

CONNECTED VEHICLE INFOSTRUCTURE PLAN



**PARSONS
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Appendix A: Existing MDOT Fiber Optic Coverage and Fiber Priorities

EXECUTIVE SUMMARY

The potential deployment of a connected vehicle system will represent new challenges to State DOT's in terms of delivering an Infrastructure which can facilitate these systems and allow for the collection and processing of the vast amount of potential data. Given the potential Notice of Regulatory Intent (NRI) to be issued by the National Highway Transportation Safety Administration (NHTSA) in late 2013, the Michigan Department of Transportation (MDOT) is looking at what steps the organization can begin taking to prepare for this significant need.

If NHTSA announces an NRI in late 2013 (the current anticipated decision date), then connected vehicle technologies could be factory installed on vehicles as soon as the 2019 model year. Given the rate of change in connected vehicle research and equipment standards, as well as the timeframe to build fleet penetration, any premature deployment of RSEs would be high-risk and carry a high likelihood of required update or replacement at the time of full national deployment.

To this extent, it is recommended that MDOT strategically deploy communications infrastructure which can serve immediate department needs while preparing for the future potential of connected vehicles. Certain elements of the future roadside infrastructure are more easily phased in over time in anticipation of possible regulation, and can yield public benefit even without a connected vehicle deployment. For example, MDOT can adopt the following near-term deployment steps while meeting prioritization strategies for preparing for a connected vehicle de-

ployment:

- Backhaul Communications – Investment in the arterial network will be critical for backhaul of the connected vehicle data, and arterial traffic signal data to the traffic operations center prior to a connected vehicle deployment.
- Advanced Signal Controllers – Controller replacement, either strategically, or as part of programmed signal modernization projects should include IP-ready ports and NTCIP compliance for a full scale Connected Vehicle deployment while still achieving integration to new or existing Advance Traveler Management Systems (ATMS).
- Conduit Installation - Institutionalization of the installation of conduit as part of the upgrade of arterial roadways, much like the department has been successful in doing for a number of metropolitan area freeways.
- Data Management Planning – Development of detailed requirements and Concept of Operations in combination with or within a Statewide Data Warehouse Strategic Plan to establish the framework for an enterprise data warehouse integrating Geographic Information Systems (GIS), Asset Management and ITS datasets.

The level of penetration of On Board Equipment (OBE) in the vehicle fleet will also be an important factor for the prioritization strategy for MDOT. This penetration includes deployment of aftermarket devices in a low-turnover market such as State of Michigan fleet vehicles, and deployment of OBE equipment in high-turnover market such as leased vehicles.

INTRODUCTION

REPORT OVERVIEW

This report will provide a proposed framework for developing the Michigan Department of Transportation's (MDOT) Infostructure Deployment Plan and provide a roadmap for deployment within the state to prepare for the department's connected vehicle program. While no specific mandates or notice of regulatory intent (NRI) have been set forth by the National Highway Traffic Safety Administration (NHTSA) today, if NHTSA announces an NRI in late 2013 (the current anticipated decision date), then connected vehicle technologies could be factory installed on vehicles as soon as the 2019 or 2020 model year. It will be many more years after this deployment where newer vehicles will gain a significant penetration into the national vehicle fleet. In addition, the rapid rate of change in technology and anticipated refinement of system requirements means that any near-term deployment of roadside infrastructure comes at great risk, and is likely to be outdated by the time a full deployment occurs. To this extent, MDOT may desire to seek more immediate benefits by deploying enabling infrastructure which can also provide utility for existing systems.

The term *Infostructure* refers to the physical communications infrastructure, or leased communications services, which would facilitate a connected vehicle deployment. This term excludes communications devices and capabilities on-board vehicles, but instead focuses on roadside, backhaul, and back-office systems which would support the required network, facilitate security systems, and allow for data aggregation and management.

This report will touch on the following elements to help plan for Infostructure Deployment in Michigan in advance of a potential Connected Vehicle mandate. All initiatives will directly serve to improve MDOT's own infrastructure and capabilities of monitoring the traffic signal systems, while keeping pace with technological changes in the Connected Vehicle program.

The report contains the following:

- Institutional Roles and Responsibilities – Defines the various parties involved with a Connected Vehicle deployment and what roles each party will play in the pre-development stage of the program.
- Infostructure Elements – Discusses the elements that make up Connected Vehicle technology and how these elements will be leveraged in conjunction with MDOT infrastructure – specifically the Dedicated Short-Range Communications (DSRC) Radio Equipment, advance traffic signal controllers, backhaul communications, data management systems, and security/credential management.
- Prioritization of Deployment Strategies – Discusses recommendations for deployment strategies specifically targeting locations of greatest benefit; triggers that will drive the deployment need, and greatest likelihood of fleet penetration.
- Near-Term Deployment Steps – Discusses steps MDOT can take to prepare for a connected vehicle deployment, including but not limited to development of an arterial traffic master plan, signal controller modernization, and development of an arterial communication network.

INSTITUTIONAL ROLES AND RESPONSIBILITIES

Any future deployment of connected vehicle technologies will come as part of a coordinated effort amongst a large number of entities, each with their independent roles and responsibilities. As connected vehicle research has intensified in recent years, the model architecture for a national deployment, and with it the roles and responsibilities of both public and private entities, have become more evident. This section outlines these anticipated roles under a large-scale deployment based on current model architectures. (Figure 1)

USDOT

The United States Department of Transportation (USDOT) is taking a leadership role in the research and development of connected vehicle technologies in partnership with Original Equipment Manufacturers (OEMs) and suppliers. This role includes establishing standards and requirements for Roadside Equipment (RSEs), development and testing of safety applications, and the study and evaluation of both the effectiveness of and driver reaction to connected vehicle technologies. These roles have culminated in the development of the Safety Pilot Model Deployment, the world's largest live field test of connected vehicle systems currently underway in Ann Arbor, Michigan. The goals of the Safety Pilot are both to collect and analyze data to determine the effectiveness of connected vehicle technologies, as well as to test a scaled deployment of roadside infrastructure.

