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Safety Pilot Model Deployment

Test Conductor Team Report

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16. Abstract

In order to potentially advance vehicle-to-vehicle (V2V) communication technology and support an agency decision regarding this technology, the U.S. Department of Transportation undertook the Safety Pilot Model Deployment (SPMD). The objective of the SPMD was to support the evaluation of dedicated short-range communication technology for V2V safety applications, which operate at 5.9 GHz in a real-world, concentrated environment. The main focus was to collect data to support (1) the functional evaluation of V2V safety applications, (2) the assessment of the operational aspects of messages that support vehicle-to-infrastructure (V2I) safety applications, and (3) comprehension of the operational and implementation characteristics of a prototype security operating concept. All of this equated to an assessment of a real-world deployment of V2V technology. The program initially covered 2 years, with the first year used to establish the site and the second year used to collect data. After the data collection 6 months were necessary to decommission the equipment and site. Given that there were other devices operating in the SPMD, such as motorcycles and transit vehicles that were still collecting data, the USDOT extended the SPMD data collection for 6 more months. The SPMD itself was started on August 18, 2011. The launch, which included the deployment of various V2V equipped vehicles and the collection of data of these various V2V vehicles interactions, occurred on August 21, 2012. V2V integrated light vehicle data collection concluded on August 20, 2013 . All V2V data collection concluded on February 28, 2014. The test conductor contract ended August 29, 2014.

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List of Acronyms

AADT	annual average daily traffic
ASD	aftermarket safety device
ASDB	aftermarket safety device for bicycles
ASDM	aftermarket safety device for motorcycles
ASIL	Automotive Safety Integrity Level
BSM	basic safety message
CCB	change control board
CCV-IT	Commercial Connected Vehicle – Integrated Truck
CRL	certificate revocation list
CSW	curve speed warning
DAS	data acquisition system
DSRC	dedicated short-range communication
DVI	driver-vehicle interface
EEBL	emergency electronic brake light
FCW	forward crash warning
GIS	geographical information system
HMI	human-machine interface
HPMS	highway performance measure system
HV	host vehicle
ILV	integrated light vehicle
IMA	intersection movement assist
IMU	inertial-measuring unit
IRB	Institutional Review Board

ISD	integrated safety device
LCDS	local certificate distribution system
MDGA	model deployment geographic area
MIS	Michigan International Speedway
NCRC	North Campus Research Complex
NDA	non-disclosure agreement
OBD	On-board diagnostic
OST-R	Department of Transportation Office of the Assistant Secretary for Research and Technology
PCMS	Property and Configuration Management System
PTRR	Problem Trouble Report and Resolution
QPL	qualified product list
RIWS	road ice warning system
RQPL	research qualified provider list
RSD	retrofit safety device
RSE	roadside equipment
RSU	roadside unit
RTCM	Radio Technical Commission for Maritime Services
RV	remote vehicle
SCMS	Security Credential Management System
SCOOT	split cycle offset optimization
SDLC	systems development lifecycle
SPaT	signal phase and timing
SPMD	Safety Pilot Model Deployment
TIM	travelers information message
TRP	transit retrofit platform

UDP	user datagram protocol
UM	University of Michigan
UMTRI	University of Michigan Transportation Research Institute
UTC	coordinated universal time
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VAD	vehicle awareness device
WAVE	Wireless Access in Vehicular Environments
WBS	work breakdown structure
WSA	WAVE service advertisements

Executive Summary

In order to potentially advance vehicle-to-vehicle communication technology and support an agency decision regarding this technology, the U.S. Department of Transportationhas undertaken the Safety Pilot Model Deployment.

The objective of the SPMD was to support the evaluation of dedicated short-range communication technology for V2V safety applications, which operate at 5.9 GHz in a real-world, concentrated environment. The main focus was to collect data to support (1) the functional evaluation of V2V safety applications, (2) the assessment of the operational aspects of messages that support vehicle-to-infrastructure safety applications, and (3) comprehension of the operational and implementation characteristics of a prototype security operating concept. All of this equated to an assessment of a real-world deployment of V2V technology.

The SPMD site encompassed the northeast, and a portion of the southeast corners of Ann Arbor, Michigan. The below graphic's outer orange outline identifies the border of the SPMD area.

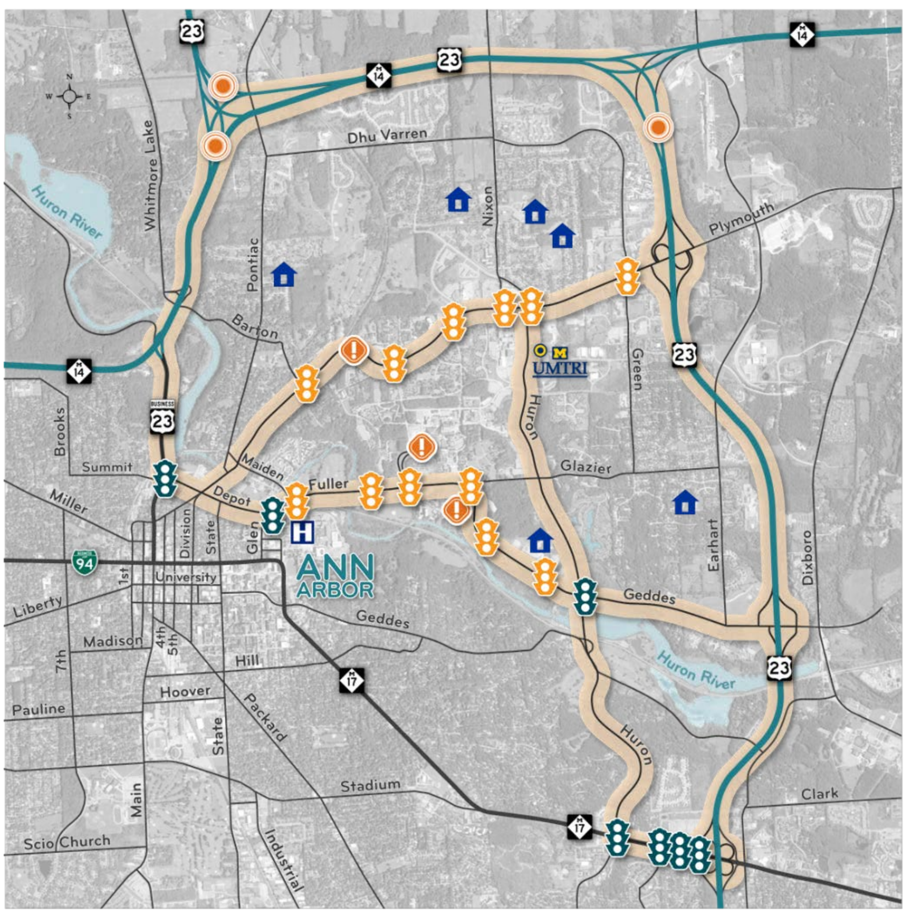

Figure ES-1: Safety Pilot Model Deployment Area

To conduct the SPMD, the test conductor, the University of Michigan Transportation Research Institute that was contracted to run the SPMD, assembled a team that would cover all aspects of establishing and operating the first real-world V2V/V2I communications test environment. The team consisted of:

University of Michigan Transportation Research Institute: UMTRI, as the prime contractor, was responsible for the overall program management of the SPMD.

Parsons Brinckerhoff: PB, a global engineering and consulting firm, was the infrastructure lead. It was responsible for all of the RSE installations for SPMD.

Leidos: Leidos led the interoperability testing as an UMTRI subcontractor. It was also responsible for the local credential distribution system that allowed for the dissemination of certificates to devices[1].

Mixon Hill, Inc.: Mixon Hill operated and maintained the infrastructure back-office for the SPMD.

Ann Arbor: The City of Ann Arbor served as the backhaul[2] infrastructure provider. It provided support for the test bed Internet service provider link for both IPv4 and IPv6 communication protocols,and supported the installation for signal phase and timing for Econolite and Siemens.

Michigan Department of Transportation: MDOT supported the project by coordinating with PB on resolving any issues with the infrastructure installations on State property (freeway sites) and within State right-of-way (including freeway sites and some arterial sites).

HNTB Corp.: HNTB developed the infrastructure installation plans for the freeway sites. It also played a major role in outreach.

Texas A&M Transportation Institute: TTI worked in the area of “other applications.” It attempted to develop an application for at-grade railroad crossings.

Escrypt – Embedded Security: As security industry experts, Escrypt was responsible for consulting and providing guidance on the development of the security management system concept of operations.

PROGRAM COORDINATION

The SPMD program was very complex and required a significant amount of coordination between USDOT, UMTRI’s test conductors, USDOT contractors, test conductor partners, and test conductor suppliers.

Beside UMTRI and its team members, coordination involved six different USDOT departments:

[1] Leidos, Inc., formerly Science Applications International Corporation, SAIC). A separate USDOT/ITSJPO contract with Leidos implemented and operated the Security Credential Management System that supplied the certificates to the LCDS.

[2] In a hierarchical telecommunications network the backhaul portion of the network comprises the intermediate links between the core network, or backbone network and the small subnetworks at the "edge" of the entire hierarchical network.

- The Intelligent Transportation Systems Joint Program Office (ITS JPO) within the Office of the Assistant Secretary for Research and Technology (OST-R) (formerly a DOT "mode" called the Research and Innovative Technology Administration, RITA);
- the National Highway Traffic Safety Administration;
- the Federal Highway Administration
- the Federal Motor Carrier Safety Administration
- the Federal Transit Administration; and
- the John A. Volpe National Transportation Systems Center ("Volpe").

The USDOT also had other contractors that needed to be coordinated with, including Leidos, the Crash Avoidance Metrics Partnership (CAMP), Battelle, Southwest Research Institute, Econolite, and Siemens.

Meetings were regularly held to manage the execution, control, and monitoring aspects of the SPMD. Various meetings that involved the test conductor, the USDOT, and its subcontractors were held to cover overall program management as well as critical components of the SPMD such as data management, V2V communications security, and outreach. Telephone conferences were held weekly or monthly, depending on the topic area and need to discuss progress and issues. Working group meetings were generally held every other month during the planning stages of SPMD. The working group meetings were intended to involve a deep dive into areas that required significant discussion and planning that could not be contained in the weekly coordination meetings. All these meetings supported coordination and information exchange among all the participants to facilitate the launch of SPMD that occurred on August 21, 2012.

SAFETY PILOT MODEL DEPLOYMENT

The program initially covered a period of 2 years, with the first year used to establish the site and the second year used to collect data. After the data collection there was a period of 6 months necessary to decommission the equipment and site. Given that there were other devices operating in the SPMD, such as motorcycles and transit vehicles that were still collecting data, the USDOT extended the SPMD data collection for 6 months.

The SPMD itself was started on August 18, 2011. The launch, that included the deployment of various V2V equipped vehicles and the collection of data of these various V2V vehicles interactions, occurred on August 21, 2012. V2V integrated light vehicle data collection concluded on August 20, 2013 . All V2V data collection concluded on February 28, 2014. The test conductor contract ended August 29, 2014.

PRE-MODEL DEPLOYMENT - PLANNING

Establishing the V2V communications environment required the development of various plans, including the experiment plan, the infrastructure site plan, the logistic plan, and the safety analysis and threat assessment plan. The environment also needed a Security Management Systems Concept of Operations that described and structured the V2V security protocols and operations that would need to be implemented and followed in the SPMD area. Devices needed to be developed, procured, tested, and installed. Internal Review Board procedures and processes needed to be followed to ensure the safety of SPMD participants. Data parameters that needed to be collected had to be identified and defined.

Due to the multiple entities collecting data, the data collection also needed to be coordinated. Given that this would be the largest ever real-world test of V2V communications technology, outreach to educate the public, media relations, and information to stakeholders all needed to be planned, coordinated, and effectively delivered.

The purpose of the experiment plan was to provide the framework for executing the SPMD program. Input from USDOT and Volpe was critical to the development of the experiment plan. Specifically, Volpe's simulation of a transportation planning model was the basis for analysis of many aspects of the plan (See Section 4.1.3). The model projected vehicle interactions of various deployment/recruitment scenarios to select the recruitment strategy that would maximize interactions.

The primary recruitment procedure was conducted with the assistance of the Ann Arbor Public Schools located in the SPMD test area. With the support of the central administration of the Ann Arbor Public Schools, emails and printed notices were distributed to the parents of students at the six public schools located in the SPMD test area. A secondary round of recruitment took place covering employees of the University of Michigan Health System, and The University of Michigan College of Engineering.

UMTRI and its team supported a variety of organizations engaged in the SPMD by providing logistical and material support. The logistics plan detailed the size and location of work, equipment, laboratory, storage, and meeting areas to be provided, how sharing of space will be achieved to minimize the required space, and how space allocation will meet the needs of the team. Space was needed for Vehicle Awareness Device installations, Aftermarket Safety Device installations, Retrofit Safety Device kit installations, Integrated Light Vehicle data harvests, interoperability testing, and personal work areas to support team partners and USDOT subcontractors on an as-needed basis.

Security is a major concern for any network. Malicious devices and malicious attackers can corrupt or disable part or all of the system. To help protect the SPMD program, the test conductor developed and implemented a Security Management Operating Concept Plan designed to prevent malicious and unintentional attacks of DSRC-based devices and of the Security Credential Management System. Security includes security of over-the-air DSRC messages, security of DSRC units and of the Security Credential Management System, security policies, physical security, and secure life-cycle.

The Security Management System Concept of Operations described two stages of operations. In Stage 1, the VADs were pre-loaded with a single batch of 2 years' worth of 5-minute security certificates. ASDs were also provides approximately 7 months of 5-minute certificates, enough for operation until Stage 2. ASDs received their certificates OTA after being bootstrapped[3] using the RSE at UMTRI. In Stage 2 of the security deployment, there was no change for VADs, but the ASDs started requesting and obtaining a batch of 2 months' worth of 5-minute certificates and associated decryption keys while moving from the

[3] Bootstrapping is the initialization process that registers (enrolls) a devices with the SCMS. It requires a temporary ID that can only be used one time. Once the device is registered it is allowed to request security certificates and decryptions keys from the SCMS.

SCMS using any RSE in the SPMD. The ISD for the CCV-ITs and all but 16 of the ILVs would remain as in Stage 1. However, 8 ILVs (one from each CAMP OEM) would transition to OTA distribution of certificates and keys, and another 8 would transition to a cellular distribution method.

The intent of the Safety Analysis and Threat Assessment Plan was to guide the execution of a functional safety and threat assessment program, to validate the overall safety of the SPMD capability, and to understand the impact of unintended or malicious attacks on the overall SPMD capability. ISO 26262 provides requirements and processes to mitigate or eliminate risks to safety. Using the 26262 methodology, none of the potential hazard events identified by the test conductor were classified as Automotive Safety Integrity Level hazard events, therefore, generally accepted systems engineering and project management practices were used for project execution as is the industry standard.

The Institutional Review Board is tasked with protecting human subjects in social and behavioral research at the University of Michigan. All research dealing with human subjects must be approved by the IRB. Nearly all human subjects participating in research at the University of Michigan are required to read and complete an IRB approved document outlining their participation in the research project. This type of document is referred to as an informed consent document, as completion by the participant indicates that they were informed of the expectations for their participation, and that they consent to the protocols of the study as they are outlined. Multiple informed consent documents (and multiple versions of each one) were submitted, approved, and used to enroll participants in the SPMD.

A combination of DSRC devices were used in the SPMD to enable the V2V and V2I communications, support V2V and V2I safety applications, and collect the data necessary to permit an evaluation of V2V safety applications by the independent evaluator. The devices were deployed from the time of launch with deployments continuing over the operations of the SPMD. Due to the prototype nature of the devices, as some devices were deployed, other devices that had been in the field needed to be taken out of service for repairs or updates. Even though there were various devices out of service, the number of devices operating in the SPMD area reached a peak of 98 percent of planned quantities.

Vehicle Awareness Device: VADs are communication-only devices, and do not contain safety applications. VADs were included in the SPMD primarily in order to increase the number of interactions that integrated light vehicles and ASDs would experience, to enable researchers to better evaluate the performance of safety applications in providing alerts to drivers during conflicts. Planned quantity – 2450, Peak Deployment quantity – 2429.

Aftermarket Safety Device : ASDs both send and receive BSMs. ASDs ran three safety applications: curve speed warning, emergency electronic brake light, and forward collision warning. Planned quantity – 300, Peak Deployment quantity – 294.

Retrofit Safety Device: RSDs are like ASDs for the commercial truck sector, and go a step beyond ASDs in that they are connected to the vehicle's data bus, and so have a richer set of inputs for the threat assessment algorithms. An offshoot of the RSD was the transit retrofit platform . It had similar content but adds two transit-only applications, namely pedestrian detection and right turn in front warning. Planned quantity RSD Truck – 16, Peak Deployment quantity RSD Truck – 16; Planned quantity Transit Buses – 3, Peak Deployment Transit Buses – 3.

Integrated Safety Devices: Safety devices, in this context, are defined as integrated devices that are part of a system that warns the driver of potential threats. These systems were designed to be "production-like" and be integrated into a vehicle like systems that were factory installed. The driver-vehicle interface was integrated into the vehicle. The device itself both sent and received BSMs and was connected to the vehicle data bus. On the light vehicle side, 64 vehicles with ISDs (known as "integrated light vehicles" or "ILVs") were provided by CAMP – 8 vehicles each from each of the 8 participating OEMs. Planned quantity ILV – 64, Peak Deployment quantity ILV – 64; In relation to the 3 CCV-IT Battelle developed , Planned quantity CCV-IT – 3, Peak Deployment quantity CCV-IT – 3.

Besides the placement of V2V devices with individual participants, fleets were also targeted in the SPMD for VADs, TRPs, RSDs, and CCV-ITs. As mentioned above, for VADs, the purpose was to seed the deployment area with additional equipped vehicles that would have heavy usage in the area to increase the interactions with all other vehicle types. Fleets operating in the SPMD area that were targeted for VADs included a local water delivery company (Arbor Springs) and another all-purpose delivery company (Metro Delivery), both with contracts with the University that ensured their frequent presence in the target area. VADs were also placed on local tow-truck fleets (Sakstrup's/Brewer's), the local public school bus fleet (Washtenaw Intermediate School District), the University of Michigan bus fleet, and many individual University business fleet vehicles such as laundry service trucks and street sweepers. University of Michigan buses were used for transit V2V devices. For the RSD for heavy trucks, two fleets (from Con-way Inc., headquartered in Ann Arbor, a freight trucking company, and Sysco Inc., of Huston, Texas, a whole food service company) were equipped with VADs. For the CCV-ITs, two smaller-scale delivery companies (Rightaway Delivery, 4H Delivery) were each selected to use one of the CCV-IT equipped tractors as part of their normal operations, however, placement of the CCV-ITs with Rightaway and 4H Delivery did not produce the level of interactions projected. Therefore to obtain more V2V interactions, it was decided that UMTRI drivers would drive the tractors on prescribed routes twice daily during peak traffic hours. The UMTRI driving provided three months of valuable data for the CCV-IT project.

