ground.

5.1.3 Integration with Existing Infrastructure
This section highlights the need for deployment plans that include location surveys and implementation requirements.

Evaluate conduit capacity prior to installation. In both the POC and VII California, existing infrastructure was targeted for use. In many instances, however, the conduit tubes were at or near capacity (defined in most instances as one-half full). Because of this, the electricians did not want to pull any more cables through the conduits because they feared damage to both the existing and new cables. Appropriate design work will increase the overall cost (dollars and time) during the planning and design phase, but this could prevent major problems in the future. Unfortunately, additional planning and design ultimately might be unable to overcome the even larger challenge of laying new conduit if that becomes necessary because of a lack of real estate, funding, and resources.

Investigate conduit contents ahead of time. Another issue encountered while running the lines is that signal wires and power wires cannot be mixed. Several experts that were interviewed point to this as an important variable in determining cost/benefit analyses. Not only is it difficult to make broad assumptions on conduit capacity, but conduit contents must be known to properly assess whether new conduit must be laid or existing infrastructure can be used. For several installations in VII California, experiments with using fiber optics to run energy to the cabinet were conducted. In the cabinet the electrical energy was converted to light and then sent to the controller where it was converted back to electric. This proved very unreliable.

"Not only is it difficult to make assumptions on conduit capacity, but the contents must be known to properly assess whether or not new conduit must be laid or existing conduit can be utilized."

Inventory existing controller types before implementation. New hardware and software for traffic signals needed to be developed for the New York World Congress deployment. The team determined during deployment that the legacy electro-mechanical controllers would not work with the applications. The team used the NEMA TS2 controller because it could integrate with the software and had the necessary conformance with NTCIP. This should be noted for future deployments as many locations across the country will need to update their signal controllers before installing a DSRC network or even individual DSRC sites at signalized intersections. The VII California team noted the monumental challenge in coordinating an upgrade to signal controllers just in California. Of the roughly 40,000 signalized intersections in the state, Caltrans owns only about 5,000,
and the rest are owned, operated, and maintained by more than 58 counties and nearly 500 cities. A program to upgrade controllers at that scale is a huge challenge, not to mention the follow-on step of integrating DSRC once the new controllers are installed.

5.1.4 Remote Recovery

**Provide multiple recovery techniques for RSE designs to minimize down time.** The Detroit POC team noted some RSEs would occasionally freeze up and require a manual reboot. This reboot was unable to be completed from the head-end and would require a technician to visit the site every time an RSE would freeze up. This task became cumbersome as the frequency of occurrences increased. Technicians were sent out every two weeks to reset RSEs. Regression testing for system operation was completed in the lab prior to deployment and was left on for eight hours, but a 24/7 test was not completed to detect this issue prior to deployment.

“RSEs used in New York City required far less rebooting than the POC—manufacturers are getting better at this quickly.”

To remedy this issue, the group used power modules to reboot the equipment from an office or any location that could remote into the site. This eliminated the need for technicians to visit each site but did not permanently fix the problem. Newer designs of RSE equipment should provide multiple recovery techniques to minimize the amount of time spent in the field and down-time operations.

The New York World Congress deployments did not experience this issue, which leads to an assumption that the POC RSEs were early generation devices and the manufacturers may have corrected the bigger problem. Further bench and field testing would be required to verify this assumption.

5.1.5 Field Deployment Design

**Review overall design of RSE field deployment to reduce points of maintenance and failure.** The basic RSE field deployment in both the POC and New York installations included five different primary components: RSE computing platform, RSE power supply, terminal server, main power supply, and backhaul modem. The design was intended to promote the maximum possible uninterrupted operation of RSE-OBE communication should the backhaul or terminal server components fail.

However, some interviewees pointed out that the downside of this design is that there are now five possible points of failure and five possible points of ongoing maintenance that could increase O&M costs and resource needs. At least one individual suggested that future designs should re-examine this approach and consider whether a new design could still accomplish the goal of maximum up-time for RSE-OBE communication while reducing possible points of failure and maintenance.