Under a national deployment scenario, it is expected that USDOT will have the following responsibilities:

- Establish requirements for roadside infrastructure, including DSRC radios and advanced signal controllers, which meet interoperability requirements with in-vehicle devices and security systems
- Develop and deploy a national security sys-

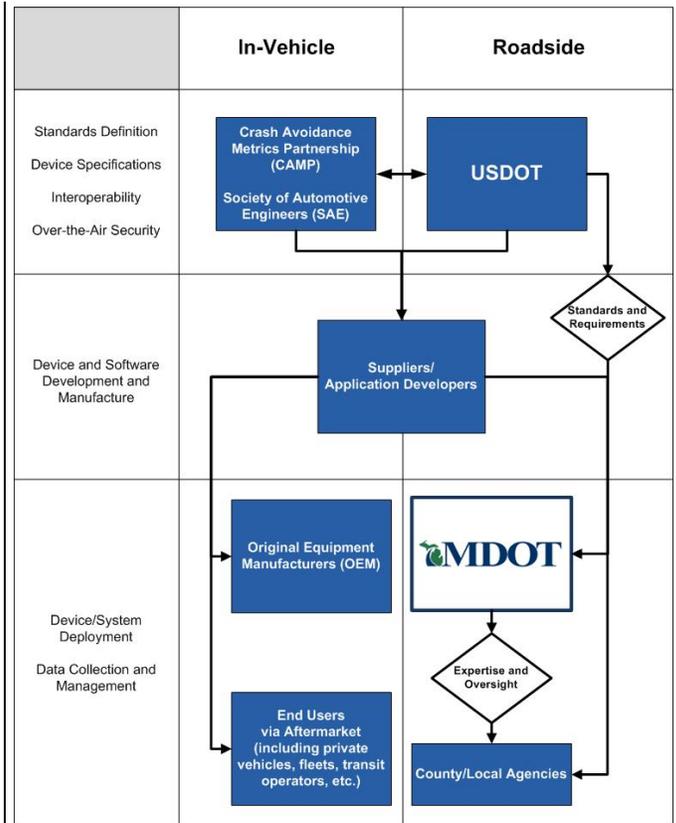


Figure 1: Roles and Responsibilities in a Connected Vehicle Deployment

tem which enables credentialing of both vehicles and roadside devices.

- Establish guidelines and requirements for safety applications to be followed by the private developers for on-board devices.
- Establish safety guidelines for in-vehicle alerts and displays.
- Establish guidelines and/or requirements for state and local agencies for deployment of roadside and security infrastructure to enable connected vehicle system functions.

MDOT

MDOT has been a leader in connected vehicle research, and in particular the study of how connected vehicle data could be used to improve MDOT's processes for traffic management, maintenance, asset management, and system planning. As connected vehicle research has advanced and matured, this role has continued to evolve, and has recent-

ly focused on supporting national-level research being conducted in the state as opposed to direct field test involvement.

Beyond the research and development phase, MDOT (and all state agencies) are envisioned to play a key role in the deployment of roadside infrastructure and systems, including conducting the following activities:

- Deployment of roadside infrastructure to enable connected vehicle integration.
- Deployment of backhaul communications infrastructure to accommodate data management functions as well as potentially security, depending on the final national deployment architecture.
- Support freeway deployments including integration of existing devices and technologies (Dynamic Message Signs (DMS), Microwave Vehicle Detection Systems (MVDS), and Curve Warning Systems) that will be used in conjunction with connected vehicle technologies.
- Installation/Maintenance and Operation of MDOT infrastructure (poles, existing devices, cabinets).
- Integration of On-Board Equipment (OBE) on MDOT fleet vehicles.

In addition, it is anticipated that data management and the use of data for public application would be the domain of each state agency for asset management, operations, maintenance and planning purposes. As such, MDOT would be responsible for the continued development of their Data Use Analysis and Processing (DUAP) system which is currently being developed to handle data management and data processing applications which serve the department's needs.

LOCAL AGENCIES

Much like State DOTs, it is expected that local agencies will be responsible for deployment, operation and maintenance of roadside equipment and communications for locations under their jurisdiction. The largest

element under local agency jurisdiction is likely to be connected vehicle infrastructure located at traffic signals, as the majority of the nation's traffic signals are managed or maintained by local agencies. Depending on the size and resources of the local agency, this function may be supported by MDOT or other larger local agencies through local agency program arrangements, much like inter-agency arrangements which currently exist for traffic signal system management and maintenance.

TRANSIT AGENCIES

Transit agencies are anticipated to have the following roles in a connected vehicle deployment:

- Retrofit of vehicles with OBE during initial deployment.
- Leveraging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications to supplement or replace existing systems such as Automated Vehicle Location (AVL) systems, route travel and arrival time systems, and transit signal priority.
- Many transit organizations do possess radio communications systems for both voice and AVL functions, including regional communication towers and other infrastructure. However, this infrastructure tends to be scaled for a limited fleet, and with limited transmission bandwidth, such that any extended use of these networks as part of a broad connected vehicle communications backhaul strategy is likely impractical.