DATA

Weekly meetings were held with CAMP, UMTRI, FHWA, Volpe, NHTSA, VTTI, Mixon Hill, and ITS JPO. The intent of the meetings was to discuss and decide upon the data content, generate a data dictionary, and coordinate data management. The data management exercise began with an examination of data resources and data mapping. The independent evaluator, Volpe, provided the test conductor team and other data providers (VTTI, Battelle, and SWRI) with a list of desired data from the SPMD. Objective, contextual, and subjective survey data was collected. The objective data for the SPMD were collected by a Data Acquisition System or by a data logger. Data acquisition systems are systems that are installed in vehicles and collected data from the V2V device, the vehicle itself via the vehicle's data bus, and also video from cameras installed in the vehicle. A data logger is a simple data recording device included in prototype devices, VADs, ASDs without DAS, and RSEs to record basic safety messages.

There were 118 UMTRI DAS units, 64 VTTI DAS units, and 4 SWRI DAS units deployed on board vehicles as part of the SPMD. The ILV data was obtained from the 64 VTTI DAS units. ASD data was obtained from 98 UMTRI DAS units.

The contextual data to be collected included BSMs detected by RSEs located in the infrastructure, weather data, and traditional traffic data. The predominant use of contextual data was to support the real-time data capture team based out of FHWA.

Subjective data, including surveys and focus groups, were used in SPMD to obtain data that could be analyzed to better understand drivers' acceptance of V2V communication technology. Before the development of the surveys, UMTRI coordinated the process with the USDOT, Volpe as the independent evaluator, representatives of CAMP for the integrated passenger vehicles, and with other stakeholders on their associated platforms. These surveys were administered to SPMD participants (drivers) at or near the end of their participation. The results of the surveys and focus groups were provided to the independent evaluator and CAMP for analysis.

TESTING

The Interoperability Test Plan submitted to the USDOT addressed interoperability of DSRC devices prior to and during the pre-model deployment dry run. Interoperability testing focused on the ability of vehicle-based and infrastructure-based devices to exchange messages over DSRC and decode, log, and/or forward, where applicable, those messages or the data contained within those messages. Interoperability testing verified that DSRC messages sent from multiple device types and multiple device suppliers could be received and decoded by other device types and other device suppliers.

The original plan for interoperability testing was to conduct the tests one time. However, since the RSEs were not available at the time that interoperability testing was to take place, testing was split into two stages. The first stage only included vehicle-based devices, and the second stage included all devices to be deployed for SPMD, i.e., vehicle-based devices and RSEs.

Stage III and Stage IV interoperability tests were added after issues were discovered after the launch of SPMD, to retest devices that had not previously implemented or passed various functional tests.

PREPARING FOR LAUNCH (model deployment readiness)

The purpose of model deployment readiness was to provide evidence of sufficiency to USDOT that the model deployment site was ready to launch meaning there could be an initial deployment of vehicles that could use V2V to support crash avoidance application and data could be collected on equipped vehicle interactions. To assess the readiness for launch 125 items were identified in various categories, including planning, security, communications, data, applications, devices, certification, and governance. For each item, an owner and scheduled completion date was identified. The readiness items were reviewed during the program coordination meetings. Detailed reviews of the readiness items were also conducted at the July 2012 working group and the August 7-8, 2012, working group meetings.

It was a requirement that all items needed to be confirmed ready for launch prior to USDOT approval to launch model deployment. All critical items were confirmed as ready for launch and USDOT approved the launch of the SPMD that occurred on August 21, 2012.

MODEL DEPLOYMENT OPERATIONS

After launch the test conductor transitioned from establishing the V2V commnications environment to operating the environment that included the continued installation and deployment of V2V devices; the monitoring of devices that included RSEs; the distribution of security credentials; and the harvesting, processing, and transferring of data.

"State of health" monitoring was conducted for both vehicle-based devices and infrastructure-based devices. For purposes of the SPMD and research analysis, each vehicle-based device was assigned a unique ID that was broadcast as part of the BSM.[4] As a vehicle drove by an RSE, the BSMs that were transmitted from the vehicle were automatically stored as part of the RSE log file. These log files were scanned on a regular basis, and a list of the unique device identifiers that were recorded was produced. From this list, UMTRI looked for the absence of specific devices and could take action to understand if the device was malfunctioning. This applied to all device that were not accompanied by a DAS.

Vehicles equipped with the UMTRI DASs (ASD-equipped vehicles, TRP-equipped vehicles, some RSD-equipped vehicles, and the CCV-ITs) were also monitored daily via cellular data link with UMTRI. For the monitoring of devices and the DAS equipment, a file was sent to UMTRI via cellular link using DAS battery power when power from the vehicle to the DAS was terminated, i.e., when the vehicle was turned off. The file contained small snippets of data and some diagnostic information. From the diagnostic information, it was easy to obtain the state of health of the DSRC device and DAS.

The 64 ILVs had cellular-based health monitoring that was handled by the CAMP VSC3 consortium under a separate contract with the USDOT.

The infrastructure was also monitored. The RSEs sent a state of health message referred to as a "heartbeat" given it was sent to the back office once every minute. If the heartbeat was not received, the RSE warranted further investigation.

A significant amount of data were collected in the SPMD and the processing, handling, parsing and storage of these data was a significant task. As indicated previously, the data collected fell into four broad categories or groups, Messages, Driving, Contextual, and Subjective. UMTRI was responsible for harvesting, processing, and transferring data from VADs, ASDs, and RSDs to USDOT. CAMP, via its

[4] The unique ID was accomplished by holding a few didgets of the BSMs random ID constent for monitoring and reseach analysis purposes. Under actual deployment all the didgets in the random ID would change at a set time interval.

subcontractor VTTI, harvested, processed, and transferred the ILV data to the independent evaluator. UMTRI harvested data from the various devices every 3 months. VTTI harvested data from the ILVs every month.

The ILV data was collected over 12 months, which included driver changes for all 64 vehicles after the first 6 months.

Although most of the decommissioning tasks were ultimately removed from the test conductor contract to allow for the transition from SPMD to the Ann Arbor Connected Vehicle Test Environment, some tasks remained for specific fleets.

OUTREACH

UMTRI's goal for the SPMD outreach and showcase task was to assist the USDOT in increasing visibility and understanding of the Vehicle Safety Communications program and its benefits on a national basis, while also educating the citizens of Ann Arbor and the industry about the SPMD Program. The UMTRI team facilitated outreach and showcase activities to educate a variety of audiences about SPMD and V2V technology as NHTSA prepared for the 2013 agency decision on V2V safety communication .

The primary deliverables of the outreach task included the development of the 2011 ITS World Congress Showcase Plan, an Overall showcase plan for SPMD, and an outreach plan. Each of these plans included specific deliverables, as described below and in the following subsections:

- The outreach effort for SPMD was kicked off at the 2011 ITS World Congress. More than 1,000 attendees visited the outdoor tent, where DSRC providers showcased their products and CAMP signed up attendees for demonstration rides.
- The showcase plan outlined the creation of facilities at UMTRI where V2V communications could be demonstrated.
- The outreach plan included the development of various promotional materials, including banners, brochures, fact sheets, and a video. It also involved numerous events that took place during SPMD. While numerous conferences and events were supported by the SPMD outreach team, the safety pilot launch on August 21, 2012, was a significant milestone and attracted national press.

SUMMARY

Over 2,800 vehicles and 25 infrastructure sites were deployed for the SPMD program. The vehicles consisted of several different types of fleets of vehicles.

- ILVs (provided by CAMP)
- CCV-IT – Integrated truck fleet (supplied by Battelle)
- RSDs heavy truck fleet (kits provided by Battelle and SWRI for test conductor installation)
- TRP fleet (provided by Battelle)
- ASD fleet
- VAD fleet

The primary deployment lasted for 1 year, but was subsequently extended for some devices for another 6 months.

The objective of the SPMD was to support the evaluation of dedicated short-range communication technology for V2V safety applications, operating at 5.9 GHz in a real world, concentrated environment. The main focus was to collect data to support the functional evaluation of (1) V2V safety applications, (2) the operational aspects of messages that support vehicle-to-infrastructure (V2I) safety applications and, (3) understanding the operational and implementation characteristics of a prototype security operating concept; all equating to assessing a real-world deployment of V2V technology.

The Ann Arbor Safety Pilot Model Deployment Experience

1 Safety Pilot Model Deployment Introduction

Vehicle-to-vehicle communication technology have long been identified as having the potential to significantly improve motor vehicle safety, but the study of these technologies to date has been limited to small field tests and technical development exercises. In order to potentially advance this initiative and help support an agency decision regarding V2V communications technology, the USDOT undertook the SPMD. Under the leadership of the UMTRI acting as the test conductor, this initiative allowed for the evaluation of a scaled deployment of V2V technologies in Ann Arbor, including nearly 3,000 equipped vehicles and more than 70 miles of instrumented roadway, making it the largest vehicle communication technology field test in the world to date.

The objective of the SPMD was to support the evaluation of dedicated short-range communication technology for V2V safety applications, which operate at 5.9 GHz in a real-world, concentrated environment. The main focus was to collect data to support (1) the functional evaluation of V2V safety applications, (2) the assessment of the operational aspects of messages that support vehicle-to-infrastructure (V2I) safety applications, and (3) comprehension of the operational and implementation characteristics of a prototype security operating concept. To carry out the objectives of the project both vehicles and infrastructure were equipped with the DSRC technology. On the vehicle side, several device and vehicle types were used.

The majority of the vehicles were equipped with a vehicle awareness device . VADs only transmitted the basic safety message (See Section 7.2.1.1 for a complete definition of BSM). They did not perform any safety functions. Basically, they acted as the “remote vehicles” or the “target vehicles.” VADs were installed on passenger, medium-duty, heavy-duty, and transit vehicles. The VAD installations were a mix of personal and fleet vehicles.

Other vehicles were equipped with aftermarket safety devices (ASDs). The ASDs were installed in passenger vehicles only. They generated warnings with an audible cue to the driver. There were two additional ASD-like devices. The first was installed on motorcycles (ASDM) and the other was installed on one bicycle (ASDB). The ASDM transmitted and received messages, but did not provide warnings to the motorcycle driver. The ASDB received messages only (the opposite of the VAD) and did not provide any safety warnings to support data collection for bicycle crash avoidance research and analysis.

Commercial trucks were equipped with retrofit safety device kits. The RSD was a type of aftermarket device but for the commercial fleet. The RSD was connected to the vehicle data bus, giving additional input for the safety warning threat assessment, whereas the ASD used in passenger vehicles was not. The RSD installation also included a tablet to provide a visual cue in addition to the audio to the driver. RSD kits were installed on two local Ann Arbor fleets. An offshoot of the RSD was the Transit Retrofit Platform . It was specifically designed for transit and was installed in the UM bus fleet.

Last, there were two integrated device platforms: integrated light vehicles and commercial connected vehicle – integrated truck . They were connected to the vehicle data bus and had a suite of warnings that include visual, haptic, and audio cues. The ILVs were supplied by CAMP as a subcontractor to USDOT. The CCV-ITs were supplied by subcontractor Battelle. The vehicle make-up and responsibilities were quite complex for this project, but can be summarized in the Table 1-1below:

Table 1-1: Summary of Characteristics of DSRC Devices Deployed in Safety Pilot

Device	Tx[5]	Rx	DVI	Vehicle Installation	Weight Class	On-Board Safety Applications	Planned Quantity
VAD	Y	N	None	Participants' personal vehicles installed at UMTRI plus offsite-fleet installations	Light, Medium, Heavy Duty and Transit	N	2450
ASD	Y	Y	Audio	Participants' personal vehicles installed at UMTRI	Light	Y	300
ASD-M	Y	Y	None	UMTRI	N/A	N	6
ASD-B	N	Y	None	Chalmers	N/A	N	1
RSD	Y	Y	Audio plus display	Kits provided by Battelle and SWRI, installed by UMTRI	Commercial Heavy Duty	Y	16
TRP	Y	Y	Audio plus display	Kits installed by Battelle on transit	Heavy Duty Transit	Y	3
ILV	Y	Y	Audio, visual, and haptic (dependent on OEM)	CAMP	Light	Y	64
CCV-IT	Y	Y	Audio plus display	Battelle	Commercial Heavy Duty	Y	3

On the infrastructure side, DSRC devices known as roadside equipment were installed in Northeast Ann Arbor in the SPMD area. In addition to the RSEs, signal-phase-and-timing-enabled signal controllers were also required, as well as an interface device between the SPaT signal controllers and the RSEs. For TRP, pedestrian detection hardware was installed at the intersection in front of the University of Michigan Hospital.

The roles and responsibilities of the test conductor team are summarized below:

University of Michigan Transportation Research Institute: UMTRI, as the prime contractor, was responsible for the overall program management of the SPMD. UMTRI was also responsible for the experiment plan; subject management (recruitment, scheduling, and institutional review board (IRB)

[5] Tx and Rx indicate if a unique ID for device transmission and receiving of messages was provided.

submissions); supplier selection for ASD, VAD, and RSE devices; installing and maintaining the vehicle fleets (VAD, ASD, RSD, motorcycle, and bicycle fleets); interacting with the commercial fleets; data management; security; state of health monitoring; and overall technology development.

Parsons Brinckerhoff: PB was the infrastructure lead. It was responsible for all of the RSE installations for SPMD. It was also were responsible for maintenance of those devices (infrastructure support).

Leidos: Leidos led the interoperability testing. It was also responsible for the LCDS. Leidos was also a subcontractor to USDOT for the SCMS and represented both the test conductor and USDOT in supporting the overall security management concept of operation development.

Mixon Hill, Inc.: Mixon Hill operated and maintained the infrastructure back-office for the SPMD. In that capacity, it was responsible for the security integrity of the back-office, and collecting, parsing, and storing the pcap files[6] offloaded from the RSEs. Additionally, it monitored the state of health of the RSEs and associated network.

Ann Arbor: The City of Ann Arbor served as the backhaul infrastructure provider. It provided support for the test bed Internet Service Provider link (IPv4 and IPv6), and support for the installation of signal phase and timing in conjunction with new Econolite and Siemens signal controllers. It also supported the project for equipment installation, power, network communications, SNMP[7] traps/monitoring/alerting (once the infrastructure equipment was configured for this feature), and operations support in the field.

Michigan Department of Transportation: MDOT supported the project by coordinating with PB on resolving any issues with the infrastructure installations on State property (freeway sites) and within State right-of-way (including freeway sites and some arterial sites). MDOT also provided financial support for the project in the way of $350,000 cash and paying over $90,000 for the freeway site installations.

HNTB Corp.: HNTB developed the infrastructure installation plans for the freeway sites. It also played a major role in outreach. HNTB developed the Orlando ITS World Congress plan and the Outreach and Showcase plan. It developed printed material for conferences, meetings, and other marketing needs. It created two videos describing DSRC technology and SPMD. HNTB also maintained the Safety Pilot Web site.

Texas A&M Transportation Institute: TTI worked in the area of "other applications." It attempted to develop an application for at-grade railroad crossings.

Escrypt – Embedded Security: As security industry experts, Escrypt was responsible for consulting and providing guidance on the development of the security management system concept of operations.

[6] Packet capture (pcap) data file used to capture data packets traveling over a network.
[7] Simple Network Management Protocol is a network broadcast that specific network monitoring and management applications use to display report, store, process, track, and use for device statistics, status, and health/state (or device message traps). SNMP can be used within network address ranges or as broadcast across networks via routing and firewall rules.

2 Program Management

The SPMD program was broken down into several stages.

1. Pre-Model Deployment
   a. Phase 1: Planning (6 months)
   b. Phase 2: Preparation and installation of required components (6 months concurrent with Phase 3)
   c. Phase 3: Execution of the pre-model deployment Tests (acceptance and interoperability of sample devices) (6 months concurrent with Phase 2)
2. Model Deployment (12 months)
3. Post-Model Deployment (6 months)

Each stage included various tasks that were described in the Test Conductor Scope of Work. The following table provide stage, phase, and task correspondence.

Table 2-1: Stages, Phases, and Tasks

Pre-Model Deployment **(Phase 1: Planning, Phase 2: Preparation and Installation of Required Components, Phase 3: Execution of the Pre-Model Deployment Tests)**	**Model Depoyment**	**Post-Model deployment**
Task 1: Program Management Task 2: Safety Pilot Planning Task 3: Coordination and Preparation of Vehicle Fleets and Drivers Task 4: Infrastructure Preparation Task 5: Pre-Model Deployment Testing	Task 1: Program Management Task 6: Model Deployment Task 8: Outreach	Task 1: Program Management Task 7: Model Deployment Closeout Task 8: Outreach

2.1 Program Management Approach

UMTRI was responsible for the overall program management for the test conductor team. Generally accepted program management principles were employed that encompassed initiating, planning, executing, monitoring and controlling, and closing processes. A program management plan was created and included the scope baseline, schedule baseline (master schedule), and the cost performance baseline (budget). The following subsidiary plans were also included.

- Configuration Management Plan
- Driver Recruitment Plan

- Driver Training Plan
- Experiment Plan
- Interoperability Test Plan
- Logistics Plan
- Model Deployment Site Plan
- Outreach and Showcase Plan
- Property Management Plan
- Risk Management Plan
- Safety Analysis and Threat Assessment Plan
- Vehicle Fleet Installation Plan – ASD
- Vehicle Fleet Installation Plan – VAD

In order to ensure a successful project, other deliverables were required in addition to the subsidiary plans listed above. In general, some of the deliverables were working documents used to communicate among all the parties involved to provide technical direction for model deployment, such as the Security Management System Concept of Operations; some were plans or instructions, such as the ASD Installation Guide; some were analysis reports, such as the Safety Analysis and Threat Assessment; some were test process documents, such as the Interoperability Test Plan. Each of the deliverables has a specific audience and purpose. A full description of all deliverables, why they were developed, and how they were used is contained in Appendix A.

Progress reports were submitted monthly. The progress reports documented the work completed in the period of performance and the work to be completed in the next period. Earned value analysis was used to track the status of the project and was also reported on a monthly basis. The EVA metrics reported indicated whether or not the overall project was on schedule and on budget. The EVA report also included any deviations from the plan or concerns that may impact the plan at a later date.

2.2 Safety Pilot Coordination

The SPMD program was very complex and required a significant amount of coordination between USDOT, the test conductor, USDOT contractors, test conductor partners, and test conductor suppliers.

USDOT offices and Modal Administrations involved with Safety Pilot Model Deployment included:

- ITS JPO/OST-R – test conductor co-COTR, Battelle CCV-IT COTR, RSD COTR (Battelle and SWRI);
- NHTSA – test conductor co-COTR, CAMP COTR, commercial truck representative;
- FHWA – Battelle COTR for SPaT interface devices, COTR for SPaT signal controllers (Econolite and Siemens), USDOT DSRC device specifications and qualification testing for the qualified product list, Leidos COTR for SCMS servers, Real Time Data Capture and Management Team (Contextual Data and the RDE);
- FMCSA – Commercial Truck Representative;
- FTA – Battelle COTR for TRP; and
- Volpe – Independent evaluator.