"Any system that includes as many as five points of failure is a system with potential problems."
5.2 In the Vehicle
The OBE communicates with the RSE and is intended for, but not restricted to, installation in or on a motor vehicle. Auto manufacturers and several private and public entities were responsible for the integration and development of the OBE that resided in all of the test vehicles. Once again, a failure to rigorously follow the systems engineering process uncovered a number of key lessons for the future.

Summary of Technical Lessons—In the Vehicle

- OBE manufacturers and RSE manufacturers should perform factory testing prior to deployment of devices.
- Algorithms should be developed within the OBE to choose the strongest RSEs for data transmission.
- Vehicle equipment messages should be standardized and additional development should be performed.

5.2.1 Communication to RSE
OBE manufacturers and RSE manufacturers should perform factory testing prior to deployment of devices. The development of the OBE should be done in a coordinated manner with RSE manufacturers and stakeholders to ensure that all firmware developments and features integrated by each vendor match. OBE manufacturers need to develop firm requirements to successfully test products prior to shipment. In at least one instance, an interviewee noted that poor communication between responsible parties led to significantly longer troubleshooting time-frames. Such issues can be reduced when manufacturers implement better quality assurance testing requirements. Following the systems engineering process and developing a strong Concept of Operations would have identified the need to perform such testing and would have included a complete IV&V process.

Algorithms should be developed within the OBE to choose the strongest RSEs for data transmission. The data transmission from OBE to RSE is an important transaction for IntelliDrive™. The RSEs are deployed in such a way that there is an overlap in coverage. As test vehicles drive through the corridor, the OBE recognizes multiple RSEs with similar signal strength, giving the OBE a short amount of time to negotiate which RSE to communicate with. Currently the selection is done solely on signal strength, as this is typically the first point of communication between devices. This, however, can cause problems when overlapping RSE coverage is present. The Detroit POC experienced garbled transmissions and dropped connections as a result of overlapping coverage. The OBE would start to transmit packets with one RSE then quickly switch to another RSE when the signal strength increased, dropping the packets from the first transmission. The OBE should have some algorithms to select the RSE device with the lowest signal-to-noise ratio as well as signal strength. This type of algorithm may reduce the frequent change in RSE connections. This issue will become increasingly important in situations with closely
spaced intersections and the need for high geographic accuracy needed for intersection collision avoidance.

In New York, the team was able to modify how the OBE equipment selected the RSE to reduce the frequent switching issues (ping pong) between multiple RSEs. In general, no issues were encountered during the demonstration or deployment. In California, much testing was performed on the OBE, including packet loss, multi-path, and saturation experiments to ensure that problems with RSE overlap did not occur.

5.2.2 Standardization

Vehicle equipment messages should be standardized and additional development should be performed. At the time of deployment there was a lack of standardization from OEMs as to the type of messages the OBE could support. In one case, SPAT messages were unable to be developed for production because the devices were unable to understand the messages. All car manufacturers should agree on one standardization so parts of the systems can be standardized as well. All OEMs should be able to “talk the same language” so that, in the future, car manufacturers could perform upgrades (and introduce new applications) based on a standard system.

5.3 Backhaul

Multiple types of backhaul methods for DSRC deployment have been tested and successfully proven to be useful forms of communication between the RSE and the back office. As with lessons in other facets of the program, specific situations and environments often dictate different solutions, and a rigorous systems engineering and requirements analysis can document such situations.