COMMERCIAL FLEET OPERATORS

Commercial fleet operators are anticipated to have the following roles in a connected vehicle deployment:

- Retrofit of vehicles with on-board equipment during the initial deployment.
- Leveraging connected vehicle V2V and V2I communications to supplement or replace existing systems such as AVL for fleet management and navigation.

OEMs AND SUPPLIERS

Although it remains unclear the extent to which user interfaces and applications may be required or optional equipment it is expected that OEMs will have the principal role in the long-term deployment of DSRC technologies into new vehicles. The OEM consortium known as the Crash Avoidance Metric Partnership (CAMP) has produced prototype fully-integrated vehicles with on-board safety systems for use in current connected vehicle testing in conjunction with USDOT. This process has yielded common standards and interoperability between in-vehicle and roadside equipment for the purpose of evaluating safety applications. This equipment has been supplied to the OEMs from a number of suppliers.

While development of user interfaces for mobility and other potential connected vehicle applications are not yet mature, it is expected that OEMs and their suppliers will further develop these once a deployment decision is addressed.

AFTERMARKET DEVICE VENDORS

Aftermarket suppliers are likely to have an

important role in any early deployment of connected vehicle systems, as the timeframe for equipping vehicles strictly as new equipment is widely seen as too long to support a connected vehicle roll-out.

Aftermarket Safety Devices (ASD) have been developed for use in current connected vehicle testing which provide a user interface and in-vehicle information and safety alerts to drivers. In addition, it is not yet fully clear the role that other mobile devices, such as mobile phones, may play in bringing connected vehicle applications into vehicles.

APPLICATION DEVELOPERS

Application developers will have several roles in a connected vehicle deployment:

- Development of regulated safety applications which must have common traits and algorithms.
- Development of commercialized applications for mobility, entertainment, etc. for use with a connected vehicle network.
- Development of data management and processing applications for both public agencies and OEMs to evaluate and process connected vehicle data.

INFOSTRUCTURE ELEMENTS

CONNECTED VEHICLE OVERVIEW

A connected vehicle 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 2). The US DOT and private and public corporations have researched connected vehicles to determine its potential benefits and costs of deployment.

The US DOT connected vehicle 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 connected vehicle applications and system components.

Some of the main elements of the connected vehicle system architecture include:

- DSRC Roadside Equipment
- Advanced Signal Controllers
- Backhaul Communications Network
- Data Management Systems
- Security/Credential Management

DSRC ROADSIDE EQUIPMENT

The RSE component is the critical element in the connected vehicle network for V2I communications. The RSE device is the primary component that sends and receives data from multiple devices within the connected