USDOT contractors included:

- Leidos as the SCMS contractor;
- CAMP for delivery of 64 ILVs;
- Battelle for the delivery of
    - 8 RSD kits (Sysco Fleet);
    - 3 buses equipped with a TRP system;
    - 3 integrated trucks (CCV-IT);
    - 16 interface devices for the SPaT enabled corridors;
- Southwest Research Institute for the delivery of 8 RSD kits (Con-way fleet)
- Econolite for the delivery of six SPaT-enabled signal controllers (Fuller Road corridor)
- Siemens for the delivery of six SPaT-enabled signal controllers (Plymouth Road corridor)

The test conductor (UMTRI) partners included (reference Section 1 for roles and responsibilities):

- HNTB,
- Parsons Brinckerhoff,
- Mixon-Hill,
- Leidos,
- Escrypt
- MDOT,
- Ann Arbor, and
- TTI.

Test conductor DSRC device suppliers included

- Savari – RSE and VAD;
- Cohda Wireless – VAD;
- Cohda-Delphi – ASD;
- Cohda-Visteon – ASD;
- Denso – ASD; and
- Arada – RSE.

Additionally, there were several other suppliers used to complete the normal course of business for the program, such as Mobile Mark, Inc.; Hirschmann Industrial Networking, Grainger Inc., and Digi-Key Electronics, to name a few.

Several meetings were regularly held to manage the execution and control and monitoring aspects of the SPMD. A brief description of the meetings that involved the test conductor and the interaction with the test conductor, the USDOT, and its subcontractors is below and is organized by the meeting champion.

USDOT

- Program management coordination – weekly meeting held to coordinate activities among all stakeholders. This meeting was used to disseminate information and coordinate activities between the various COTRs. It was also used to track and resolve issues, coordinate schedules, and plan for the overall program. Attendees included NHTSA, ITS JPO, FHWA, FMCSA, FTA, Volpe, SWRI, Battelle, CAMP, VTTI, Leidos, and the test conductor, UMTRI. Topics such as the readiness checklist were reviewed and updated regularly in preparation for model deployment launch.
- Data management – weekly meeting held to develop the data dictionary and interface and coordinate all data management efforts. Attendees included test conductor team (UMTRI, Mixon Hill, and Leidos), CAMP, VTTI, FHWA, Volpe, NHTSA, and SWRI.
- Security – weekly meeting held to finalize the Security Management Operating Concept and rollout plan for all USDOT subcontractors. The document was written by the test conductor and requirements cascaded to the USDOT subcontractors via the respective COTRs. Attendees included NHTSA, Volpe, FHWA, CAMP, VTTI, Security Innovation, and the test conductor team (UMTRI, Leidos, and Mixon Hill).
- Working group meetings – generally held every couple of months during the planning stages of SPMD. The meetings were intended to involve a deep dive into areas that required significant discussion and planning that could not be contained in the weekly program management coordination meetings. The working group meetings typically lasted for two to three days and the attendees depended upon the topic.
- Briefings – conducted quarterly. The briefings were a formal presentation that provided USDOT with a status of the SPMD program, identified any issues, and clarified technical direction as appropriate. The briefings were generally open to all stakeholders and were well attended.
- Outreach – monthly meeting to discuss upcoming conferences and other industry events and coordinate the activities required to support those events. Attendees included ITS JPO/OST-R, NHTSA, and the test conductor team (UMTRI and HNTB).

UMTRI, as the Test Conductor

- Data management – weekly meeting led by UMTRI, held with the test conductor team to resolve issues, prepare documents, and support USDOT data management initiatives identified in the USDOT weekly meeting. Test conductor attendees included UMTRI, Leidos, and Mixon Hill.
- Security – weekly meeting held with the test conductor team to prepare documents and diagrams for review and discussion in the weekly USDOT security meeting. It was the test conductor’s responsibility to deliver the Security Management Concept of Operation document. Test conductor attendees included UMTRI, Leidos, Mixon Hill, and Escrypt.
- Test Conductor team – bi-weekly meeting led by UMTRI to report on the status of the infrastructure, back-office, interoperability testing, and outreach. Issues were identified and discussed for resolution and planning. Test conductor team attendees included UMTRI, Mixon Hill, Leidos, Parsons Brinckerhoff, and HNTB.

- UMTRI SPMD team – weekly meetings held with the internal UMTRI team that focused on VAD, ASD, RSD, TRP, motorcycle, and bicycle installations, recruitment, and subject management. Test conductor attendees included only UMTRI personnel.
- Cohda Wireless supplier meeting – bi-weekly meeting led by UMTRI and attended by Cohda Wireless to discuss and resolve open action items and coordinate upcoming deliverables and events for ASDs and VADs, such interoperability testing.
- Savari supplier meeting – bi-weekly meeting led by UMTRI and attended by Savari, Parsons Brinckerhoff, and Mixon Hill to discuss and resolve open action items and coordinate upcoming deliverables and events for VADs and RSEs such as coordinating the rollout plan for a software update.
- Denso supplier meeting – bi-weekly meeting led by UMTRI and attended by Denso to discuss and resolve open action items and coordinate upcoming deliverables and events for ASDs. After the contract with Battelle expired for RSD support, RSDs were also brought into this meeting and were tracked by the test conductor.

2.3 Project Scope Management

The overall scope of the contract was to establish a real-world model deployment test site for enabling wireless communications among vehicles and with roadside equipment, and foster natural interactions among equipped vehicles to facilitate operation of V2V-based crash avoidance warning systems. The deployment site was to encompass vehicles of various types that include a mix of integrated, retrofit, and aftermarket vehicle safety systems. Some of the model deployment data generated and archived was used to help support the estimation of safety benefits that was used by NHTSA as an input to their decision concerning whether to require V2V technology in future vehicles, as well as for use by the broader industry to refine and develop additional V2V crash avoidance applications.

The scope baseline was documented in the program management plan and consisted of the scope statement and the work breakdown structure (see Appendix B). As the project progressed, issues were identified and the ensuing resolutions impacted the scope of the project. Additionally, USDOT modified the project to address various technical, procedural, and operational issues as the issues were identified and modification of the project was deemed the best alternative. Sometimes the contract was modified due to external dependencies not meeting program timing. Contract modifications that were made that impacted the scope of the project are described below. Not all modifications are listed as they did not affect the scope of the project.

2.3.1 MOD 2

- Added a project decision log as a deliverable due at the end of the project. The intent of the project decision log was to capture any decisions that were made that may have an impact on policy for a national deployment.
- Revised the deliverables for the process for equipping vehicles with ASDs and VADs and the associated schedules. The vision for SPMD was that QPLs would be available at the start of the program. The suppliers would be selected from that list and the processes created for

installation. However, since this was not the case, it was agreed to submit an outline first that contained all items that would need to be defined to make the installation process complete. After supplier selection and pre-model deployment testing was complete, the final installation processes were submitted for both ASDs and VADs.

2.3.2 MOD 4

- USDOT brought an additional RSD vendor on board. This increased the number of RSD kit installations that were to be installed by the test conductor from eight to sixteen. It also increased the amount of support and coordination required by the test conductor from supporting one company (Battelle) to supporting an additional company (SWRI).
- USDOT requested equipping the entire Battelle RSD fleet with an UMTRI DAS, deviating from the original plan of only equipping 4 of the 8 Battelle RSD kits with a DAS. The request also included fabricating 2 spares.
- Because USDOT did not be provide a VAD QPL, the test conductor needed to increase its involvement in the supplier evaluation and selection process. The test conductor became responsible for putting together a comprehensive Request for Quote package that included engineering requirements and conducted an in-depth supplier evaluation – rather than selecting suppliers from the QPL list.
- The responsibility for tracking, inventory, maintenance, insurance, driver selection, subjective questionnaires, data harvest scheduling and coordination, and decommissioning of the ILVs was moved from CAMP to the test conductor.

2.3.3 MOD 6

- The final RSE 3.0 design specification to be used for the SPMD was delayed until March 2012. This caused the RSE QPL promise date to change from January 2012 to March 2012 to sometime in April or May 2012 to allow enough time for prospective suppliers to incorporate the design specification changes in their products prior to qualification testing. Because of the delay, the RSEs were not installed prior to pre-model deployment testing or model deployment launch. It was decided to implement a 2-stage RSE installation plan. In the first stage, repurposed roof-of-concept RSEs would be installed at six key locations in the model deployment area. These RSEs would be updated to offload data logs to meet the data collection goals. In the second phase, the SPMD RSEs would be installed according to the original plan. This was in early December 2012, after the model deployment launch.
- The revised RSE specification included IPv6, which required the test conductor to modify the interface between the City of Ann Arbor back-haul (IPv4) and the RSEs. To implement this, the test conductor updated the infrastructure site plan; purchased and installed additional infrastructure equipment; and supported USDOT DSRC/IOP device testing by setting up temporary IPv6 servers, working with device vendors to use the temporary back office, and supporting interoperability testing over the IPv6 network.
- The Transit Retrofit Package contract was awarded by USDOT in December 2011, after the test conductor contract award and after the initial infrastructure site plans were developed. The TRP program included the development of a pedestrian crosswalk detection safety application. In

order for this application to function properly, a crosswalk motion sensor was required to be installed at the applicable intersections and connected to the roadside equipment already deployed at that intersection. To support the TRP program, the test conductor updated the model deployment site plan, coordinated with the TRP team to procure additional equipment for the installation, and maintained the TRP-related infrastructure.

- USDOT revised the minimum performance requirements for data acquisition for heavy vehicles impacting RSD, TRP, and CCV-IT. The additional scope for the test conductor was to add forward range sensors to the UMTRI DAS.
- As roles and responsibilities were defined during the development of the introduction of the ILV fleet, the test conductor took on the role to provide license plates and insurance to the CCV-IT trucks that were transferred to the test conductor.
- The initial plans for the antennas to be used for VAD and ASD installations were to use a dual-band magnetic mount DSRC/GPS antennas. However, this configuration was not suitable for a 1-year deployment on participants' personal vehicles. The types of damage that could occur included uneven fading, pitting, and scratching of painted surfaces, broken leads, water intrusion that follows the antenna leads, and the potential for body panel damage due to antennas that come lose. In an attempt to compromise between an interior- and exterior-mounted antennas, it was decided that antenna installation testing would be included in the scope of the project. The test conductor collaborated and coordinated testing with CAMP.
- It was projected that the ASD QPL would not delivered in time to meet the final due date for ASD procurement. It was decided that as in the case for VADs, the test conductor would increase involvement in the ASD supplier evaluation and selection process. The test conductor became responsible for putting together a comprehensive RFQ package that included engineering requirements and conducting an in-depth supplier evaluation – rather than selecting suppliers from the QPL list. Furthermore, the units for both Stage I interoperability and pre-model deployment testing were purchased from all prospective suppliers, and the final supplier selection process was conducted afterwards.

2.3.4 MOD 11

- To better understand the level of security of the SCMS for the SPMD, the USDOT conducted unannounced security penetration testing. The testing showed flaws in the system and identified corrective actions for the device manufacturers. Given that the test was unannounced and information was not provided to either federal project managers or the Test conductor, corrective action was taken to protect the system once the security breach was detected. Protecting the system entailed quarantined and sanitized all of the data collected between program start and December 2012 when the test was conducted. In order to do this, a temporary network was established and the existing network was rebuilt. All devices were given new IPv6 addresses, and all passwords were changed for data transfers between Mixon Hill, Ann Arbor, and the UMTRI team.

2.3.5 MOD 12

- In order to support future USDOT research goals related to DSRC technology, USDOT decided to continue to maintain and operate the SPMD environment. The implementation of this direction was done in two steps. First, the data collection was continued for an additional six months to allow USDOT to develop a transition plan from SPMD to the proposed Connected Vehicle Test Environment.

2.3.6 MOD 13

- Since the site is transitioning to an operational test bed, the second step was to remove the decommissioning activities from the post-model deployment phase of the program.

2.4 Project Time Management

An initial master schedule was developed and submitted with the Program Management Plan. There were two major schedule milestones that dictated the overall schedule. The first was that the model deployment launch date needed to occur by August 21, 2012, in order to ensure that the second major milestone was met – the NHTSA agency decision by the end of 2013. A high-level view of the initial master schedule is shown in Figure 2-1 below.

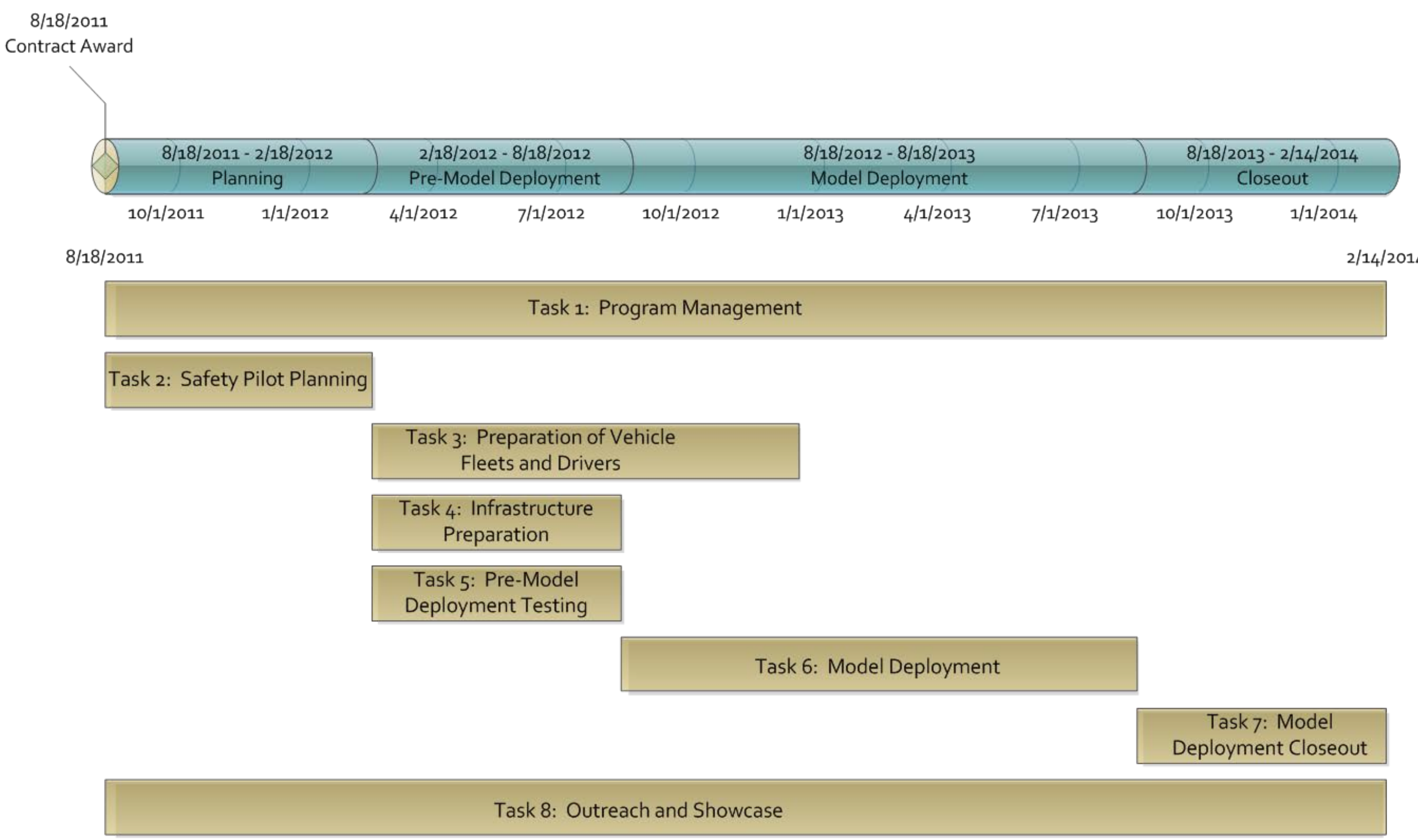

Figure 2-1: Initial High Level Master Schedule

The master schedule was updated on a monthly basis. The initial schedule did not include all tasks since many of the subsidiary plans were under development. Specifically, the items below were added after the initial release of the master schedule.

- Infrastructure Site Installation Schedule
- Interoperability Testing Schedule
- Vehicle Fleet Installation Schedules
- Showcase and Outreach Schedule
- Overall Logistical Support Schedule

Additionally, as activities were refined in the coordination and working group meetings, the schedule was updated accordingly. For example, once it was determined that additional antenna testing was required, a plan was developed to conduct the testing and that plan was added to the master schedule. The schedule was also updated as issues were discovered and the ensuing resolutions impacted the schedule. As with many projects, the master schedule was a "living document" and would be updated to reflect the current status of the program.

Several factors impacted the schedule, including:

- Device readiness:
    - Affected RSE installation schedule. The two-stage RSE installation approach (see section 2.3) introduced about a 4-month delay in having fully functional RSEs deployed. However, by implementing this approach, the August launch date remained intact.
    - Siemens controller timing delayed SPaT roll-out on Plymouth Road Corridor.[8] There was confusion in program direction on which SPaT specification to use, which caused a 12-month delay in the Siemens installations. However, since no SPaT applications were introduced in SPMD, there was no impact to the project.
    - Interoperability Testing – at the start of SPMD, additional rounds of testing were added because of device availability. As the project progressed, additional rounds of testing were added because of corrective updates to resolve issues in the field. The rounds of testing were strategically placed in the schedule to support future work, instead of delaying it.
- Ability to recruit participants to meet initial VAD installation schedule. Initially, the VAD installations were scheduled to start August 10, 2012, and be completed by October 19, 2012. Instead, the participant VAD installations were completed by November 30, 2012, and the fleets were completed by March 29, 2013.
- Longer-than-anticipated ASD installation times made it impossible to meet initial ASD installation schedule. Initial ASD installations were scheduled to begin August 6, 2012, and be completed by October 8, 2012. The actual ASD model deployment installations started October 8, 2012, and were completed April 1, 2013.
- Ability to place Integrated Truck fleet delayed its introduction. The CCT-IT tractors were transferred to UMTRI on September 4, 2012, and the trailers were transferred on September 24, 2012. Initially Con-way was slated to place the CCV-IT trucks in its fleet. However, the trucks' configuration was not conducive to Con-way's use. Two substitute fleets were identified: the Blue Day Cab was deployed with Rightaway on November 2, 2012, and the Red and White trucks were deployed with 4H on January 28, 2013.
- Lack of IPv6 service provider capabilities delayed RSE freeway sites deployment scheduled for December 2012. The freeway site installations were completed in March 2014 but were not brought online until June 9, 2014 due to the security certificate issue described in section 4.4.

Even with the additions in scope and issues found during ramp up and after deployment, The SPMD launch took place on schedule, August 21, 2012, that supported the 2013 NHTSA agency decision. The final high-level view of the schedule is shown in Figure 2-2 below.

[8] A new version of SPaT was developed by FHWA and transmitted during the SPMD. RSE and vehicles logged receipt of the messages, however, there were no applications using the SPaT message.