Summary of Technical Lessons—Backhaul

- Use a licensed frequency band of WiMax to increase reliability and stability of the network
- Consider security and accessibility implications when choosing a backhaul method
- Use multiple backhaul methods to provide the best coverage and failure protection, although this also increases maintenance and support responsibility

5.3.1 Security and Reliability

Use a licensed frequency band of WiMax to increase reliability and stability of the network. In the Detroit POC, an unlicensed spectrum of WiMax was used for the backhaul communication method at 15 locations that provided connectivity at approximately 6Mbps. The throughput realized in the Detroit POC was able to handle the amount of data flow of current IntelliDrive℠ applications without experiencing any latency issues. The fact that it was unlicensed also meant no additional costs. However, unlicensed and unsecure networks are susceptible to attack and interference, hindering the reliability of the IntelliDrive℠ system. When considering WiMax as a backhaul solution, the cost of
using a licensed frequency should be factored into the decision matrix against the costs of other backhaul methods.

**Consider security and accessibility implications when choosing a backhaul method.** The NYCDOT used a private city wireless network (3G cellular, EVDO1) for its backhaul, which was attractive from cost (existing infrastructure) and security standpoints since the network was typically restricted to use by emergency vehicles, homeland security, and the NYCDOT.

Unfortunately, that same security benefit resulted in a challenge when partnered companies wanted to use the internet while accessing the network. As a result, only four companies were provided external access to the city’s private network, and four firewalls were put in place to allow the internet to speak with the radios as required by the application. Because of the sensitivity of the information and the potential security risk of the information being broadcast on the internet, the NYC team steered clear of 2.4 GHz radios, which traditional WiFi resides on.

### 5.3.2 Alternatives Analysis

Use multiple backhaul methods to provide the best coverage and failure protection, although this also increases maintenance and support responsibility. A direct fiber optic connection can carry a strong signal over a wide distance (depending on type), resulting in better quality transmission. Fiber cable is less susceptible to breaking when compared to copper and coaxial cable and provides a higher data throughput as compared to other forms of communication. However, if fiber does not exist it can also be the most costly of solutions up front. A thorough alternatives analysis—typically performed as part of the Systems Engineering process—would identify various situations within the specified deployment environment.

For the Long Island deployment, agency personnel were planning to install fiber for other ITS devices and were able to capitalize on the DSRC installation to “kill two birds with one stone.” In most instances, the fiber connection will also be owned, operated, and maintained by the agency as well, eliminating monthly recurring charges and complications with leased facilities. Unfortunately, not all agencies will have the ability to provide a direct fiber link (due to limitations in funding, real estate, conduit capacity, etc).

The Long Island deployment also included some 3G backhaul solutions that were extremely reliable, and thanks to a unique existing contract, the team was able to secure these services at an attractive monthly rate. Not all agencies will have this opportunity, and in some instances, the quoted rates were extremely unattractive.

The Caltrans/PATH team would have liked to use fiber optics for its backhaul method in California, but lines were not available in the area. T1 lines (leased from Speakeasy) were used, and the PATH team members were happy with the connection as it was low latency. The cost, however, can outweigh the benefit of using T1 lines, running close to $500 per month.

“This isn’t one shoe fits all, the backhaul method that is optimal in many instances is dictated by the environment and can be identified during the analysis phase of the project.”
Unlicensed WiMax is attractive from a cost perspective, but there are environmental (line of site) issues to contend with, as well as interference issues often beyond the agency’s control. The California team wanted to use the municipal WiFi that was in the planning stages but, unfortunately, that system never deployed due to contractual hurdles and VII California team members had to find other backhaul alternatives. Any use of municipal systems should consider the long-term viability of such a program.

5.4 Enterprise Network Operations Center and Service Delivery Node

The Enterprise Network Operations Center (ENOC) is used by system operators to control and manage the overall network and RSE suite. The Service Delivery Node (SDN) is composed of interfaces to the backbone (to other SDNs), the backhaul (to RSEs), and the Access Gateway (to network users), routing functions to properly direct message traffic and a set of core services.

Summary of Technical Lessons—ENOC/SDN

- Identify equipment by a static value, such as an intersection ID or some other pre-defined value
- Ensure all critical connections are monitored and tracked
- Create a standard for IntelliDrive™ components to interconnect to the back office
- Develop a process flow to clearly identify roles and responsibilities

5.4.1 Operations Center

This section discusses operations center requirements and their implementation in accordance with those requirements.