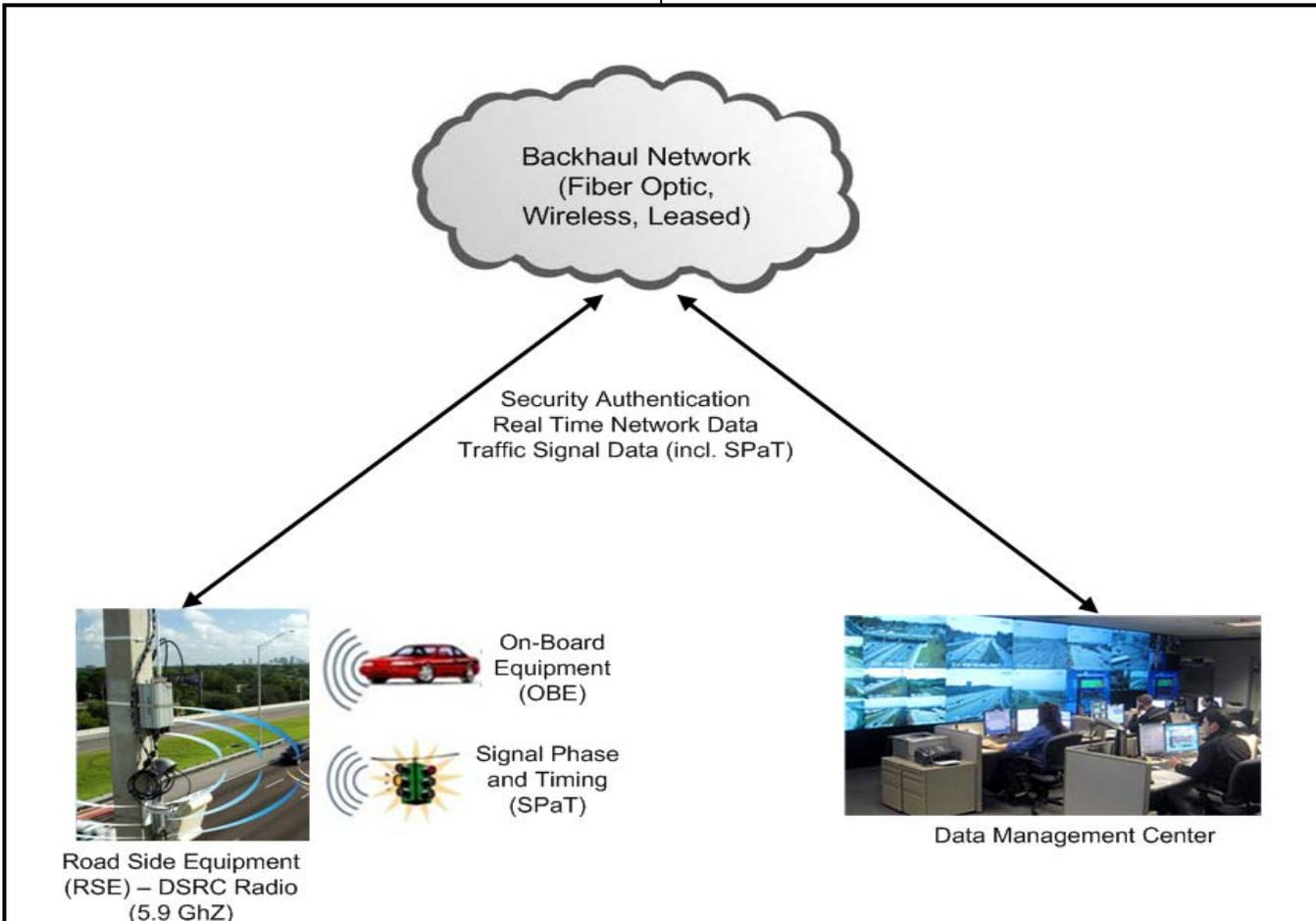


Figure 2: Connected Vehicle Network

vehicle architecture. The RSE communicates with the OBE and sends and receives information about infrastructure based conditions, such as Signal Phase and Timing (SPaT) and geographic-based data for safety applications. The RSE also plays a critical role in the security system architecture, as well as serving as the key gateway to log and transmit data from OBEs to central data collection points.

The RSE communicates to vehicles using DSRC, which 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 the Federal Communications Commission (FCC) Report & Order – Feb. 2004 (75 Megahertz (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

There have been several successful trials of DSRC RSEs for connected vehicles in the United States over the past five years. The capabilities of these devices have improved interoperability of the units with various OBE modules and back-end systems. Further development of roadside equipment is anticipated to continue until full-scale deployment is planned.

DSRC RSE is intended for, but not restricted to, installation at a fixed location on the roadway. The units can be installed on freeway or arterial roadways using existing or proposed roadside infrastructure. For freeway applications, the DSRC equipment can be co-located with any MVDS strain poles, spun-concrete poles and DMS structures. For arterial applications, the use of traffic signal strain poles and mast arms provide a high degree of flexibility to provide coverage through an interchange. The use of bi-

directional or omni-directional antennas on these structures provides capability to cover four-way direction of traffic leading into the interchange.

ADVANCED SIGNAL CONTROLLER TECHNOLOGY

Traffic signal controllers play another critical element in the connected vehicle architecture by providing capability to transmit SPaT data to approaching vehicles for a host of safety and mobility applications. SPaT information includes the signal phase (green, amber, or red) and the amount of time remaining until the change of the phase for each direction of travel (approach) and lane at the intersection. This information can be used in applications to help increase fuel efficiency, safety, and mobility for all road users.

The use of advanced signal controller technology will enable future integration of a connected vehicle system. Controllers that are Internet Protocol (IP)-based enable seamless communication with connected vehicle systems that are all currently IP-based.

In addition the use of SPaT-enabled signal controllers, the implementation of National Transportation Communications for ITS Protocol (NTCIP) based communications at the traffic signal controller achieves greater ability for interoperability of the traffic signal data to be integrated with back-end systems and Advanced Traffic Management System (ATMS) software suites. NTCIP based controllers offer flexibility for agencies to share traffic data with multiple traffic management systems, provides a choice of manufacturers that are NTCIP compliant, enables inter-agency coordination, and avoids early obsolescence.

BACKHAUL COMMUNICATIONS

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. Although many of the connected

vehicle data logs are very small in data size, the volume of packets (based both on the volume of vehicles and the ten-times per second frequency of transmission) necessitates a backhaul communication network of relatively high bandwidth and throughput, as well as high degree of reliability and low latency to ensure data processing by the back-end system is completed in a timely manner. Various uses of backhaul communications can be implemented for connected vehicle deployments.

FIBER OPTICS

A direct fiber optic connection can carry a strong signal over a long distance (depending on type), resulting in better quality transmission. While fiber cable is as susceptible to breaking when compared to copper and coaxial cable, it provides a higher data throughput. However, if fiber does not exist it can also be the most costly of solutions up front. Fiber Optic Cable requires the installation of underground fiber optic cabling along MDOT right of way connecting to a central Transportation Operations Center (TOC). Fiber Optic is a preferred communication method in urban deployment areas where existing fiber optic lines may already exist. However, rural deployments and arterial roadway infrastructure may leverage other forms of backhaul communications due to high cost of construction to build a dedicated fiber optic network.

WIRELESS COMMUNICATIONS

Wireless backbone technology is a microwave radio relay technology for transmitting digital signals between two locations on a line-of-sight radio path. Radio waves are transmitted between the two locations with directional antennas, forming a fixed radio connection between the two points. Long daisy-chained series of such links could be used to form a communication network backbone. The basic components required for operating a radio link are the transmitter, towers/poles, antennas, and receiver. These

components would be installed at every DSRC equipment location for transmission of the vehicle data to the back-end system.

Unlicensed wireless communications can be used for short range communications and avoids the delay and higher cost of the Federal Communications Commission (FCC) licensing process encountered for Licensed Backhaul communication links. Unlicensed backhaul communications can achieve up to 54 Megabits per second (Mbps), which far exceeds the requirement for Connected Vehicle data transmission. However, no interference protection exists in the unlicensed band, and the resolution of interference problems is pushed into the lap of the system owners and maintainers. Manufacturers have incorporated more sophisticated modulation schemes in their equipment which minimizes interference possibilities in a live deployment.

Alternatively, licensed backhaul communications can be used for backhaul of the data from the DSRC Equipment location. However, licensing with the FCC can create additional burden when deploying the system including the cost of obtaining a usable frequency, delay in obtaining clearance from the FCC, ongoing maintenance of the links and continued renewal process.