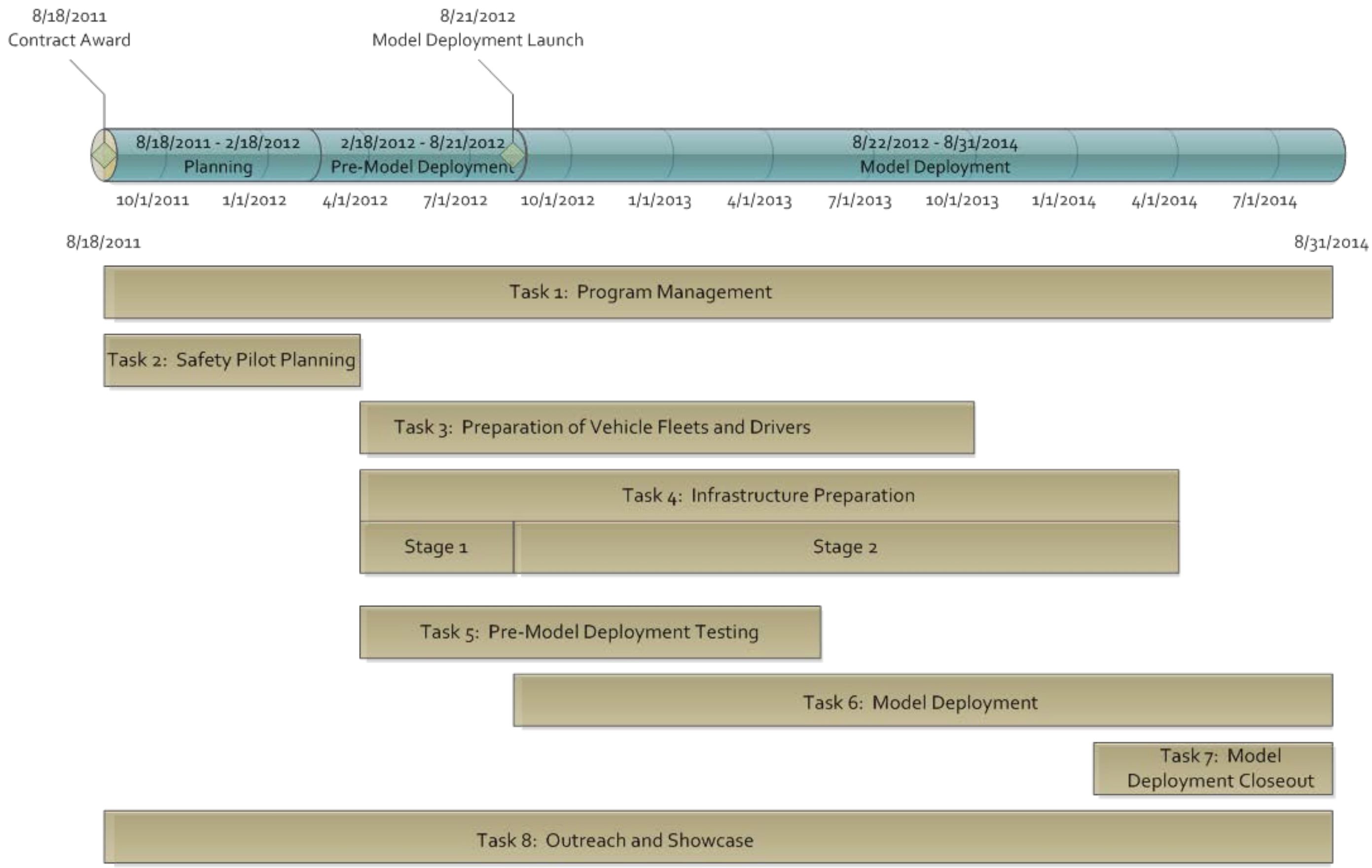

Figure 2-2: Final High-Level Program Schedule

2.5 Project Cost Management

The original budget for the Safety Pilot Model Deployment is shown in Table 2-2 below:

Table 2-2: Original Safety Pilot Model Deployment Budget by Task

Budget Task Area	Federal Funds	Cost Share	Total
Task Area 1: Program Management	$1,269,064	$603,884	$1,872,948
Task Area 2: SPMD Planning	$1,381,184	$278,439	$1,659,623
Task Area 3: Coordination & Preparation of Fleets & Drivers	$3,373,581	$492,029	$3,865,610
Task Area 4: Infrastructure Preparation	$3,919,921	$170,126	$4,090,047
Task Area 5: Pre-Model Deployment Testing	$980,186	$390,755	$1,370,941
Task Area 6: Model Deployment	$2,222,352	$1,414,326	$3,636,678
Task Area 7: Model Deployment Closeout	$889,164	$120,542	$1,009,706
Task Area 8: Outreach & Showcase	$895,871	$389,121	$1,284,992
TOTAL	**$14,931,323**	**$3,859,222**	**$18,790,545**

The cost baseline changed during the course of the project due to changes to the scope and schedule changes discussed in the sections above. The budget changes are shown below inTable 2-3, "Summary of Budget Changes from Contract Modifications." Only the modifications that impacted the cost are included in the table.

Table 2-3: Summary of Budgets Changes From Contract Modifications

Budget Description	Federal Funds	Cost Share	Total
Original Budget	$14,931,323	$3,859,222	$18,790,545
MOD 4	$643,088	$160,772	$803,860
MOD 5	$2,240,351	-	$2,240,351
MOD 6	$4,109,710	-	$4,109,710
MOD 8	$891,024	-	$891,024
MOD 11	$434,537	-	$434,537
MOD 12	$2,269,190	$597,289	$2,866,479
TOTAL	**$25,519,223**	**$4,617,283**	**$30,136,506**

- MOD 4:
    - Increase the number of RSD kits from 8 to 16
    - Fabricate 6 additional DAS and install in 4 RSD heavy duty vehicles
    - VAD supplier selection (in lieu of a QPL)
    - Move responsibility of CAMP vehicles to test conductor (tracking, inventory, maintenance, insurance, driver selection, subjective questionnaires, data harvest scheduling and coordination, and decommissioning)
- MOD 5:
    - Increase the budget to account for the actual cost of VAD devices as opposed to the original plug number used to create the proposal budget
- MOD 6:
    - Implement a two-stage RSE deployment
    - Support IPv6 interface to SCMS
    - Install and maintain infrastructure for TRP pedestrian application
    - Update heavy-vehicle DAS
    - ASD supplier selection (in lieu of a QPL)
    - Driver clinics for TRP in SPMD and increase the amount of compensation for TRP participation as a result of the unanticipated volume of drivers that would be involved
    - Transfer CCV-IT to test conductor
    - ASD and VAD antenna installation and packaging design and testing
- MOD 8:
    - Additional support required for RSEs (engineering labor hours) to complete the installation as a result of the immaturity of product
    - Additional labor required beyond initial estimates to complete VAD and ASD builds as determined after the installations processes were finalized

    - Additional servers required for the back office management and storage of pcap and BSM data – the amount of data collected far exceeded initial estimates
- MOD 11:
    - Additional engineering hours and servers required to quarantine and clean data from unanticipated consequences of USDOT security testing
- MOD 12:
    - Data collection extended for six additional months

2.6 Property and Configuration Management Plan

For a project this large, it was imperative to be able to accurately track all assets and their respective configurations. Otherwise, it would have been impossible to manage any type of change control. Two separate PCMS were used – (1) for infrastructure-installed components and (2) for vehicles and vehicle-installed components.

2.6.1 Infrastructure PCMS

The methodology for property management for the infrastructure included labeling each device used during SPMD on the front face and rear face (center top; unless obscuring a critical sub-component). These labels provided the asset or property tie-in to the tracking system for identification, confirmation, tracking and support for configuration management. The components were classified by device type/class (network end point, network backhaul, radio, network router, network switch, VMS, detector, etc.). Each device label used the year, the three alpha-numeric device class abbreviation, three-character manufacturer abbreviation, site ID, and device ID to comprise a unique asset identifier. The unique asset identifier was tied to a unique database record within the property management system. A simple (lightweight) Web-based application for entry and management of critical component and property management attributes was developed and used for SPMD. This application reduced the amount of time required to effectively input, store, retrieve, and access property information for the infrastructure components. This system supported the following uses within the application framework:

- Property Management (tracking key asset infrastructure fields and datasets)
- Infrastructure Components Configuration Management (tracking device, component, cabling, CM datasets)
- Basic Reporting and Querying (based on input criteria)
- Web-enabled entry, edit, retrieval, and storage for assets and configuration data

2.6.2 Vehicle-based PCMS

The vehicle-based PCMS used barcodes because of the volume of vehicles and devices that were tracked. As each ASD and VAD device was received from the supplier, a tracking number was assigned. The tracking number was printed on a barcode and affixed to the device. The tracking number was designed to easily discern the device type by combining a three-letter device designation with a one-letter supplier designation plus a four-digit number to uniquely identify each device. The serial numbers for each of the devices were stored in a database along with the tracking number.

In addition to tracking the ASD- and VAD-equipped vehicles (Table 2-4), entries were done for the RSD, TRP, CCV-IT, and ILVs as well. Device barcodes were assigned as TRPXXXX, RSDCXXXX (SWRI), RSDDXXXX (Battelle), ISPDXXXX, and CCVDXXXX.

Table 2-4: Device Barcode Designations

Device Type	Device Designation	Supplier Designation	Sample Tracking Number
Aftermarket Safety Device	ASD	C = Cohda/Delphi V = Cohda/Visteon D = Denso	ASDC1234 ASDV1234 ASDD1234
Vehicle Awareness Device	VAD	C = Cohda S = Savari	VADC1234 VADS1234

A second database was created to store all vehicle installations. For each vehicle installation the following were recorded: date and time of the installation; participant ID; VIN; certificate batch; width and length of the vehicle; x-, y-, and z-offset; vehicle type, year, make, model, and color; unique ID, device barcode, visit type, location of installation, and installer

Pictures were taken to document the state of the vehicle and the installation. Specifically, pictures were taken of the front, rear, and both sides of the vehicle; the GPS antenna installation; the DSRC antenna installation; the device installation and device barcode; the power source location; and the license plate. Additional pictures were taken for ASD installations to include the DAS and peripherals and the speaker. The pictures could be retrieved at a later date to confirm details of the installation like antenna placement or type, type of power source (add-a-circuit versus OBD II connector), original state of the vehicle (proof of any existing damage), device location, etc. Some of the pictures taken are shown Figure 2-3 below.

Figure 2-3: Sample pictures stored in the PCMS. From left to right – power source, right side of vehicle, and location of VAD and barcode

Also, the VIN was used to create another database that documented the vehicle attributes that could be joined with the installations database for a richer data set for purposes of the SPMD. The vehicle attributes were:

- Year, make, model, and series,
- Body style,

- Weight, width, length, and wheelbase,
- Restraints,
- Engine size,
- Transmission,
- Class,
- Style, and
- MSRP.

In addition to the installation information, the configuration file was recorded. The configuration file was what was written to the media that was then read and used by the DSRC device. The configuration file included the unique ID, antenna offsets, vehicle length and width for all vehicles, and security certificates for VADs only. Figure 2-4 below is an overall representation of the PCMS used for vehicle installations.

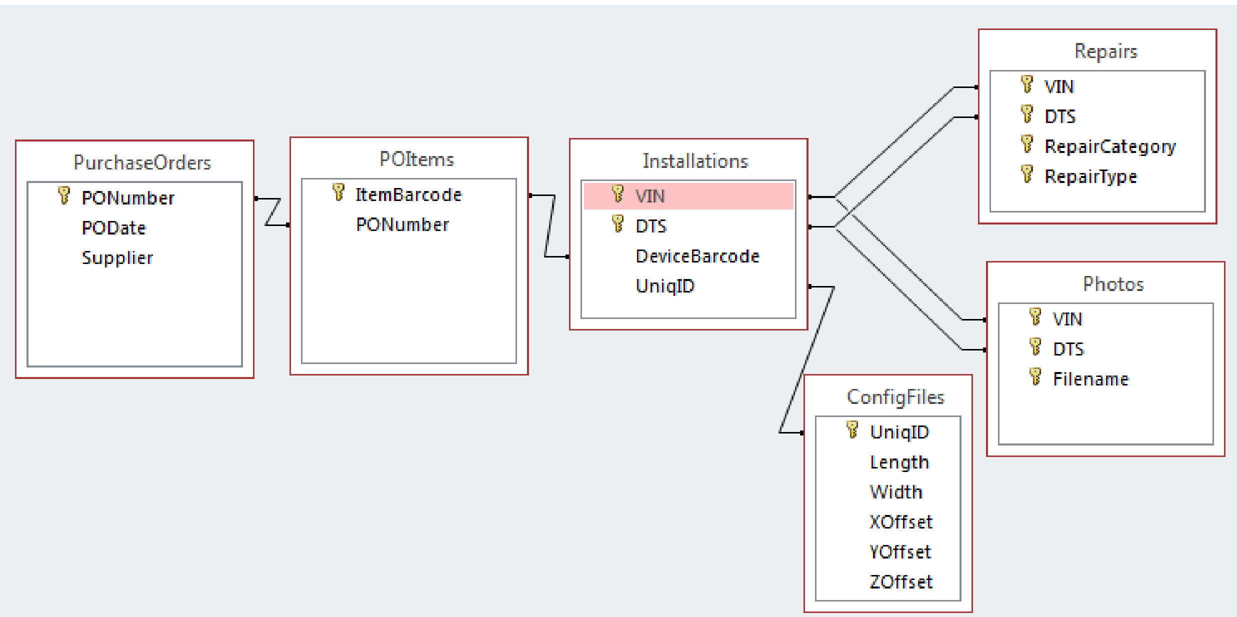

Figure 2-4: High Level Depiction of the PCMS Components

The PCMS was based on requirements identified at the beginning of the contract. As such, the vehicle PCMS was very capable of tracking the installations. However, other needs arose during post analysis. At that point it was discovered that it was not as straightforward to track device and vehicle updates that were completed. No one realized the magnitude of changes that would occur in the field at the program onset and the level of detail need to analyze the root cause of false positive alerts. Initially, the test conductor designed a Web-based tool to do this, but it was not searchable at the level of detail need by the analysts. Therefore, changes were made to create a repair table to better track updates.

The last component of the PCMS system was change control. The process for changing any component (hardware, software, or firmware) in the deployment system was the same, regardless of manufacturer or device. For SPMD, issues were identified through Interoperability Testing and performance issues identified in the field. Once an issue was identified, a SPMD change request was initiated. The change requests were called “problem trouble report and resolution.” A unique number was assigned to each PTRR. The numbering was sequential starting with SPMD-001. Each PTRR had a unique title for easy association with the issue. The subsystem and component was clearly identified. The PTRR was issued to all affected parties (issue owner). The issue owner used system engineering best practices to:

- Describe the issue,
- Determine the root cause,
- Develop the corrective action,
    - Short-term corrective action,
    - Long-term corrective action,
- Develop an implementation plan, and
- Verify/validate the change.

All PTRRs were reviewed by UMTRI to represent the vehicle and fleet interests, by Parsons Brinckerhoff to represent the infrastructure interests, and by USDOT to represent all government stakeholders and their contractors. Over the duration of SPMD, 57 PTRRs were identified and addressed.

2.7 Risk Management Plan

The risk management plan was created and submitted as part of the overall project management plan. The risk log was begun in November 2011 and was completed in December 2011. It was created by

- Identifying risks,
- Qualitatively analyzing the risks,
- Quantitatively analyzing the risks, and
- Creating risk response plans.

The risk log moved from the planning process to the controlling process (monitor and control risk) and was reviewed regularly at the test conductor team meetings. In addition to the risk log and the associated high-level contingency plans, USDOT and UMTRI also developed in-depth risk response plans for possible events that might occur and significantly affect the success of the SPMD launch. The possible identified events are summarized below.

- Insufficient number of V2V interactions in the field
- Not enough drivers recruited
- Unqualified Stage 2 RSE vendors
- IPv6 that did not work as intended
- Security was not fully defined and implemented as required
- Antenna testing results showed that interior mounted antennas provided unacceptable performance
- PII data was accessed by general public or otherwise breached
- Someone hacked into a DSRC unit and now has valid certificates

- A “crisis” was encountered by a participant (a crisis was defined as an event that resulted in harm to the participant or by the participant, adverse publicity, and/or adverse impact for the SPMD project, USDOT and its contractors, and the project partners)

A full description of the risks, how they were monitored and their contingency plans are fully described in a presentation to USDOT titled “Review of Risk Response Plans” by Debby Bezzina, dated April 16, 2012 (Appendix C). This document was reviewed regularly by the test conductor and USDOT to evaluate whether a trigger point had occurred and to evaluate if and when a contingency plan should be executed. It also aided evaluation of alternative options for mitigating the risks. The ensuing discussions between the test conductor and USDOT helped to maintain focus on successfully launching model deployment on time.

3 Outreach

UMTRI's goal for the SPMD outreach and showcase task was to assist the USDOT in increasing visibility and understanding of the vehicle communications program and its benefits on a national basis, while also educating the residents of Ann Arbor and the industry about the SPMD program. The UMTRI team facilitated outreach and showcase activities to educate a variety of audiences about SPMD and the benefits of vehicle communication technologies as NHTSA prepared for the 2013 agency decision on whether to move forward with regulation to require V2V technology in new vehicles.

The primary deliverables of the outreach task included the development of the 2011 ITS World Congress Showcase Plan, an Overall showcase plan for SPMD, and an outreach plan. Each of these plans included specific deliverables, as described below and in the following subsections:

- The outreach effort for SPMD was kicked off at the 2011 ITS World Congress. More than 1,000 attendees visited the outdoor tent, where DSRC providers showcased their products and CAMP signed up attendees for demonstration rides. Details of this event are included in Section 3.1.
- The showcase plan outlined the creation of facilities at UMTRI where V2V communications could be demonstrated. The specifics are provided in Section 3.2.
- The outreach plan included the development of various promotional materials, including banners, brochures, fact sheets, and a video. It also involved numerous events that took place during SPMD. While numerous conferences and events were supported by the SPMD outreach team, the Safety Pilot launch on August 21, 2012, was a significant milestone and attracted national press. Recognition of SPMD activity increased significantly after the launch event.

3.1 2011 ITS World Congress (Orlando) Showcase Plan

The initial outreach task involved the development of a showcase plan for the 2011 ITS World Congress in Orlando on October 16-20, 2011. HNTB was responsible for preparing the showcase plan, but more importantly, executing preparations for the 2011 ITS World Congress. Given that the subcontract for outreach activities was executed on August 18, 2011, less than two months were available to develop and execute the plan for the World Congress.

The 2011 ITS World Congress Showcase Plan involved considerable coordination with SPMD partners and potential vendors, including USDOT, CAMP, DSRC equipment providers, the World Congress organizers, members of the Battelle Connected Commercial Vehicle Project, and members of the SPMD test conductor team.

The primary deliverable of the showcase plan was the SPMD exhibit at the 2011 ITS World Congress. An accelerated project management plan was put into place involving planning, coordination, design, assembly, and staffing of a SPMD exhibit at the ITS World Congress to complete the exhibit and SPMD collateral materials (banners, brochures, signage, etc.) within less than two months.

Table 3-1includes the various activities and deliverables involved in delivery of the showcase at the 2011 ITS World Congress.