**Identify equipment by a static value, such as an intersection ID or some other pre-defined value.** In the Detroit POC, the ENOC identified the RSE equipment by serial number. However, this can create confusion when equipment changes. This requires NOC operators and network users to be notified in the event of a hardware change. During the systems engineering stage, a process should have been identified to help identify and track every asset in the field and back office.

**Ensure all critical connections are monitored and tracked.** Critical operations were implemented to be monitored by the NOC. An issue arose in the Detroit POC because everything was not being monitored. The intention was that all devices and RSE connections would be monitored via the NOC and that all critical personnel should have access to the NOC. Accurate and timely record keeping is essential for tracking all equipment and sites. All critical RSE connections (e.g., PDS/AMDS Brokers, SIT Tunnels, etc.) should be monitored via the NOC, and critical personnel should have access to the NOC.

5.4.2 Standardizing Back Office Operations

**Create a standard for IntelliDrive™ components to interconnect to the back office.** Very little work has been done to standardize the SDN and funnel information to the back office in a shared way. Each demonstration, the Detroit POC, New York ITS World Congress, and Bay Area Test Bed, used a different
means for developing an SDN. The NYSDOT wrote and developed software for the SDN prior to
deployment. There is also no concrete way that has been developed to identify components and
interfaces.

An ideal scenario would be if additional protocols and
global objects were defined in the NTCIP standard so that
multiple communicating products for the back office can
interact with one another, thereby eliminating the need for
recurring software development. Software development
would be required by vendors but only to interconnect with
a standardized system.

In California, automotive companies did not need an SDN because PATH developed its own data server
to output the information. In the Detroit POC, a Booz Allen proprietary system was developed, but
when the system was put into use in New York too many compatibility problems were discovered.
Instead, NYSDOT contractors successfully developed a separate SDN in a relatively short period of time.

Along with creating a standard for SDNs, requirements and performance metrics should be established
to evaluate how well the system is functioning. The System Engineering Process for ITS Design should
be followed for future developments of IntelliDrive so that a full set of user-defined requirements are
created and test programs are available to validate the main system works. Future deployments of
IntelliDrive\textsuperscript{SM} systems should run through rigorous testing of the SDN with multiple head-end
applications, multiple RSE vendors, and multiple OEM OBE manufacturers.

5.4.3 System Control

This section highlights the need for a Concept of Operations, along with the associated requirements,
plans, methods, and procedures.

**Develop a process flow to clearly identify roles and responsibilities.** In addition to the expected
jurisdictional concerns, questions concerning the control, operation, and maintenance of the system,
once deployed, will need to be addressed. These include the following:

1. Who is responsible for the various parts of the system?
2. What happens if the backhaul fails?
3. Who is in charge maintaining and operating the field equipment once it is installed?
4. Who is in charge maintaining and operating the back office equipment once it is installed?
5. If an application deals with safety (e.g., collision avoidance, stop time, etc.) who is responsible
   (liable) if a crash occurs? What if the system went down?
6.0 Conclusion

The lessons learned from these interviews provide a wide range of technical and non-technical suggestions to be considered. However, it is clear that adherence to a rigorous program management effort, relying on the systems engineering process as a guide, will help reduce or eliminate many of the challenges and hurdles encountered during some of the early IntelliDrive™ deployments. The evolution of VII/IntelliDrive™ will undoubtedly uncover new challenges, but already we are seeing progress and a sincere desire to not repeat mistakes.

The deployment of DSRC is still in its infancy. Many challenges encountered during the Detroit POC, as well as with VII California and the New York ITS World Congress, are not uncommon in situations where new technology is being implemented for the first time. These could, in some instances, be considered normal growing pains. However, some of the non-technical challenges are definitely within the control of all parties involved, and it is hoped that some of these lessons are taken into consideration and sincerely addressed for future deployments.
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