LEASED COMMUNICATIONS

This backbone technology would be comprised of leased cellular, cable, or dedicated communications link (e.g. T1, DS3, etc.) at every DSRC Equipment location. The use of leased communications provides a high degree of flexibility for locations that are not accessible by state-owned fiber optics and licensed/unlicensed wireless radios. Depending on the coverage location, leased services may be the most cost effective method of backhauling the data vs. building infrastructure to these locations.

The recent boom in cellular data transmissions in the last decade have made 3rd Generation (3G) and 4th Generation (4G) cellular services a very attractive option that provides

medium-high network reliability and adequate speeds for Connected Vehicle applications. However, a major limitation with the use of cellular communications in the near term is the readiness of the wireless industry to provide static IPv6 addresses. Based on the current USDOT specifications for RSEs, IPv6 static addressing for the backhaul, which has resulted in challenges integrating remote sites as part of the USDOT's Safety Pilot Model Deployment program. It is unclear at this time if the USDOT will allow a hybrid addressing model using both IPv4 and IPv6, but early coordination with the cellular companies will be critical for locations that do not have a publically-owned backhaul. Cable/DSL services also provide a reliable connection on to the internet for backhaul but present security challenges must be resolved in order to protect data transmissions. The use of firewalls and other IP security features are critical for data security on the local side of the communication network.

DATA MANAGEMENT SYSTEMS

Much of the utility of connected vehicle technologies to public agencies lies not only in their function in real-time on roadways, but in use of the vast amount of data generated by these systems. MDOT has undertaken extensive research in the potential use of this data through the Data Use Analysis and Processing (DUAP) program, and subsequent projects. This research has aimed to understand how this data can be stored, managed and applied for various uses, including asset management, traffic operations, and long-range planning.

Data management systems and relational database systems (DBMS) have been in the industry for multiple decades, and will play a key function in addressing the data warehousing and processing needs of a connected vehicle deployment. It is generally expected that the agency having jurisdiction over a particular RSE/network gateway would have the responsibility (if so desired) of collecting data logs from vehicles and the

network in general for agency use for applications such as those being evaluated with DUAP. It would then be incumbent upon MDOT to enter into inter-agency agreements as necessary to facilitate data sharing as desired. However, the final framework for data management systems is yet to be completed and may yet change as part of continued deployment planning.

In addition to backhaul communications, data management systems must include consideration of equipment, architecture and applications. There is potential for either centralized or regional data architecture, depending on application requirements and available backhaul connectivity between regions.

SECURITY/CREDENTIAL MANAGEMENT

Given the expansive number of network users and devices on a connected vehicle network and the sensitivity of the data transmitted, both in terms of privacy and motorist safety, extensive effort by USDOT and partners has been placed on developing security systems and processes. The systems currently being tested and introduced into model deployments involve processes and security methodology to validate both infrastructure and on-board vehicle equipment on the network. Vehicle equipment devices are ultimately issued certificates (e.g. credentials) on a periodic basis over-the-air and from the security back-office system. These certificates are used to validate their presence on the network and enable V2V and V2I communications between other authorized devices/users.

From an infrastructure standpoint RSEs also require security certificates in order to validate both communications from authorized vehicle equipment and maintain valid secure connection with back-office systems. These certificates are not time dependent but instead are predicated/validated based on their fixed position (Latitude and Longitude geospatial coordinates), whereby an RSE that is physically moved would no longer have valid

communications or certificates. Given the geographic scope requirements to enable a seamless security model, and the mobility of the equipped vehicle fleet, it is anticipated that security systems and processes would be designed and implemented as a national or, possibly, multi-national North American system. Thereby individual states would not be required to setup independent security

systems/models and responsibility for design and implementation of the security system would be incumbent upon USDOT and other federal agencies. The role of state and local agencies in system security could be primarily centered on providing connectivity from roadside devices to the network, and security of data collected locally.

PRIORITIZATION OF DEPLOYMENT STRATEGIES

KEY TRIGGERS FOR MICHIGAN DEPLOYMENT

The decision regarding a national deployment of connected vehicle technologies remains years away. While NHTSA intends to make a decision regarding moving forward with rulemaking in late 2013, the rulemaking process can take several years, with the ultimate outcome and rules yet uncertain.

Given the need for interoperability of systems and broad market penetration for it to be effective, at the time that regulation is put into effect, there must be a coordinated, strategic deployment plan for connected vehicle technology, both in-vehicle and roadside. At this time, standards and requirements should be finalized for RSE equipment, as well as timeframes for required deployment if such a thing is regulated. Given the rate of change in connected vehicle research and in technology in general, any premature deployment of RSEs would be high-risk and carry a high likelihood of required update or replacement at the time of full national deployment.

While RSE deployment is unlikely to be a sound near-term investment, certain elements of the future roadside infrastructure are more easily phased in over time in anticipation of possible regulation, and can yield public benefit even without a connected vehicle deployment. The following is a summary of key deployment elements and recommended triggers for beginning implementation of the three principle infrastructure elements:

BACKHAUL COMMUNICATIONS

- Trigger: *Immediate*
- Risk: Low to Moderate

Backhaul communications will be a critical element for the ultimate function of a connected vehicle system, for security applications as well as data transfer and storage. Current specifications for RSEs and antici-

pated volume of data will require a robust, high-bandwidth Ethernet communications network with the ultimate capability of migrating from the current standard Internet Protocol version 4 (IPv4) to the next generation IPv6 as well as the ability of leased service providers (cellular/cable companies) to provide IPv6 addressing. While wireless networking equipment continues to improve in both reliability and bandwidth, it also poses risks in terms of the security of unlicensed wireless bands, potential for interference due to excess wireless traffic, and a higher risk of need for replacement due to aging technology by the time a connected vehicle system is deployed. As such, a fiber-optic network is viewed as a more sustainable and future-proof solution which could accommodate both connected vehicle network backhaul, as well as serving as the communications conduit to signal controllers and traditional ITS devices.