Table 3-1: Showcase Deliverables at 2011 ITS World Congress

TASK	DELIVERABLE	COMPLETION DATE
COORDINATION		
Engage CAMP regarding participation in SPMD exhibit	Exhibit layout showing CAMP table	September 12 – October 20, 2011
Engage 8 vendors regarding participation in the SPMD exhibit	Exhibit layout showing vendor tables and displays set up in clusters by device type	September 12 – October 20, 2011
Engage CCV Project participants for participation in the SPMD exhibit	Exhibit layout showing CCV project kiosk	September 12 – October 20, 2011
Coordinate showcase planning activities with USDOT		September 12 – October 20, 2011
Conduct coordination meetings prior to the World Congress	Coordination meeting notes	Weekly until October 13, 2011
EXHIBIT		
Develop preliminary exhibit layout	Exhibit schematic	September 23, 2011
Finalize exhibit layout	Final exhibit schematic	September 30, 2011
Order exhibit utilities: • Power • Network access	Purchase power and network access	September 23, 2011
Order exhibit furnishings: • Two-sided banner	Furnishings ordered and checked	September 30, 2011

stands • Sign stands • Tables • Chairs • Table drapes • Carpet		
Order other exhibit services	Service requisition and order	September 30, 2011
Prepare preliminary signage	Preliminary signs for devices	October 5, 2011
Prepare final signage	Final signs for devices	October 7, 2011
Prepare preliminary banner design	Preliminary graphics and banner content submission	October 5, 2011
Prepare final banner design	Final banner graphics and content submission	October 7, 2011
Print banners	Two copies each of four final banners	October 7, 2011
Deliver exhibit materials	Materials delivered to site	October 14, 2011
Assemble exhibit	Completed exhibit according to plan	October 14, 2011
Staff exhibit	UMTRI team personnel on site	October 16-20, 2011
Tear down exhibit	Exhibit teardown and shipping	October 20, 2011
PRINT MATERIAL		
Prepare preliminary brochure layout, content and graphics	Preliminary brochure design	October 7, 2011
Prepare final brochure layout, content and graphics	Final brochure design	October 10, 2011

Print brochures	5,000 brochures	October 10, 2011
Deliver brochures	Brochures delivered to site	October 14, 2011
WORLD CONGRESS SHOWCASE DEBRIEFING	Meeting notes	October 28, 2011

The SPMD team met the task deadlines and received positive feedback from all participants on the quality of the exhibit, especially given the tight deadline, and the attention received from ITS World Congress attendees.

The SPMD exhibit at the 2011 ITS World Congress was highly successful. The exhibit was created in a large tent in the parking lot adjacent to the exhibit hall. DSRC providers showcased their products, and CAMP signed up attendees for demonstration rides. An interactive display with tablet computers was the centerpiece of the exhibit. Attendees could view animated scenarios of various V2V applications while they waited for the CAMP demonstrations. Overall, more than 1,000 people ventured into the SPMD exhibit area to meet the vendors, participate in the CAMP demonstrations, or to understand the SPMD program. Attendees included U.S. Congressmen, congressional staff, and many other VIPs from industry and government.

3.2 Showcase Plan

The SPMD showcase plan included the following elements:

- Establishment of showcase facilities at UMTRI and the University's North Campus Research Complex; and
- Establishment of SPMD demonstrations of various applications.

The SPMD showcase complemented other outreach activities through the use of common branding and consistent messaging. Showcase elements were integrated with other outreach activities to provide a broad and captivating outreach and showcase effort.

Elements of the SPMD showcase are described below.

3.2.1 Showcase Facilities

The SPMD showcase facilities are located at UMTRI and the North Campus Research Complex. The SPMD showcase facilities were intended to be practical and functional while also immersing visitors in the SPMD experience. The showcase facilities were designed to accommodate audiences of varying sizes to offer in-depth exploration and examination of SPMD. The showcase facilities planned include:

- The SPMD conference room at UMTRI. This conference room was initially intended to be a control facility for monitoring SPMD operations, for holding small group meetings, and for demonstration of the Data Use, Analysis and Processing Project (a project sponsored by Michigan Department of Transportation). Development of DUAP took longer than anticipated and was not implemented during the model deployment. However, the room was used for small group meetings and deep dives into SPMD during the model deployment.

- The SPMD installation facility at UMTRI. The SPMD installation facility was a key element of the showcase facility at UMTRI. Numerous tours were conducted through this facility, including large indoor and outdoor garage facilities with bays for installations in large vehicles. Hundreds of vehicles were equipped and maintained in these facilities throughout the model deployment.
- The SPMD showcase lobby display and meeting rooms at the NCRC. The NCRC was used for many SPMD meetings, including quarterly briefings. The lobby display attracted considerable attention from students, faculty, and visitors, and was helpful in recruiting SPMD participants.
- Instead of using a test track as initially proposed, Ann Arbor area highways and streets provided the primary demonstration routes for showcasing SPMD applications and technologies. This demonstrated to stakeholders and visitors that SPMD involved real-world drivers and road conditions during all seasons.

3.2.2 SPMD Demonstrations

Demonstrations of vehicle communication applications were integral to an immersive experience for hosted groups. The demonstrations were designed to enhance understanding of the enabling technologies, showcase the potential benefits of vehicle communication technology deployment, and allow participants to experience safety applications first-hand.

On-road demonstrations were conducted by members of the test conductor team along carefully planned routes, including Baxter Road, Green Road, Plymouth Road, Fuller Road, and other area streets. The intent of the on-road demonstration was to showcase SPMD applications in a 20-minute scripted tour.

The tours were conducted in a 15-passenger van, equipped with an ASD. The driver pointed out interactions with other equipped vehicles and roadside unit that came within range. The ASD included a driver-vehicle interface to demonstrate how a driver would interact with the system. The tour also included a brief stop at an RSE location to describe how the infrastructure was configured and integrated with a traffic signal controller for SPaT interactions.

Given the duration and timing of the tours, it was not always possible to experience V2V interaction. However, it was possible to describe such interactions during the tours and also demonstrate V2I applications on these tours that included:

- Curve speed warning,
- Pedestrian warning infrastructure, and
- Ice warning.

The tours were generally combined with a presentation about SPMD and a tour of the installation facilities and other showcase elements.

While over 100 such tours and demonstrations were given during SPMD, it also became clear that all requests could not be accommodated because of the pressing project needs on a daily basis. Equipment, staff, facilities and other program resources were needed on a daily basis for the execution of the model deployment at the same time resources were needed to monitor, maintain, and operated the SPMD.

3.3 Outreach Plan

The Safety Pilot Communications and Outreach Plan presented a comprehensive approach to engage participants, demonstrate SPMD applications, and convey the vision of the SPMD program to a broad array of audiences. This was accomplished through targeted outreach efforts, the creation of on-site facilities, events and demonstrations, creative exhibit materials, and a proactive approach for promoting the SPMD program. The outcome has been broad national and international recognition of SPMD activities and the Vehicle to Vehicle Safety Communications for Application ResearchProgram

The SPMD Communications and Outreach Plan contained the following audiences and elements.

- Community outreach and communications
- Technical and industry outreach
    - Presentations to industry groups
    - Conference participation
    - Hosted events
- Media outreach and communications
- Policymaker outreach

Each of these audiences was critical to SPMD and USDOT education and communications objectives. The outreach approach for each of these audiences was customized as demonstrated in Table 3-2.

Table 3-2: Audiences and Elements of the SPMD Outreach Plan

AUDIENCE	TARGETS	MESSAGE	MEDIA
COMMUNITY OUTREACH AND COMMUNICATIONS			
Community and Program Participants	UM, UM Hospitals, VA Hospital, EPA, Ann Arbor Area Businesses, Con-way Freight, Sysco, AATA	Benefits of participation, FAQs, program updates	Presentations to employees, fact sheets, instructions, brochures, direct mail, Web site, social media

AUDIENCE	TARGETS	MESSAGE	MEDIA
General Public	Local and national media, civic groups, schools, area businesses, the university community	Program facts and vision, FAQs, potential benefits, potential program impacts, businesses opportunities, program costs, program updates	Web site, social media, presentations at schools and other civic venues, fact sheets, brochures, press releases, newspaper and magazine articles, documentary films
TECHNICAL AND INDUSTRY OUTREACH			
Transportation Industry	Auto Industry, infrastructure providers, commercial vehicle operators, transit operators, etc.	Access to and availability of test bed resources, data types and availability, status of the deployment	Web site, social media, technical presentations and papers, technical meetings/conferences
Trade Associations	ITSA, SAE, AASHTO, APTA, SEMA, etc.	Business development opportunities, professional capacity building, status of the deployment	Presentations at meetings, exhibitions, technical papers, white papers, Web site, social media, brochures
Researchers	University consortiums, international research organizations, NAS/TRB, SHRP, etc.	Access to and availability of test bed resources, data types and availability, status of the deployment	Web site, social media, technical presentations and papers, technical meetings
Vendors & Application Developers	DSRC vendors, SEMA, CES, etc.	Access to and availability of test bed resources, data types and availability, status of the deployment	Web site, social media, technical presentations and papers, technical meetings
Federal, State, & Local Government Agencies	Transportation departments, transit agencies, etc.	Program facts and vision, FAQs, potential benefits, program costs, program updates	Web site, social media, presentations, brochures, fact sheets, technical papers, white papers, exhibitions
Other Industry Groups	Insurance industry, transportation safety organizations, advocacy groups, business associations, investment	Program facts and vision, FAQs, potential benefits, program costs, program updates	Web site, social media, presentations, brochures, fact sheets, white papers

AUDIENCE	TARGETS	MESSAGE	MEDIA
	community, etc.		
MEDIA OUTREACH AND COMMUNICATIONS			
Local and National Media	Newspapers, bloggers, trade publications, Web sites, industry newsletters, television	Program facts and vision, FAQs, potential benefits, program costs, program updates	Web site, social media, press releases, press kits, brochures, fact sheets, white papers
POLICY-MAKER OUTREACH			
Federal, State, & Local Elected Officials	Congressional representatives, congressional staff, State legislators, governors, mayors	Program facts and vision, FAQs, potential benefits, program costs, program updates	Web site, social media, presentations, brochures, fact sheets, white papers

The majority of these outreach efforts were jointly performed by USDOT and SPMD test conductor team members. However, community outreach was primarily performed by UMTRI, and federal policymaker outreach was primarily performed by USDOT. The remaining elements were closely coordinated between USDOT and UMTRI through regular (bi-weekly and monthly) meetings and ad hoc meetings, conducted as needed to address specific communications issues.

Community outreach was especially important for driver recruitment and community support of SPMD activities. UMTRI developed an innovative approach for driver recruitment by reaching out to area schools. This approach was highly effective in recruiting the number of drivers required for the program.

Technical and industry outreach activities were especially effective in producing widespread recognition of the SPMD, but also in educating the industry about V2V communication standards, deployment considerations, and other technical aspects of the SPMD program. Many presentations were given to various industry groups throughout the United States and at international venues.

Conference participation was a significant portion of the outreach plan. The SPMD test conductor team participated in numerous conferences as an exhibitor, often in conjunction with other USDOT programs. Table 3-3 provides a list of conferences that was included in the communications and outreach plan, beginning with the 2011 ITS World Congress in Orlando. As a result of the multimodal focus of SPMD, the list includes conferences for commercial vehicles and public transit.

Table 3-3: Outreach Plan Conference Schedule

PLANNED CONFERENCE	DATE
ITS World Congress - Orlando	October 2011
SAE World Congress - Detroit	April 2012
ITS America Annual Meeting - National Harbor	May 2012
ITS Michigan Annual Meeting - Dearborn	May 2012
ITS World Congress – Vienna, Austria	October 2012
Transportation Research Board – Washington, DC	January 2013
American Trucking Association Technology and Maintenance Conference – Nashville	March 2013
SAE World Congress – Detroit	April 2013
APTA Bus and Paratransit Conference - Indianapolis	May 2013
ITS America Annual Meeting – Nashville	June 2013
ITS World Congress – Tokyo	October 2013
Transportation Research Board – Washington, DC	January 2014

The SPMD exhibit was used at all of these conferences except the 2014 TRB Annual Meeting. Although a joint decision was made between UMTRI and the USDOT not to exhibit at TRB in 2014, SPMD was part of the technical program at this event.

In addition to this list of planned events, SPMD was also showcased at the:

- 2013 Institute of Transportation Engineers Great Lakes District Annual Meeting in Grand Rapids, Michigan;
- 2013 APTA ITS Best Practices Workshop in Romulus, Michigan; and
- 2013 IEEE International Conference on Connected Vehicles in Las Vegas.

These additional events facilitated outreach to the traffic engineering community, the transit community, and electrical engineers. These audiences will be involved in deployment of the technologies involved in vehicle communications. The events were conducted within the outreach budget allocated.

Another element of technical and industry outreach involves hosted events in Ann Arbor, at UMTRI and the SPMD test site. The hosted events included:

- The SPMD launch, August 21, 2012;
- The Global Symposium on Connected Vehicles and Infrastructure, May 14-16, 2013 (shown in the outreach plan as "Industry Day");
- The 2013 ITS Michigan Annual Meeting held as an ancillary event in conjunction with the Global Symposium on Connected Vehicles; and
- The 2014 Global Symposium on Connected Vehicles and Infrastructure, April 21-23, 2014.

The SPMD launch was a national media event. NBC national news was on-site at UMTRI to provide a story that aired during the Today Show on the morning of August 21, 2014. Media attention and recognition of SPMD increased significantly after that event, with hundreds of stories in local and national press during the ensuing year.

In addition to the planned, hosted events, numerous one-on-one meetings and tours were held with key stakeholders during the model deployment. Participants included University of Michigan faculty, staff, students, and leadership; government agency officials; industry participants; and foreign delegations. Such meetings were set up by UMTRI upon request from various organizations.

Media relations during the model deployment were highly successful, although this element of the plan required the greatest level of coordination between UMTRI and USDOT. With numerous modal agencies and NHTSA involvement in executing a coordinated communications strategy, it often was difficult to achieve consensus on a media communications approach. However, from these diverse perspectives, an effective media communications effort emerged.

Media outreach was kicked off at the SPMD launch in August 2012, which was a tremendous success at engaging national and local media as a result of the combined efforts of the outreach team. SPMD was featured in hundreds of news stories and industry publications between the August 21, 2012, Safety Pilot launch and the end of data collection in February 2014. Periodic meetings (weekly at first, then bi-weekly and monthly later during the model deployment phase) were helpful in coordinating efforts between UMTRI and USDOT regarding media relations.

3.3.1 Promoting SPMD – Communications and Outreach Tools

Promotion of SPMD was essential to maximize participation and interest in SPMD, but also to promote larger goals of the SPMD program and build awareness regarding NHTSA's 2013 agency decision[9] on V2V technology.

The outreach team developed numerous tools to promote SPMD and to optimize SPMD recognition. They included:

[9] February 3, 2014, NHTSA announcement to move forward with V2V technology for light vehicles

- A graphics portfolio with standard branding materials and templates to be used for all marketing material;
- Presentation materials, including a PowerPoint template with the SPMD wallpaper;
- Exhibit material, including banners, signage, and posters;
- Collateral material, including an attractive brochure that was updated twice during the model deployment and translated into Japanese and Chinese;
- The SPMD Web site (www.safetypilot.uswww.safetypilot.us) and the UMTRI SPMD Web site (http://safetypilot.umtri.umich.edu/) that were used primarily for driver recruitment; and
- The SPMD video and the TRP video.

Other outreach material developed, beyond those included in the Communications and Outreach Plan, included:

- FAQs and fact sheets regarding SPMD;
- Press kits; and
- "Best of ITS" award submission for the 2014 ITS World Congress in Detroit.

These documents were developed as part of the outreach approach for SPMD as outlined in the UMTRI scope of work for the program. All of these tools were part of a comprehensive education, marketing and communications strategy, and used at various events to promote SPMD.

4 Pre-Model Deployment Phase 1: Planning

The planning phase was 12 months long. It included the following work, described in detail below.

- Experiment Plan
- Infrastructure Site Plan
- Logistics Plan
- Security Management System Concept of Operations
- Safety Analysis and Threat Assessment Plan
- IRB Certification Process

4.1 Experiment Plan

The purpose of t he experimental plan was to provide the framework for executing the SPMD program. As such, the experiment plan includes a description and characteristics of the model deployment test area, the population of vehicles and drivers to participate in the model deployment, the V2V communications safety equipment and applications being examined, and specific data elements being collected. Input from USDOT and Volpe was critical to the development of the experiment plan. Specifically, Volpe's simulation of a transportation planning model was the basis for analysis of many aspects of the plan. The model projected vehicle interactions of various deployment/recruitment scenarios to select the model that would maximize interactions. The sections below summarize the final experiment plan and highlight deviations from the plan as the SPMD program progressed.

4.1.1 Safety Pilot Model Deployment Test Area

The SPMD site encompasses the northeast and a portion of the southeast corners of Ann Arbor (see Figure 4-1). The test area includes three major east-west corridors through the east side of Ann Arbor, along with portions of the highways M14 and US23 surrounding the northeast corner of the city. The site encompasses 72 lane miles of roadway, and a wide range of functional classes and annual average daily traffic volumes. The busiest sections in the SPMD test area are the entrances to the highways from North Main Street, Plymouth Road, and Washtenaw Avenue, with ADTs in excess of 30,000 vehicles. Destination generators in the area include several health care centers and hospitals (the University of Michigan Health System, the University of Michigan East Ann Arbor Heath Center, the Ann Arbor Veterans Affairs Hospital, and St. Joseph Mercy Hospital). Local primary and secondary public schools also serve as higher volume origins and destinations for residents of the community. There are four public elementary schools, one middle school, and one public high school in the SPMD geographic area.

There are several institutions of higher education located in or adjacent to the model deployment test area serving as major travel origins and destinations for both educational and employment purposes. The largest of these are the University of Michigan's North and Central Campuses.

Additionally, other major employers include Domino's Pizza, Con-way Freight, Toyota Technical Center, the U.S. EPA Emissions Laboratory, NSK Corp., Masco Cabinetry, and the National Sanitation Foundation.

In total, 24 crash types were found to occur along roads in the SPMD test area. The total number of crashes on route segments in the SPMD test area for the 2001 to 2009 period was 7,296. For SPMD intersections and curves the number of total crashes was 1,424. The three top crash types recorded along SPMD route segments, with crash count indicated in parentheses, were: Rear-End (2,545), Fixed Object (1,332), and Side-Swipe Same Direction (912). The three top crash types recorded within the SPMD-instrumented intersections and curves were: Rear-End (664), Right Turn (158), and Angle Straight (108).

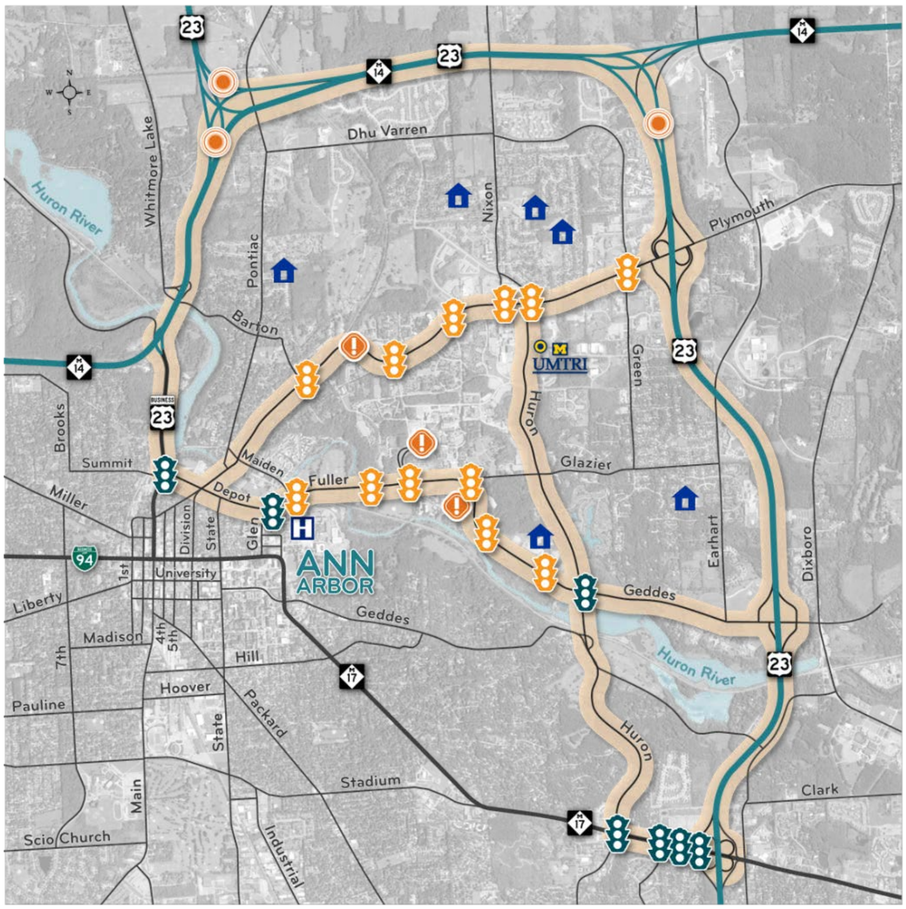

Figure 4-1: Safety Pilot Model Deployment Area

4.1.2 Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communication, Safety, and Data Collection Devices

A combination of DSRC devices were used in the SPMD to enable the V2V and V2I communications, support V2V and V2I safety applications, and collect the data necessary to permit an evaluation by the independent evaluator. The descriptions of each device type are below and the planned deployment volumes for each device are shown inTable 4-1.

Only relatively minor changes were made to the vehicle make up from the original proposal. First, USDOT added a second RSD subcontractor, bringing the total RSD for heavy duty from 8 to 16. Second, the number of transit VADs was reduced from 100 to 82. The intent of the original proposal was to use Ann Arbor Transportation Authority buses. However, after program onset it was determined that there was no set route for a specific AATA bus, only for specific bus drivers. Therefore, there was no guarantee that the buses would be driven in the SPMD area. The university buses, however, were guaranteed to operate in the area, but there were not enough of them to make the 100-transit-vehicle target. Third, the definition of heavy vehicles used was relaxed somewhat to include vehicles on the lower range of the heavy-duty spectrum since it was difficult to find commercial trucks operating consistently within the geographic model deployment area.

Table 4-1: Device Allocation by Vehicle Category

Vehicle Category	ISD	RSD	ASD	VAD	TOTAL
Passenger Cars	64		300	2218	2582
Heavy Trucks	3	16		50	69
Light/Medium Duty UM fleet				100	100
Transit		3		82	85
TOTAL	**67**	**19**	**300**	**2450**	**2836**

Vehicle Awareness Device : Vehicle awareness devices are communication-only devices, and do not contain safety applications. VADs were included in the SPMD predominantly to permit the level of interactions between vehicles equipped with the various safety applications that were necessary to evaluate the safety applications themselves in providing alerts to drivers during conflicts. VADs were planned to be installed on light, medium, and heavy duty vehicles, as well as transit. The test conductor was responsible for the 2,450 VAD installations. The majority of the SPMD fleet were VAD-equipped vehicles.

Aftermarket Safety Device : Aftermarket safety devices both send and receive BSMs. ASDs run three safety applications: curve speed warning, emergency electronic brake light, and forward collision warning. An audible alert was presented to the driver for any of the three safety applications. ASDs were included in the SPMD to evaluate the effectiveness of aftermarket devices to potentially accelerate the penetration of DSRC-equipped vehicles in a national deployment. The test conductor was responsible for and installed approximately 300 ASDs on participants' vehicles, 100 of which hadUMTRI DAS.

Retrofit Safety Device: Retrofit safety devices are like ASDs, but are geared toward the commercial truck sector. They go a step beyond ASDs in that they are connected to the vehicle's data bus so have a richer set of inputs for the threat assessment algorithms. The RSDs also have a tablet for visual cues to the driver in addition to the audible warning. UMTRI was responsible for installing the RSD kits provided by Battelle and SWRI (as subcontractors to USDOT). An offshoot of the RSD was the transit retrofit platform . It had similar content but adds two transit-only applications, namely pedestrian detection and right turn if front warning. The TRP kits were installed by Battelle and delivered to the test conductor as part of a separate contract.

Integrated Safety Devices: Safety devices, in this context, are defined as integrated devices that are part of a system that warns drivers of potential threats. These systems were designed to be "production-like" and be integrated into vehicles as though the systems were factory-installed. The driver-vehicle interface was integrated into the vehicle. The device itself both sent and received BSMs and was connected to the vehicle's data bus. On the light vehicle side, 64 vehicles were provided by CAMP – 8 vehicles each from each of the eight participating OEMs. These vehicles are referred to as integrated light vehicles . On the heavy vehicle side, 3 equipped commercial trucks were provided by Battelle under a separate contract with USDOT. These vehicles were referred to as the Connected Commercial Truck – Integrated Truck, CCV-IT.

4.1.3 Participant Recruitment and Device Assignment

The process used to recruit participants was a departure from UMTRI's original proposal, but was based upon an improved understanding of the data needs and the independent evaluator's expectations gained through discussion of the evaluation needs and analytical modeling. The original approach focused solely on the recruitment of employees from the University of Michigan Health System, where a high concentration of vehicles would gather on a regular basis and a predetermined number of miles could be accumulated based upon knowledge of where the employees lived and worked. The revision focused on recruitment of participants and their vehicles predominantly from the community that comprises the SPMD test area, with additional recruitment from the Health System. This approach was selected in order to achieve several objectives that a health-system-only recruitment approach would not likely achieve. For example, one additional consideration was the variety of vehicle interactions that could be expected with participants recruited from the community. Because the community-based participants had a wide range of origins and destinations for their trips, the range of interaction types (same direction, opposite direction and cross traffic) was higher than if concentrating only on commuter traffic to/from work at the health system – which would have been largely same-direction travel.

The primary and initial recruitment procedure was conducted with the assistance of the Ann Arbor Public Schools located in the SPMD test area. With the support of the central administration of the Ann Arbor Public Schools, emails and printed notices were distributed to the parents of students at the six public schools located in the SPMD test area. A secondary round of recruitment took place covering employees of the University of Michigan Health System, and the University of Michigan College of Engineering.

4.1.3.1 Interaction Scenario Analysis

The nature of the recruitment strategy was driven largely by the need to maximize the likelihood of interactions (i.e., V2V communications) between vehicles in the SPMD by recruiting from three distinct populations: members of the community (connected to the Ann Arbor School System), employees of the University of Michigan Health System, and faculty and staff of the College of Engineering, all of which groups drive regularly in the SPMD area.

Researchers at the Volpe Center developed a model of the number of interactions that could be anticipated in the SPMD. The modeling considered a variety of site characteristics, in addition to the populations of vehicles and their respective devices, in attempting to predict the number of interactions between equipped vehicles. The modeling relied on data regarding trip-taking behaviors, traffic volumes, and the location of various origins and destinations for the SPMD test area. The modeling also included an analysis that examined the impact of adding additional devices on the number of interactions that could be anticipated.

Both the public school and Health System interaction scenarios were modeled and analyzed in an effort to estimate the level of interactions that could be anticipated among all equipped vehicles. The analysis identified the level of estimated interactions in relation to distance between interacting vehicles, and the roads on which these interactions would take place. These estimates were used to select from the various recruitment strategies.

Another benefit of the analysis was that these estimates of interactions formed a performance metric. Broken down by month, it gave a good indication of whether or not the project was on track to meet its data collection goals. And because it was broken down by month, corrective actions could be taken early on in the project rather than waiting until the end when the data analysis was already underway by the independent evaluator. If the interactions were too low, alternative strategies identified in the risk management plan in relation to various causes and remedies for low interactions could have been undertaken.

4.1.3.2 Vehicle and Participant Selection: Lay Participants

Lay participants were required for VADs, ASDs, and ILVs. The VADs and ASDs were installed by UMTRI on the participants' personal vehicles. Participants were also selected for using an ILV, designed and delivered by CAMP, in lieu of their personal vehicles.

UMTRI initially set up a Web siteto take enrollment information from prospective participants and save it to a database. This Web site also served to help disseminate information about SPMD. Prospective participants coming to the site were asked for their contact information, the make, model, and year of their vehicles, and some information about their driving patterns throughout the SPMD area.

Prospective participants were then given the message that if their driving was appropriate, they would be contacted about enrollment. Participants reporting the most driving in the SPMD area were contacted first. The criteria were relaxed as the prime participants were either enrolled or did not respond to emails and phone calls. Any participant with a local address who responded with any weekly driving through any of the areas of interest was contacted and an attempt was made to enroll them.

Prospective participants were directed to the Web site through in-person outreach. The first targets were families in the public school system with children in the elementary, middle, and high schools within the target area. UMTRI researchers attended parent-teacher-student meetings at the various schools to disseminate information and to answer any questions the parents might have. Members of the PTSOs were also informed that participants would be given the option of donating their participation payment to the PTSO at their school.

Next, recruitment was done via the University of Michigan Medical Center Human Resources Department and the University of Michigan College of Engineering. Both are large employers centered in the SPMD area, with strong ties to UMTRI. E-mails were sent to different departments directing people to the recruitment Web site.

Once the vehicle type and driver patterns of a prospective participant were analyzed, that participant was put into the VAD pool (the main pool). The participants were then further analyzed and placed into the ASD and ILV pool as described below.

ASD-only. Participants selected to receive an ASD were chosen from the same registration pool as the VAD participants (via the registration Web site).
Any participant who met the following criteria was offered the opportunity to have an ASD installed in their cars instead of a VAD:

1) Reported substantial driving in the SPMD area;
2) Indicated they would be interested in having a warning system installed in their cars; and
3) Reported owning one of the target vehicles (for ASD-only, this was almost anything).

ASD with DAS. ASD with data acquisition system recruitment was done similarly to the ASD-only recruitment, however a much smaller subset of vehicles was suitable to house the custom UMTRI DAS kits. Any participant with one of the target vehicles (based on year, make, model, and trim), was offered the opportunity to have an ASD with DAS installed on their cars. These participants received double the compensation of the VAD and ASD participants. Those not interested received either a stand-alone ASD or a VAD.

ILV. The participants selected to receive and drive the 64 ILVs faced the most in-depth screening process relative to other participants. The recruitment was slightly different for the first round of ILV participants (selected August 2012) as compared to the second round (selected March 2013). For the first round, the prospective participants reporting the most driving in the SPMD area, as well as a centralized (in the SPMD area) home address were selected to be screened via a phone interview. In the interview, participants were asked to confirm the driving patterns that they reported to the Web site. They were also asked about the normal trips they make in the SPMD areas as part of their weekly driving. The participants who were selected based on these phone interviews often had multiple standard destinations (gym, church, school, work, children’s activities) within the SPMD area, as well as just generally a large amount of miles driven. Participants were also selected based on their gender and age in order to try to balance the design as much as possible (64 into 6 groups does not divide evenly). Finally participants had to agree to provide UMTRI with their driving records and to attend a training session on a particular day, after which they would receive the vehicles.

Participants in the second round were selected based on an analysis of the data from the RSEs that collected this data from VAD-equipped vehicles traveling in the SPMD area. Participants whose VADs were seen most frequently by the RSEs around the SPMD area were considered first, particularly those with substantial reported driving in the target areas and a local address. These participants were screened via the telephone in the same manner as the participants in round 1.

4.1.3.3 Vehicle and Participant Selection: Fleet Vehicles

Fleets were targeted in the SPMD for VADs, TRPs, RSDs, and CCV-ITs. For VADs, the purpose was to seed the deployment area with remote vehicles that would have heavy usage in the area to increase the interactions with all other vehicle types. Fleets operating in the SPMD area were targeted for VADs included a local water delivery company (Arbor Springs) and another all-purpose delivery company (Metro Delivery), both with contracts with the University, which kept them in the target area. Also approached were local tow-truck fleets (Sakstrup's/Brewer's), the local public school bus fleet (Washtenaw Intermediate School District), the University of Michigan bus fleet, and many individual University business fleet vehicles such as laundry service trucks and street sweepers. Fleet-based participation was not handled through the Web site, but on a fleet-by-fleet basis.

For the TRP, drivers who consented for the TRP portion of the SPMD were selected based on the likelihood that they would drive one of the three TRP-equipped buses over the course of the data collection (roughly calendar year 2013). Any driver who might be placed in one of these buses was eligible to receive the training and consented to have their data (including video) collected. Certain drivers who UMTRI identified as most likely to drive the buses were specifically targeted in order to maximize the amount of usable data.

For the RSD for heavy trucks, two fleets (Con-way Freight and Sysco Foods), which were known to have operations in the SPMD area, were asked to participate in the SPMD. Eight trucks from each fleet were equipped with an RSD. The drivers normally assigned to these trucks on these routes were approached by UMTRI researchers at their place of employment and responded that they would be willing to participate.

For the CCV-ITs, two smaller-scale delivery companies (Rightaway Delivery, 4H Delivery) were selected to use one of the CCV-IT equipped tractors as part of their normal operations. The drivers who drove the tractors were met at their place of employment and enrolled.

4.1.4 Identification of Data Needs to Support Goals and Objectives

Weekly meetings were held with CAMP, UMTRI, FHWA, Volpe, NHTSA, VTTI, Mixon Hill, and ITS JPO. The intent of the meetings was to discuss and decide upon the data content and format to generate a data interface or data dictionary, and coordinate data management. The data management exercise began with an examination of data resources and data mapping. The independent evaluator, the Volpe Center, provided the test conductor team and other data providers (VTTI, Battelle, and SWRI) with a list of desired data from the SPMD. The data for the SPMD comes from a variety of sources:

- Data from DASs installed on integrated vehicles,
- Data from DASs installed on ASD-equipped vehicles,
- Data from DASs installed on RSD-equipped vehicles,
- Data from DASs installed on TRP-equipped vehicles,

- BSM data logged on VADs
- BSM data logged on ASDs (without DAS), and
- BSM data collected via RSEs.

In addition to the vehicle- and RSE-based data, contextual data was taken from Ann Arbor and weather-related sources in the SPMD test area.

4.1.4.1 Basic Safety Messages

The basic safety message was transmitted by all DSRC devices at 100 ms intervals. The message provided information about the transmitting vehicle including that vehicle's GPS position, speed, and heading. The BSM was defined by the SAE J2735 standard.[10] The log data collected on VADs, ASDs, RSDs, TRP, and integrated vehicles contained all of the BSMs transmitted by each device in addition to a date/time stamp for each BSM. Vehicles equipped with ASDs, RSDs, and the integrated vehicles continuously monitored for BSMs transmitted by other vehicles, and those that were equipped with DASs stored BSMs used for alerts. The BSM data were retrieved by UMTRI, VTTI, or SWRI researchers on a regular basis, typically 1 to 3 months, dependent on each organization's data collection schedule. Because the BSM was transmitted at 10Hz on all devices, it generated a large amount of data that was captured and stored for the project.

The components of the BSMs for the SPMD included:

- Unique device identifier,
- Latitude,
- Longitude,
- Elevation,
- Positional accuracy,
- Vehicle speed,
- Vehicle heading, and
- Acceleration (longitudinal).

4.1.4.2 Data Acquisition Systems

There were 118 UMTRI DAS units, 64 VTTI DAS units, and 4 SWRI DAS units deployed on-board vehicles as part of the SPMD. Additional DAS units were built as spares, and for use on prototype test vehicles. The various DASs were installed on the equipped vehicles in the quantities below:

- 100 ASD w/UMTRI DAS,
- 12 RSD w/UMTRI DAS,

[10] SAE J2735 did define the BSM; however during development and testing it was discovered that the interpretation of the standards did not always result in interoperability among devices. Testing identified these issues and corrections were made to devices to make them interoperable. In addition, these activities resulted in a list of clarifications that were submitted to the SAE J2735 committee for their consideration.

- 4 RSD w/SWRI DAS,
- 3 TRP w/UMTRI DAS,
- 3 CCV-IT w/UMTRI DAS, and
- 64 CAMP ILVs w/VTTI DAS.

Typical DAS data included:

- Time,
- Distance,
- GPS location, heading, and quality,
- Speed,
- Acceleration,
- Yaw rate,
- Turn-signal and wiper state,
- Brake and cruise control status,
- Forward object detection,
- Lane tracking and lateral position,
- Inform and imminent warnings,
- Remote vehicle BSM and classification,
- Video: forward, cabin, rear-left, rear-right (ILV video included forward, driver's face, left and right sides of vehicle, rear, and cabin), and
- Triggered audio.

4.1.4.3 Contextual Data

The contextual data can assist the independent evaluator in understanding the context in which the SPMD was conducted, but the predominant use of contextual data was to support the real-time data capture team based out of FHWA. The contextual data to be collected include BSMs detected by RSEs located in the infrastructure, weather data, and traditional traffic data. The following contextual data samples were provided to USDOT's real-time data capture management team.

- Traffic counts for limited segments in SPMD area at daily levels
- National Functional Classification (NFC) map – all public roads are classified according to the function they serve within the overall roadway network, allowing roads to be compared across different regions
- List of special events
  - Art Fair July 17-20, 2013
  - 2012 UM home football games: September 8, 15, October 13, 20, November 10, 17
  - 2013 UM home football games: August 31, 2013
  - Ann Arbor Marathon June 9, 2013
  - Rolling Sculpture Auto Show July 12, 2013
  - Mayor's Green Fair June 14, 2013

- Construction projects since August 2012 and proposed through August 2013 (planned node improvements, planned segment improvements)
- AATA routes (AATA and UM GIS files)
- AATA schedules
- UM transit schedules
- Fatal and injury crashes since August 2012
- Bike facilities
- Signal phase and timing for some key intersections adjoining the SPMD area
- Signal phase and timing for SPMD intersections
- Historical bicycle counts (no Bicycle counts have been taken since August 2012)
- Weather (from publicly available sources)

4.1.4.4 Subjective Data

Surveys and focus groups are methodologies that UMTRI has successfully employed in several previous USDOT-funded programs. Surveys are a proven method to collect subjective data that can be used to examine consumer acceptance, understanding, and performance of a system. Furthermore, both objective and subjective data are required to support a decision concerning V2V technology. Before the development of the surveys, UMTRI coordinated the process with USDOT, the independent evaluator, representatives of CAMP for the integrated passenger vehicles, and with other stakeholders on their associated platforms. These surveys were administered to the participants at or near the end of their participation. Surveys were not administered to participants with VAD-equipped vehicles.