While MDOT is in the process of building out a significant fiber optic network along freeways in the Detroit and Grand Rapids metropolitan areas, MDOT and local agencies have very little fiber optic infrastructure along rural freeways and arterial roadways, relying instead on wireless communications, leased communications and other means to communicate to signals or arterial-based ITS devices. Because arterial V2I communications is likely to play the most critical safety role in any connected vehicle deployment, this is a significant gap which MDOT could begin addressing immediately as part of traditional programs, such as signal system upgrade and road reconstruction, particularly given the relatively high cost. MDOT and DTMB have been working on sharing fiber both on the State network and with school districts who have underutilized capacity. This effort should continue.

The primary cost elements for fiber optic installation are born in underground infrastruc-

ture (conduit, handholes), fiber optic cable, and networking equipment. Once the initial investment is made to install fiber-optic cable and associated infrastructure, the incremental cost of increasing the fiber quantity of a given cable or even adding cables beyond what would be needed simply for signal system management is very low, thereby rendering a low risk of any lost investment should a connected vehicle deployment not go forward.

ADVANCED SIGNAL CONTROLLERS

- Trigger: NHTSA 2013 Rulemaking Decision
- Risk: Low to Moderate

While advanced signal controller technology capable of producing SPaT messaging is not yet fully matured, it appears likely that the required functionality can be delivered on modern controller types typically used by MDOT (including the EPAC M52 and 2070N controllers) with only modification of the controller firmware. Therefore, once a decision on rulemaking is issued (based in part on the potential for SPaT to enhance intersection safety), and further development occurs in the coming year, there is likely to be sufficient clarity to warrant controller replacement, either strategically, or as part of programmed signal modernization projects.

Given MDOT's goal of updating controllers systematically as part of its current program, and the relatively low cost of signal controllers, this is anticipated to be a relatively minor item to facilitate an ultimate connected vehicle deployment.

ROADSIDE EQUIPMENT (RSE)

- Trigger: Conclusion of rulemaking and regulation (or as specifically justified for research or incubator applications)
- Risk: *High*

With the current utility of RSEs limited to research applications, and the likely changes and updates to DSRC technology and system requirements, it is not recommended that any widespread deployment occur in ad-

vance of the conclusion of rulemaking in regards to connected vehicle application. Exceptions to this recommendation would be in cases of strategic deployment for research or incubator needs.

Furthermore, RSEs do not have utility without backhaul communications in place, and must therefore follow, or be deployed in conjunction with, any backhaul communication system implementation.

TARGET LOCATIONS

At this time, infrastructure-based safety applications consist primarily of SPaT-related applications at traffic signals, and curve warning systems. Curve warning sites are geared towards curves with an advisory speed less than that of the prevailing speed limit, and which exhibit a documented crash history related to the roadway curvature (sideswipe, run-off-road, etc.). While these sites could be on arterial or freeway corridors, they are more limited in nature, and less dependent on exact location.

Therefore, greatest emphasis for deploying backhaul communications to enable future V2I applications is along arterial corridors with the following characteristics:

- High-volume arterial corridors
- High density of traffic signals
- Corridors with intersection crash rates at or above the state average

The following provides a roadmap for a communications network deployment building off of existing infrastructure strategically to meet these goals.

Priority 1: Install backhaul on metropolitan arterial trunklines crossing existing fiber-equipped freeway corridors

Arterial trunklines would gain the most in the near-term by deployment of backhaul infrastructure from the addition of a wired interconnection. Further, locations that cross an existing MDOT-owned fiber optic corridor would have the benefit of a direct connection

onto a state network for the purpose of traffic management (See Appendix A). This could help to support future deployment of centralized signal system management software in metropolitan areas around the state.

Priority 2: Continue fiber backhaul installation on major metropolitan freeway corridors

Fiber installation along freeway corridors is ideally suited to serve as the backbone for a broad communications network, as well as to connect traditional ITS devices and ultimately provide data gathering gateways for connected vehicle communications.

In recent years MDOT has undertaken a significant deployment of fiber-optic infrastructure on Detroit and Grand Rapids-area freeways. However, there remain significant gaps in fiber deployments in the metropolitan regions, including Lansing, Flint, Midland, Saginaw/Bay City and Kalamazoo. Although existing unlicensed, licensed, or leased wireless communications may be available in these cities, closing these gaps with fiber would enable broader arterial deployment with high throughput and provide a centralized network for each region.

Priority 3: Install backhaul on metropolitan arterial trunklines parallel to equipped freeway corridors

Once arterial trunklines which cross fiber-equipped freeways have been upgraded to include fiber communications, deployment along parallel arterials can begin. This sequence allows a build-out of the fiber network in such a way that the network expands from a backbone link.

Priority 4: Install backhaul to remote critical freeway and arterial curve locations

The final priority for backhaul communication build-out would be to install high-bandwidth communications links to remote areas near curves with known crash histories, which may most benefit from curve warning application use.

It should be noted that traffic signal controller upgrades should be considered for inclusion in any project which involves fiber optic installation along an arterial corridor, as well as signal modernization projects.

FLEET PENETRATION

Should connected vehicle systems advance to deployment, the key driver of the effectiveness of such a system will be the level of penetration of OBEs in the vehicle fleet.

On average, the vehicle fleet experiences a complete turnover approximately every 10-15 years. Therefore, in addition to introduction of factory-equipped vehicles, deployment via aftermarket vendors is likely to play a key role in accelerating market penetration. The mechanisms to do this, including the possibility of consumer incentives (similar to coupons for conversion to digital television) are not yet known.

The State of Michigan manages several thousand vehicles including State Police, MDOT maintenance, and courtesy patrol vehicles which present an opportunity to deploy aftermarket devices to increase market penetration. Leveraging and equipping this fleet can make a meaningful impact in an early deployment scenario. However, given that penetration of this broader fleet will be beyond the meaningful involvement of MDOT, understanding the areas where fleet penetration is likely to increase the fastest can help to prioritize infrastructure deployments where they will see the greatest use. One measure to assess the rate of vehicle fleet turnover is the percentage of motorists in a given market that lease vehicles. In general, because of typically short lease terms, lease vehicles are exchanged for new vehicles on a much more frequent basis than owned vehicles. Therefore markets with higher rates of leasing are likely to experience faster overall fleet turnover, and thus penetration of OBE. Though leasing rate data by market in Michigan is not publically available, commercial services are likely available to provide this market analy-

sis should MDOT determine it useful to help | prioritize deployment locations.

NEAR-TERM DEPLOYMENT STEPS

INSTITUTIONALIZE CONDUIT INSTALLATION DURING ARTERIAL/FREEWAY CONSTRUCTION

MDOT's best and least expensive opportunity to begin expanding the infostructure network would be to identify and if necessary amend programmed reconstruction projects along freeways or arterial trunklines to include at a minimum dedicated conduit for ITS use, as well as fiber optic cable if there is an immediate need (i.e. existing traffic signals or ITS devices which could be integrated onto it).

As part of a major construction project, the addition of conduit becomes an almost incidental cost, versus the construction of conduit by itself in a developed corridor, which can be complex and costly. This advanced planning could provide a jump-start to infostructure deployment which may otherwise take many more years to plan and construct.

Beyond looking at immediately programmed projects, it is critical that MDOT begin to institutionalize the installation of conduit as part of the upgrade of arterial roadways, much like the department has been successful in doing for a number of metropolitan area freeways. By shifting towards a routine installation, the long-term cost of installing infostructure in these corridors is greatly reduced.

SIGNAL CONTROLLER MODERNIZATION

The modernization of existing signal controllers is a proactive measure to prepare MDOT for a full scale Connected Vehicle deployment. Between 60-70% of existing traffic signal locations are time-based control systems that do not have adequate equipment at the location to enable integration into a centralized system. 20-30% of controllers operate using a closed-loop system with most sites having some provisions

for a low-data phone drop.

With the advancement of the internet in the last two decades, the movement toward IP convergence has prompted a shift towards traffic signal controllers that are enabled with IP ready ports, and the latest firmware to be integrated in to ATMS. ATMS such as *Actra/Tactics* which typically reside at the DOT TOC, are typically connected to the individual traffic signal locations by means of a backhaul method. However, before a backhaul method can be selected for full integration to a traffic management system, the individualized controller locations must be modernized to accept newer IP-ready connections. These connections can either be wireless, fiber or leased communications. However, given the long-term data volume anticipated, planning for fiber connections is recommended.

Regardless of the backhaul communication methods, typically a Registered Jacks (RJ)-45 Ethernet port allows flexibility for integrating the signal controller into a traffic management system and for connected vehicle application. An Ethernet port on the controller can be used to make a connection between various switching equipment located in the traffic cabinet for putting communications onto a fiber connection, wireless radio, or leased cellular/cable communications system. Legacy signal controllers have serial ports that could be used as a communication method. However additional serial to Ethernet convertors would be required in addition to switching equipment. That would create additional points of failure.

The development of NTCIP has further enabled seamless integration of multiple vendors' signal controllers into various traffic management systems. The current version of NTCIP is readily available and can be upgraded on traffic signal controllers via a firmware update. Many of the older control-

lers can be upgraded using the firmware update. However, most new controllers are NTCIP compliant and do not need any type of modification.

The proactive steps of modernizing the signal controller will ensure MDOT is ready for a connected vehicle deployment as well as controller integration in to various ATMS clients, especially since back-end systems will be IP based and ATMS clients require NTCIP compliant controllers.

Additionally, space constraints should be considered in regards to signal controller cabinets. The provision now of additional space at locations with significant equipment requirements can save significant cost at the time of RSE deployment by accounting for sufficient space for future DSRC radio stacks and related power equipment. As deployment decisions begin to take hold, the revision of controller cabinet specifications and standards may be warranted to account for this additional standard equipment in the future.

ARTERIAL COMMUNICATIONS NETWORK PLAN

Arterial roadways within the State of Michigan will play an important role in the coverage of connected vehicles. While MDOT has invested heavily in freeway deployments of traditional ITS devices, a further investment in the arterial network will be critical for backhaul of the connected vehicle data. A communications backbone is imperative for security authentication, as well as backhaul of data logs from the vehicles themselves, which is anticipated to account for a significant throughput.

Since MDOT has invested in ITS infrastructure on the freeways, it would not be uncommon to find a 90 foot pole at key freeway interchanges. In many of the urban interchanges in Grand Rapids, Metro Detroit, Greater Ann Arbor, Lansing, Flint, Bay City/Saginaw, and Kalamazoo, existing infrastructure can be found with usable back-

haul communications to an MDOT TOC. Though a wired system is recommended for an ultimate connected vehicle system, these aggregation points can be used to build a wireless or wired arterial infrastructure. A wireless system which consists of point-to-point (PTP) and point-to-multipoint (PTMP) radios can be used at traffic signal locations and can be mounted on traffic signal poles. A wireless link between the traffic signal locations and the aggregation points along key freeway can be easily achieved within four to seven miles, depending on the type of equipment selected. These links can be extended further using repeater locations which bounce wireless links off one another before getting to the aggregation point.