4.1.4.5 Device Identification

Early on in the program, it became clear that each device installed in a vehicle should have a unique ID so that the data could be verified during the data analysis process. For example, if there were two remote vehicles transmitting in the area, it could be determined which of the two vehicles elicited an alert in the host vehicle. The purpose of the unique ID in the SPMD was two-fold—first, was to be able to distinguish vehicles for data analysis purposes. The unique ID was housed in the temporary ID field in the BSM. Instead of a rolling ID, one byte was static. The device IDs were assigned by the test conductor. Second, the unique ID lent itself to state of health monitoring as described in 7.1.

4.2 Infrastructure Plan

Initially, through the systems engineering process, the UMTRI team identified a series of stakeholders who would be needed across the team to evaluate, assess, and determine initial project planning activities. Through the initial project planning activities, the UMTRI team reached out to Ann Arbor key stakeholders (city mayor/executive, public works director, manager of IT, and manager of traffic signal maintenance). During early coordination meetings, the project needs and requirements were discussed and evaluated to assess and determine their feasibility. Afterward, design meetings, system/network architecture, and site evaluations (communications pathways/corridors) were evaluated.

Three key political issues had to be dealt with early in the feasibility and evaluation processes. First, the potential upgrade for a number of traffic signal controllers (to handle signal phase and timing broadcast) with the same vendor (Siemens) used currently with the city and a replacement of a series of TSCs from a secondary vendor (Econolite). Second, the TSC upgrades resulted in additional downstream impacts.

- The central office signal control software (Siemens Tactics software) needed to be upgraded to handle the Ethernet-based “new” controllers and retain the SCOOT adaptive signal timing/coordination algorithm and capability throughout the project (except on the Econolite enabled transportation corridor and TSC intersections).
- The network had to support both IPv4 and IPv6 simultaneously, which meant that the city had to upgrade a number of switches (firmware) to support the overlay of IPv6 for the Safety Pilot project. A downstream related impact was the separation of network traffic between the city-only data and Safety-Pilot-only data. During the network segmentation design and negotiation processes with Ann Arbor, they required the final review/approval of the network design, including the full implementation of a separate data security methodology, equipment and devices, as well as a fully separated Internet service provider data connection between Ann Arbor and the IPv6/IPv4 Internet to support Safety Pilot SCMS traffic and data offload traffic from the RSEs.

Third, Ann Arbor had to commit to the schedule, resource commitments for installations, and the longer-term operations and maintenance support needs for the infrastructure for the Safety Pilot project. This had both a man-power impact and cost implication for Ann Arbor; these commitments needed a series of approvals and cross-departmental agreements on handling resource and cost impacts.

Site planning for initial roadside equipment locations that would support various vehicle comminications needs such as security and other infrastructure based messages was part of the early phases of project initialization and stakeholder coordination meetings. During the site evaluations several key criteria were established to identify locations that would support V2I communications for the transfer of over-the-air security material, and traveler information messages (TIM) to V2V equipped vehicles; and the experimental transmission of the update SPaT message.

- Gateway access origin/destination to Ann Arbor on peak travel and transportation corridors
- Locations (origins/destinations) of peak roadway users (UM hospital, UM campus buildings, and major employment facilities/locations) in combination with travel/trip patterns in the Ann Arbor metro area
- Existing signalized intersection locations
- Existing city owned high-speed network (IP-enabled) TSC intersections
- Easily deployable high-speed network (IP-enabled) TSC intersections
- Siemens TSC intersections on SCOOT[11]

[11] Split Cycle Offset Optimisation Technique (SCOOT) is an adaptive traffic control system for controlled road crossings originally developed by the Transport Research Laboratory It is used extensively throughout the United Kingdom as well as in other countries. SCOOT automatically adjusts the traffic signal delays to adapt to traffic

- Siemens TSC intersections that do not require SCOOT
- Siemens TSC intersections that could be converted readily from SCOOT to time of day signal patterns using Econolite TSC
- Number of network hops/hub connections from center to field
- Cabinet space for additional SPMD equipment
- Power/grounding sufficient to add SPMD equipment
- Feasibility to deploy 1Gpbs Ethernet center to field network connectivity supporting transactional load
- Rack space, power, HVAC sufficient and a specific installation location identified in city hall to support security, network, and routing equipment for SPMD
- Sight distance for traveler information messages (TIMs), curve speed warning/curve radii design evaluations versus current posted speed (locations to support CSW broadcast)
- Radio coverage/broadcast distance evaluations
- Sites requiring WSA broadcast applications
- Sites requiring SPaT/GID broadcast applications

Once sites were evaluated, the short list of locations and application types were presented to the stakeholders. A secondary design support meeting was held in the field with the RSE vendor to evaluate, assess, and recommend radio coverage/radio quantity design changes. A final set of equipment materials was designed and prepared by site location including each TSC field cabinet and completed network/fiber interconnection plans . Equipment was delivered and the PCMS was updated with purchases, sites, and equipment deployment. Equipment components were pre-configured and bench-tested, then deployed/installed in the field locations by Ann Arbor signal maintenance technicians. Then the equipment was field-tested and evaluated for functional performance. Lastly, the equipment configurations were updated and issues with equipment performance (trouble tickets) were tracked using a Web-based system for development updates and subsequent software updates from vendors.

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conditions, using data from traffic sensors. Sensor data is gathered from multiple sensors within clusters of road crossings called "regions," and used to guide crossing timing decisions throughout each region.

4.3 Logistics Plan

UMTRI and its team supported a variety of organizations engaged in the SPMD by providing logistical and material support. The logistics plan detailed the size and location of work, equipment, laboratory, storage, and meeting areas to be provided, how sharing of space will be achieved to minimize the required space, and how space allocation will meet the needs of the team. Space was needed for VAD installations, ASD installations, RSD kit installations, ILV data harvests, interoperability testing, and personal work areas to support team partners and USDOT subcontractors on an as-needed basis.

Logistics varied slightly from the original plan, particularly for finding suitable space for CAMP's ILV monthly data harvests and office space. The following facilities were used for SPMD:

NCRC Lab: Used for interoperability bench testing. Also included some office space for the Leidos team. Enough space to accommodate all suppliers.

NCRC High-Bay: Originally intended for ASD installations but ended up being used for prepping vehicles for interoperability field testing because of its close proximity to the lab. Also used for the first ILV data harvest, but was not a fully suitable location for that purpose.

NCRC Office: Not in the original plan – a single-person office in the building directly north of UMTRI for CAMP subcontractors use during data harvests and an equipment storage area between data harvests.

UMTRI West High-Bay: All ASD installations were completed in the west high-bay. Also used for ASD data downloads.

UMTRI East High-Bay: All RSD kit installations were done in the east high-bay. The CCV-IT installations were completed in this high-bay as well. Additionally, the motorcycle installations (that were added as an "other application") were completed in the east high-bay. The second ILV data harvest was done in the east high-bay, but this was also not fully suitable for the CAMP team.

Temporary Structure: All VAD installations and data downloads were completed in the temporary structure that was constructed specifically for SPMD. The 3,325-square-foot facility was also used for some of the RSD installations or updates if additional room was needed from the east high-bay. The remaining ILV data harvests were completed in the temporary structure. When the data harvests were going on, only off-site VAD (fleet) work was completed. Stage 4 interoperability bench testing was completed in the temporary structure as well. The lease on the NCRC lab was let go prior to knowing that Stage 4 testing was required.

Figure 4-2: Initial Construction of Temporary Structure

Other UMTRI Office Space: Other single offices in UMTRI were provided to various USDOT personnel or their contractors on an as-needed basis.

Bus Depot Facility: In the original plan, the bus depot facility on Baxter Road was identified as a potential installation site for trucks and transit, but was not used for this purpose. The trucks were completed either at UMTRI or at the fleet facilities, such as the Con-way yard. All VAD bus installations were completed at the bus yard near Michigan Stadium.

The logistics plan detailed the transportation of ILV and trucks to the SPMD area. However, the final arrangement for the transportation was made during planning for the introduction of those fleets and is described in section 4.2.1.

The logistics plan included the initial description of the data retrieval process and data transfer processes. But the data requirements capture was done at a later point and is discussed in section 5.3.

Last, the logistics plan identified Brewer's as the tow truck company to be used on an as-needed basis. Further, the logistics plan provided three names and locations of three hotels within close proximity to UMTRI that honored a government rate (Hampton Inn, Hawthorne Suites, and the Holiday Inn).

4.4 Security Management System Concept of Operations

Security is a major concern for any network. Malicious devices and malicious attackers can corrupt or disable part or all of the system. To protect the SPMD program as much as practical, the test conductor developed and implemented a Security Management Operating Concept Plan designed to prevent malicious and unintentional attacks of DSRC-based devices and of the security credential management system (SCMS) server . The Security Management System Concept of Operation Plan indicated how the system needed to be implemented and operated to ensure security of over-the-air DSRC messages, security of DSRC units; and of the security credential management server, security policies, physical security, and secure life-cycle.

IEEE 1609.2 provides mechanisms to authenticate and encrypt over-the-air messages between DSRC devices, ensuring that data being received can be verified to be legitimate and actionable. The DOT Security Credential Management System specification extends IEEE 1609.2 to introduce an SCMS. The SCMS issues certificates, processes misbehavior reports, issues certificate revocation lists, and provides these to vehicle-based DSRC devices.

The Security Management System Concept of Operations development brought together all SPMD stakeholders. Working meetings were held weekly, called by USDOT that included CAMP, UMTRI, Mixon Hill, Leidos (representing both the test conductor as the local certificate distribution system operator and USDOT as the test bed operator), and other USDOT contractors as appropriate. In addition, the test conductor held additional weekly meetings to complete the plan to be reviewed at the USDOT meeting. Furthermore, a security workshop was held February 8, 2012, as well as a security coordination meeting March 5, 2012, for all stakeholders.

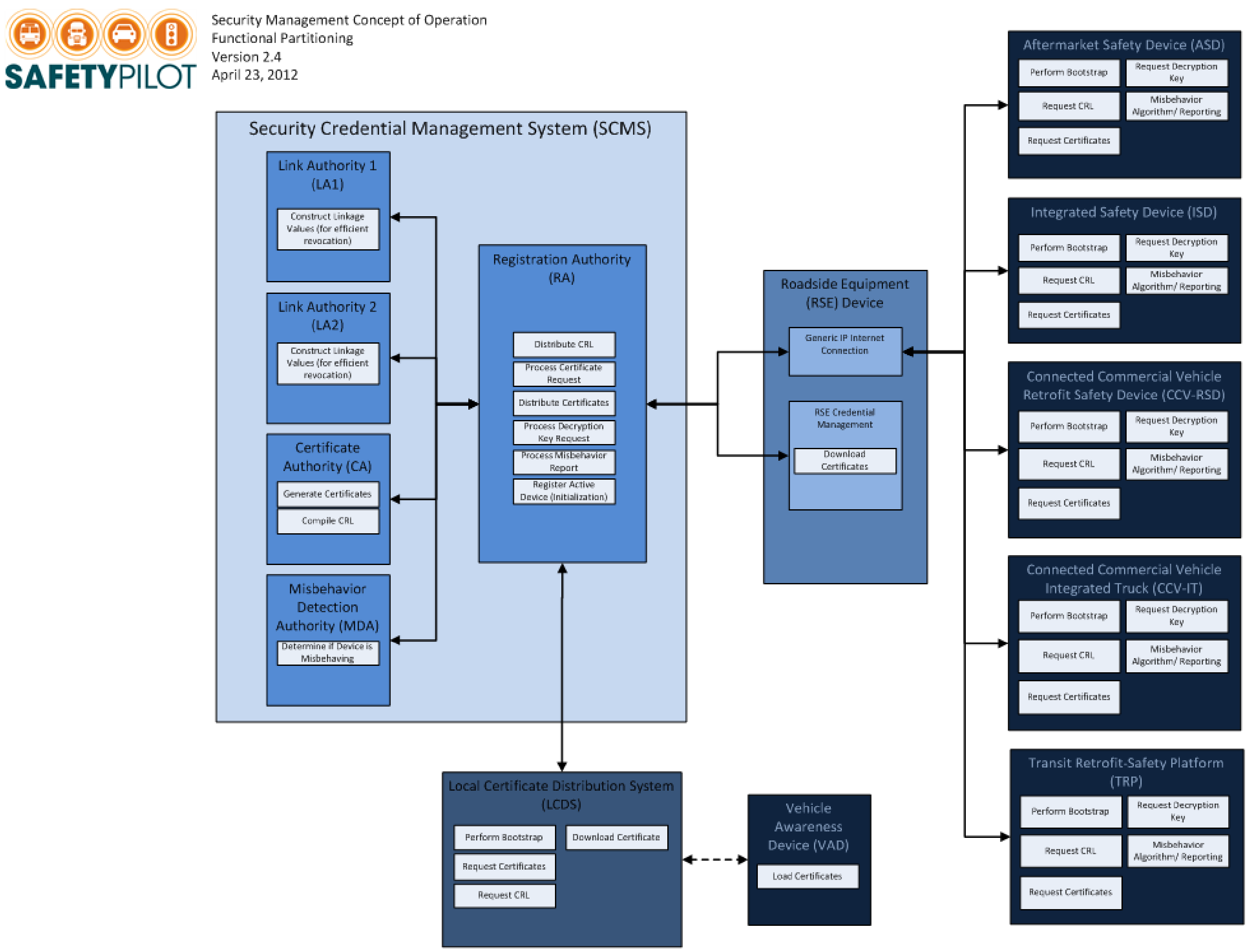

Figure 4-3: Security Functional Partitioning

4.4.1 Security Functions

Figure 4-3 depicts the security functional partitioning and gives an overview of the functions supported by SCMS, LCDS, RSE, and vehicle devices.

Security Credential Management System

The SCMS provided by the test bed operator (Leidos) consisted of a server that supported various security functions that included linkage authority, certificate authority, misbehavior detection authority, and registration authority. The SCMS processed certificate requests and issued certificates, provided decryption keys, received misbehavior reports, revoked units, and issued a certificate revocation list. The connection to the SCMS to vehicles and vice versa was provided by the test conductor by wired connection for VADs (local certificate distribution system) or RSE for other devices. All RSEs had a connection to the SCMS to offer the SCMS' services to vehicle-based devices.

Vehicle Awareness Devices and Local Certificate Distribution System

VADs broadcasted BSMs but didn't receive BSMs or communicate to the SCMS. Therefore these devices did not have any need for misbehavior reporting, requesting CRLs, etc. However, the VADs still needed to sign all transmitted BSMs with a valid security certificate to interact with the other deployed vehicles. The LCDS generated batches of 5-minute certificates that were delivered for installation on the VADs by the test conductor. UMTRI staff loaded the 2-year batches of certificates obtained by the LCDS from the SCMS on to external media. The external media was then inserted into the VAD during the installation process.

Road-Side Equipment

RSEs offered a generic IPv6 connection for vehicle-based devices to connect to the SCMS. Once the generic IP connection was established, the secure over-the-air message format was applied to support decryption keys, certificate revocation list, misbehavior reports, and OTA certificates. RSEs also offered secure broadcast services, including SPaT, TIM, and GID. The RSEs required a security certificate as well. The security certificate[12] was requested by the infrastructure team, generated by the SCMS, and then installed by the infrastructure team on the RSE during the installation and configuration process.

Active Vehicle-Based Devices

ASDs, ISDs, CCV-RSDs, CCV-ITs, and TRPs sent and received BSMs and produced and transmitted misbehavior reports. They were intended to establish a connection to the SCMS via RSE and then request the SCMS' services for bootstrapping[13] and requesting security certificates. A temporary ID was

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[12] The RSE was supplied 3 certificates to sign the various messages.
[13] Bootstrapping is the initialization process that registers (enrolls) a devices with SCMS. It requires a temporary ID

required for the bootstrapping process. Each temporary ID could only be used once and was then deactivated after bootstrap in the SCMS. Once bootstrapped, the devices then could request and download security certificates and decryption keys. These devices also sent and received misbehavior reports and required a CRL.

4.3.2 Security Responsibilities

Responsibilities of the functional blocks of the SPMD security management system were distributed between the test conductor and USDOT subcontractors.

Test Conductor Responsibilities:

- Developed the overall Security Management System Concept of Operations (test conductor team)
- Delivered the LCDS (Leidos)
- Cascaded requirements to the VAD suppliers to accept pre-loaded certs on an external media format (UMTRI)
- Installed the pre-loaded certs on the VADs (UMTRI)
- Cascaded requirements to the ASD suppliers for OTA security approach (UMTRI)
- Cascaded requirements to the RSE suppliers (UMTRI and Parsons Brinckerhoff)
- Requested and installed RSE certificates (Parsons Brinckerhoff)
- Coordinated with USDOT and their subcontractors (UMTRI)

USDOT Subcontractor Responsibilities:

- Operated the SCMS (test bed operator Leidos)
- Cascaded requirements to ISD supplier (CAMP)
- Cascaded requirements to heavy duty ISD supplier (Battelle)
- Cascaded requirements to RSD suppliers (Battelle and SWRI)
- Cascaded requirements to TRP supplier (Battelle)

4.3.3 Security Final Implementation

The initial plan for security was to pre-install two years’ worth of certificates on VADs, and for the remaining vehicles, to install 5-minute certificates and a one-year fall back certificate via OTA as described in the preceding sections. However, several factors complicated the plan:

- Many devices were already designed, manufactured, and delivered before the requirement was defined and cascaded.
- The two-stage RSE deployment limited OTA functionality.
- The USDOT tasked CAMP with testing a cellular approach for security certificate distribution.

Because of these factors, a two-stage security management system deployment was developed and implemented. Stage 1 is depicted in Table 4-2 below. The VADs were pre-loaded with a single batch of two years’ worth of 5-minute security certificates as planned. ISDs for both ILVs and the CCV-ITs were loaded with long-term certificates that had an expiration date of after the scheduled end of SPMD. The

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that can only be used one time. Once the device is registered it is allowed to request security certificates and decryptions keys from the SCMS.

date of May 31, 2014, was selected as the end date to ensure that SPMD was completed and all vehicles decommissioned. None of these devices would require bootstrapping.

The RSDs, TRPs, and ASDs were all to use bootstrapping. Once bootstrapped, a six-month batch of 5-minute security certificates and decryption keys would be requested and download either via Ethernet[14] or OTA. The actual stage 1 implementation was deviated slightly from the plan. The SWRI RSD team used the process for requesting and loading the 5-minute certificates. The Battelle RSD team pre-loaded 5-minute certificates, similar to the VAD process instead of the prescribed method. The TRP used a pre-loaded long-term certificate. The ASDs opted for using the UMTRI RSE for OTA certificate downloads. Lastly, The VAD and ISD implementation was as planned.