A fiber optic network is ultimately recommended as an arterial communication network to accommodate future connected vehicle data. Fiber along arterial roadways can be costly from the perspective of building new underground infrastructure and the potential utility conflicts which are commonly found on Michigan's urban roadways. The majority of the arterial roadways do not currently have conduit, which significantly increases the cost of deploying fiber along these roadways, and increases the importance of planning for this need in advance.

A first step in preparing for a modernization project is to develop a master plan to determine how and when the project should occur. An arterial network master plan will move the department in a direction of having full visibility of the arterial network. Today, MDOT has select locations that cover arterial deployments, specifically those they can monitor from a TOC. The following questions should be considered in the arterial traffic network master plan:

- How extensive of a backhaul system should be developed?
- What locations will provide the greatest benefit for a deployed system?

- Can the deployment be completed in phases to minimize high capital investments in a single project?
- Is there an existing ATMS available to handle Arterial device communications?
- Is it possible to integrate existing traffic signals in to a new or existing ATMS?

The general prioritization discussed in the previous section can help to provide a framework for such a plan, considered along with near-term utility and other factors.

DATA MANAGEMENT PLAN

To effectively manage large data repositories, traditional barriers between organizational groups and business needs will need to be transformed within MDOT. The beginning of this transformation should be a detailed requirements and Concept of Operations in combination with or within a Statewide Data Warehouse Strategic Plan. This strategic plan would outline the various components (ITS subsystems) to integrate within the enterprise data warehouse and setup an initial framework for data integration across the silos (between subsystems and business units).

The work initiated by the Data Strategy working group and draft policy is a good starting point to the strategic plan that would facilitate and establish the framework for an enterprise data warehouse integrating Geographic Information Systems (GIS), Asset Management and ITS datasets. Each information model (GIS, ATMS, ITS) should contain best practices for database schema design and integration, leveraging a core geospatially enabled and accurate base-map (centerline and cadastral data layers), which are effectively maintained through the Michigan Geographic Framework (MGF). Statewide Light Detection And Ranging (LIDAR) and Orthophoto datasets should be flown on an annual or semi-annual basis and integrated with the baseline GIS data model within the data ware-

house.

Once a migration plan is established from the funding and initiation of the strategic plan, the enterprise data warehouse hardware and software should be procured and setup. This would allow for a controlled scale proof-of-concept to be established and demonstrated from a use perspective with a series of dashboards, online mapping and web-based user applications (internal for MDOT personnel and public user subscribers). The data aggregation should be undertaken in a series of phases by ITS subsystem and performed based on prioritization of the datasets. Based on the initial projections, the hardware and database type required to perform under this load condition would most likely be Oracle (based on current use) running on dedicated application hardware with separate storage platform/architecture.

Data aggregation would be best served by integrating real-time (one per minute or one per five minute intervals) from key ITS subsystems, with a retention period of 45 days being represented as current data. Once data moves past 45 days to 12 months, data should be represented and stored for trending and current analysis due to its recent occurrence. After 12 months, data should be moved on an annual basis to secondary storage disks to allow for rapid access but represented as archival. This would allow for longer term business analytics and metrics analysis/trending. Once data is past five years old, it can be permanently archived to a hierarchical storage platform for periodic use and access. Use of this methodology of storage and database record management would allow MDOT to cost effectively integrate ITS subsystems into an enterprise data warehouse with an effective data storage solution. The 12 month duration for active storage, less than DTMB's current practice of 24-month storage, is recommended due to the anticipated volume of connected vehicle data.

However, when data analytics across the department becomes a reality, a larger number of months of active data may be needed and should be considered as part of the ultimate data management solution.

Through the use of an enterprise data warehouse that is geographically dispersed within the State, the warehouse would best be implemented as regional nodes within a Real Application Cluster (RAC). The RAC nodes support single database instance with availability between three facilities (Southeast Michigan TOC (SEMTOC), Statewide TOC (STOC), and West Michigan TOC (WMTOC) in the event of a node failure. This essentially creates a fault-tolerant enterprise solution for the data warehouse instance. This clustered design premise would support real-time database updates from Structured Query Language (SQL) triggers or dynamic data replication per each ITS subsystem into the enterprise data warehouse information model. The hierarchical storage would become an integrated component and directly attached to each RAC node using a NetApp Scalar storage appliance or similar performing device. This allows for the database to utilize the storage tiers directly, while maintaining performance, supporting data hierarchies

and the archival processes.

Data security and privacy are large and distinct concerns of both the public at-large, key stakeholders and funding providers. Long-term the best practices outline encryption methods as Secure Sockets Layer (SSL) (with active wildcard certificates across the application-tier) on the front-end applications. Additionally, removing vehicle and consumer private data (Name, Social Security, Phone Numbers, Vehicle Identification Numbers (VIN), License Plates) or minimally encrypting these key data fields will be an ongoing requirement for managing real-time data from connected vehicle programs.

To derive and leverage real-value from these data stores, specific types of analysis will be needed from an Asset Management perspective (vehicle type, model, year, miles travelled, origin/destination positional location by trip, road departure/lane departure and position, incident type/date and position, date/time trip data, average speed by roadway segment, temporal/physical data conditions/feeds). Matching this Asset Management and performance analysis to specific user data may or may not be of long-term cost benefit to MDOT.