Stage 2 of the security deployment is depicted inTable 4-3. For VADs, there was no change. The changes came into play with the active devices (devices operating in the field). For ASDs, they were already bootstrapped in Stage 1. For Stage 2, the ASDs requested a batch of two months' worth of 5-minute certificates and associated decryption keys. This went as planned. The ISD security for the CCV-ITs and all but 16 of the ILVs would remain as is in Stage 1. However, 8 ILVs (one from each CAMP OEM) would transition to OTA distribution of certificates and keys and another eight would transition to a cellular distribution method. This also went according to plan. The CCV-IT platform was unable to support OTA security protocol and was never changed from the pre-loaded certificates in Stage 1. The Battelle RSD was tested for OTA security certificate downloads (Stage III Interoperability Bench and Field Testing), but was not implemented in the deployment. The TRP platform was never updated, tested, or enabled for OTA security certificate downloads and remained in the pre-loaded state.

Table 4-2: Stage 1 Security Deployment

Security Option Packages	VAD	ASD	LV – Int. ISD	HV – Int. CCV-IT	CCV - RSD	TRP
1. No Security Communications a. Decrypted Certificates Preloaded onto Devices b. Devices Not Bootstrapped c. No RSEs Required	X		X	X		
2. Limited Security Communications a. Bootstrapped by Supplier b. Supplier Generates Request for Certificates c. Certificates Loaded onto ASD (OTA/Wire) during Installation at UMTRI d. RSEs Required in Controlled Environment (UMTRI Garage)		X			X	X

[14] The secure connection was provided by UMTRI

Table 4-3: Stage 2 Security Deployment

Security Option Packages	VAD	ASD	LV – Int.	HV – Int.	HV – RSD	TRP
1. No Security Communications a. Decrypted Certificates Preloaded onto Devices b. Devices Not Bootstrapped c. No RSEs Required	X		X 6 per OEM			
2. DSRC Security Communications a. Encrypted Certificates via RSEs b. Decryption Keys via RSEs c. CRLs via RSEs d. Submit Casual/Test Reports for Misbehavior Detection e. Devices are Bootstrapped if they were not done so in Stage 1		X Bootstrapped in Stage 1	X 1 per OEM; Bootstrapped in Stage 2	X Bootstrapped in Stage 2	X Bootstrapped in Stage 1	X Bootstrapped in Stage 1
3. Cellular Security Communications a. Encrypted Certificates via Cellular b. Decryption Keys via Cellular c. CRLs via Cellular d. Devices are Bootstrapped			X 1 per OEM; Bootstrapped in Stage 2			

A summary of the actual security implementation is shown in Table 4-4 below

Table 4-4: Summary of Security Implementation[15]

Device Type	Stage 1	Stage 2
1. VAD	Pre-loaded 2-year batch 5-minute certificates	No Change
2. ASD	OTA Bootstrapped at supplier 6-month batch initial download at UMTRI 5-minute certificates	Continuing OTA 2-month batch field downloads 5-minute certificates
3. IV ISD	Pre-loaded long-term certificate	6 per OEM – no change 1 per OEM DSCR OTA 1 per OEM cellular OTA
3. CCV-IT ISD	Pre-loaded long-term certificate	No Change
3. Batelle RSD	Pre-loaded 2-year batch 5-minute certificates	No Change
3. SWRI RSD	OTA Bootstrapped at supplier 6-month batch initial download at SWRI 5-minute certificates	Continuing OTA 2-month batch field downloads 5-minute certificates
3. TRP	Pre-loaded long-term certificate	No Change

Last, it was decided at the program onset that not only were the long-term certificates going to expire on May 31, 2014, but the SCMS designed the Certificate Authority to expire on May 31, 2014 as well. Any certificates generated after May 31, 2014 using the original root CA would be invalid, regardless of the fact that the certificate expiration date was later than May 31, 2014. The problem was that the SPMD was extended six months, and then the decommissioning activity was deleted to keep the vehicles in the deployment area to transition to a new cooperative agreement in September 2014. Since the certificates expired May 31, 2014, all devices needed to be updated. For ASDs, this required that the devices be re-bootstrapped. For the other devices, new security certificates were loaded. The RSEs also needed new security certificates loaded. Because this update could not happen instantaneously, there was a period of time (several months) in which there were a mix of devices that were incompatible, i.e., ones operating with the past certificates and others operating with new certificates. During this period of mixed certificates, only those using the same certificates were able to use messages to support the various safety applications and issue alerts.

[15] Each OEM supplied 8 vehicles. For the IV ISD the number represents the number of vehicle per OEM (8) and how the security was implemented. Six of 8 vehicles from each OEM used pre-loaded certificates. One vehicle from each OEM used DSRC OTA to obtain security certificate updates and 1 vehicle from each OEM used cellular to obtain security certificate updates.

4.5 Safety Analysis and Threat Assessment Plan

The intent of the Safety Analysis and Threat Assessment Plan was to guide the execution of a functional safety and threat assessment program, to validate the overall safety of the SPMD capability, and to understand the impact of unintended or malicious attacks on the overall SPMD capability.

The overall goal in designing a safety-critical system is to eliminate hazards from the design, or, if that is not feasible, to minimize risk by modifying the design so that there is either very low probability of the hazard occurring, or a reduced impact from the hazard if it does occur. To demonstrate that a system is safe, it is necessary first to ensure that, given that the specifications are correctly implemented and no failures occur, the operation of the system will not result in a mishap. Second, the risk of faults or failures leading to a mishap must be eliminated or minimized by using fault-tolerant or fail-safe procedures. If it is not possible to completely eliminate hazards, then in order to reduce risk, the exposure time (length of time of occurrence) of the hazard must be minimized. Hazards need to be handled appropriately whether they result from component failures or whether they exist as a result of other failures such as those due to design errors or unforeseen events. ISO 26262 provides requirements and processes to mitigate or eliminate these risks. Debby Bezzina was appointed the safety manager, and had responsibility in three key areas:

- Overall safety management,
- Safety management during development of the infrastructure preparation and the coordination and preparation of vehicle fleets, and
- SPMD closeout.

An automotive safety integrity level (ASIL) workshop (internal) was held November 11, 2011, to identify all hazard events and analyze those events. Figure 4-4 depicts the method used to perform ASIL decomposition.

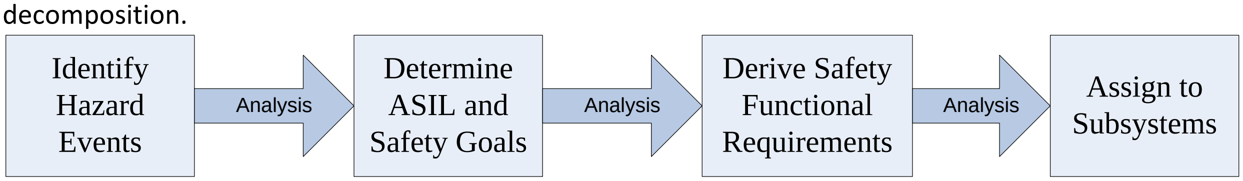


Figure 4-4: ASIL Decomposition Method

The ASIL decomposition workshop team identified and analyzed 13 potential hazard events summarized below in Table 4-5.

Table 4-5: Potential Hazard Events

Description	Impacts
Independent of the function of the safety system installed on the vehicle, there is a crash. The equipment installed by the test conductor affects the crashworthiness of the production vehicle.	Safety of the participant.
In the case of a pedestrian crash, the exterior mounted equipment poses a greater risk or inflicts more harm than otherwise would have occurred.	Safety of a pedestrian.
The RSE and related equipment are installed such that there is additional	Safety of the participant.

Description	Impacts
damage or harm inflicted in the case of a vehicle crash into the RSE mounting structure.	
Improper installation causes a device to misbehave – issue warnings when there is no hazard present.	Safety of the participant. Since these are warning systems, the driver is still in control of the vehicle and will need to assess the situation and determine how to react, e.g. brake, steer, or not take action. In this case since the driver still needs to respond with the appropriate respond (same design if avoiding a crash), there is no increase to the potential injuries. Therefore, we designate the potential severity as S0. UMTRI can show with data collected on previous programs, such as IVBSS, that false warnings do not pose a hazard.
A device is misbehaving due to someone hacking into the system. For instance, someone steals the security certificates and pretends to be an ASD, ISD, or VAD. Another scenario is that they hack into the backhaul and pretend to be an RSE. These types of activity may result in false warings or equipped vehicle not issuing a warning.	In this case, given the equipped vehicles are also interacting with un-equipped vehilces the driver still needs to identify potential hazardous situations. Therefore from a device functional design perspective there is no increase to the potential injuries. The resultant potential severity is S0 (not a safety related function). CAMP Vehicle Safety Consortium 3 (VSC3) has also determined that these types of "spoofing scenarios" don't pose additional hazard to the driver. Since these are warning systems, the driver is still in control of the vehicle and will need to assess the situation and determine how to react. UMTRI can show with data collected on previous programs, such as IVBSS, that false warnings do not pose a hazard.
The system negatively impacts the signal controller to cause the light to go down.	The symptom is the same as if a lightning strike caused a power outage. There are failsafe already built into the signal controller and the default mode would be a flashing stop (it is mechanically impossible to make the controller four-way green). Therefore, the model deployment system does not increase the potential severity to a driver's normal day-to-day activities.
Improper installation of the ASD, VAD, or DAS drains the battery, leaving the driver stranded in the middle of the night.	Safety of the test participant.
Improper installation of the ASD, VAD, or DAS leads to degradation of the CAN bus interface.	Safety of the test participant.
The driver has a misperception of how the system works. For instance, the driver thinks it is more protective than just a warning system and expects the vehicle to take control and avert the threat.	Safety of test participant.
A piece of Safety Pilot equipment in the cabin becomes loose.	Safety of test participant. Causes driver distraction or occludes the driver's vision, causing an accident.
A short in the equipment being installed by the test conductor causes overheating.	Safety of test participant or component failure.
A driver becomes hurt in the high-bay or other work areas.	Safety of the test participant.
Someone hacks into the data flow.	Personal information and other information is stolen.

Using the methodology illustrated above, none of the potential hazard events were classified as ASIL hazard events, therefore, generally accepted systems engineering and project management practices were used for project execution as is the industry standard. Accordingly, the test conductor used the following to mitigate risks that were identified during the ASIL decomposition process:

1. Risk Register and Risk Management Plan. The items were added to the risk register, and risk mitigation plans were developed.
2. Security management concept of operations. The security management test conductor team worked hand-in-hand with the SCMS contractor, the LCDS contractor, and USDOT to mitigate risks stemming from breaches in security protocol.
3. VAD and ASD Installation procedures. The test conductor team worked with ASD and VAD device manufacturers to understand installation requirements and incorporate them into the installation designs.
4. Infrastructure Installation Plan. The test conductor worked with RSE device suppliers to understand installation requirements and incorporate them into the installation designs.
5. Interoperability Test Plan. This testing was in conjunction with USDOT certification testing and device manufacturer qualification testing to minimize risk.

During the SPMD, none of the potential risks identified occurred.

4.6 IRB Certification Process

The IRB is tasked with protecting human subjects in social and behavioral research at the University of Michigan. All research dealing with human subjects must be approved by the IRB. The general process involves completing an online application via the University of Michigan's eResearch portal and submitting any associated documents. Generally, the IRB returns with either approval or comments and questions within a couple weeks. If changes are required for approval, the application and documents are re-submitted with the necessary changes made and often with explanations of these changes. For a project as large as the SPMD, there are often multiple IRB applications and amendments to the applications throughout the project as new needs are understood and new challenges are met.

Nearly all human subjects participating in research at the University of Michigan are required to read and complete an IRB-approved document outlining their participation in the research project. This type of document is referred to as an "informed consent document," as completion by the participant indicates that they were informed of the expectations for their participation, and that they consent to the protocols of the study as they are outlined. Multiple informed consent documents (and multiple versions of each one) were submitted, approved and used to enroll participants in the SPMD. Separate informed consent documents were created for participants for each separate portion of the SPMD including:

- VAD participants,
- ASD participants,
- ASD with DAS participants,
- ILV participants,

- TRP participants,
- RSD and RSD with DAS participants,
- Integrated truck participants, and
- Motorcycle participants

Three main applications were filed for SPMD. The amendments to the applications are found in Appendix D.

Application #1 Initial Top-Level Recruiting Umbrella Application (HUM00062873 - April 2012)

The process for obtaining IRB approval for all aspects of the SPMD began with an initial application dealing with only the recruitment of the VAD and ASD drivers. This original “umbrella” application was filed on April 6, 2012, and was approved on April 12, 2012. This approval allowed UMTRI to begin reaching out to the community in hopes of recruiting the 2,500 to 2,800 participants necessary to fulfill the requirements for both the VAD and ASD portions of the SPMD. This application contained information about the SPMD in general and specific information about UMTRI’s recruitment strategy.

There were four amendments to this IRB application. These amendments included provisions for recruitment material (which targeted three populations: Ann Arbor Public Schools, UM College of Engineering, and UM Health System), including the SPMD Web site, as well as increased payments for participants (from $100 to $200 per year).

Application #2 Model Deployment – Aftermarket Safety Devices With Data Acquisition Systems (DAS) and Integrated Light Vehicles. (HUM00063435 – June 2012)

This application contained the initial details regarding participants selected to drive either an ASD with DAS or an ILV. It was submitted June 11, 2012, and approved June 27, 2012. Eventually this application would also cover the RSDs on the heavy trucks, the TRPs on the UM buses, and the integrated trucks. The collection of video data on these platforms, including video of participants’ faces, forms the primary distinction between this application and Application #3 below. The two main documents included in this original application at the time of submittal were the informed consent documents for both the ASD with DAS participants and the first group of 64 ILV participants.

Fourteen separate amendments were submitted to modify this application. The major revisions that these amendments addressed included changes to the download schedules and participation duration for the ILVs as well as a post-drive questionnaire and training materials for the drivers of the ILV; details about and documents relating to the RSD, TRP, CCV-IT, and ASD w/ DAS platforms; and details concerning the motorcycle data collection program. Details of each amendment are provided in Appendix D.

Application #3 Model Deployment – Vehicle Awareness Devices and Aftermarket Safety Devices. (HUM00065235 – June 2012)

This application contained the initial details regarding the participant enrollment in these two portions of the SPMD. It was submitted June 21, 2012, and approved June 29, 2012. The two main documents included in this original application at the time of submittal were the informed consent documents for both the VAD and ASD participants. This application also covered fleet VAD installations.

Five amendments were filed for this application. Changes to the original application included an increase to the payment amount for VAD and ASD participants (from $100 to $200); the addition of fleet vehicles to SPMD; and a 6-month and then year-long extensions to the VAD and ASD drivers' participation.

5 Pre-Model Deployment Phase 2: Preparation and Installation of Required Components

Phase 2 of pre-model deployment was meant to prepare the vehicles and infrastructure for model deployment. The following sections will give an overview of the coordination and preparation required for:

- ILV fleet,
- VAD fleet,
- ASD fleet,
- Integrated heavy vehicle fleet,
- RSD fleets
- TRP fleet, and
- Infrastructure installations.

5.1 Introduction of the Integrated Light Vehicle Fleet

CAMP, as a subcontractor to USDOT, delivered 64 ILVs. The vehicles delivered were a mix of 2010, 2011, and 2012 models years. The makes of the vehicles are provided inTable 5-1.

Table 5-1: Manufactures and Models of the ILVs

OEM	Manufacturer	Model	QTY
Ford	Ford	Taurus	8
GM	Buick	LaCrosse	6
GM	Cadillac	DTS	2
Honda	Acura	TL	8
Hyundai-Kia	Hyundai	Sonata	8
Mercedes	Mercedes	C300	8
Nissan	Infiniti	M37	8
Toyota	Toyota	Venza	8
VW-Audi	VW	GTI	4
VW-Audi	Audi	A4	4

The introduction of the ILV fleet took significant coordination between USDOT, CAMP, and the test conductor team. In order to define the tasks and timing required to launch the ILVs and the roles and responsibilities, the process for introducing the integrated fleet was developed. Many of the activities were done in the pre-model deployment phase in preparation for launch. The schedule was developed that would meet USDOT timing for an August 21, 2012 launch data and meet all program milestones for testing, recruitment, and training.

Before the vehicles could be launched, IRB approval was required. CAMP provided the descriptions of the basic safety functions and the corresponding DVI, and a description of planned training material (pamphlets, videos, etc.). UMTRI, acting as the test conductor, then prepared and submitted the IRB application. The training process also needed to be defined so that during recruitment, the test conductor would be able to describe what was expected of the participant. Two rounds of deployment were planned for the ILVs. Each deployment would last 6 months and have 64 drivers balanced for age and gender (per OEM).

The ILVs were also part of the Interoperability Testing and Pre-Model Deployment Testing.

- Stage 1 Interoperability Testing – Bench. CAMP provided DSRC radios, which were returned to CAMP after testing:
    - Two VSCA (common platform between GM, Ford, Honda, Mercedes-Benz, and Toyota), and
    - Two Proxy-BSM (common platform between Hyundai-Kia, VW-Audi, and Nissan).
- Stage 1 Interoperability Testing – Field. CAMP provided four vehicles and two drivers for interoperability field testing.
- Pre-Model Deployment (Dry Run). CAMP providing eight vehicles for pre-model deployment dry run, one from each OEM. These vehicles were transferred to UMTRI (as the test conductor) as government-furnished equipment (GFE) and were not returned to CAMP until after the first deployment concluded.
        - UMTRI insured the vehicles (CAMP/USDOT provided VIN, make, and model).
        - Vehicles were transferred from CAMP to USDOT to UMTRI.
            - Transfer took place at UMTRI,
            - Vehicles detailed by CAMP prior to transfer, and
            - CAMP delivered the vehicles to UMTRI.
- Stage 2 Interoperability Testing – Bench. CAMP provided DSRC radios, which were returned to CAMP after testing:
    - Two VSCA (common platform between GM, Ford, Honda, Mercedes-Benz, and Toyota), and
    - Two Proxy-BSM (common platform between Hyundai-Kia, VW-Audi, and Nissan).
- Stage 2 Interoperability Testing – Field. The test conductor used 2 of the vehicles from the pre-model deployment dry run, one of each DSRC radio platform (VSCA and Proxy-BSM)

To prepare for launch, the first 64 subjects were recruited, scheduled, and trained, and the remaining 56 vehicles were transferred to the test conductor (UMTRI).

- Recruitment: UMTRI was responsible for recruitment and scheduling participants as discussed in Section 4.1.3.
    - Participants were balanced for age and gender.
    - Participants were selected based on answers on driving frequency from the application questionnaire.
- Vehicle Transfer: CAMP was responsible for transferring the vehicles to UMTRI.

    - CAMP delivered the vehicles to UMTRI.
    - The vehicles were transferred from CAMP to USDOT to UMTRI (at UMTRI).
    - UMTRI detailed the vehicles prior to deployment.
- Training: joint effort between UMTRI and CAMP
    - UMTRI described the overall SPMD program.
    - UMTRI obtained driver's consent.
    - The 64 participants were scheduled over a two-day period in groups of four sorted by OEM.
    - UMTRI worked with Ann Arbor and the University of Michigan to close roads as needed for training.
    - CAMP presented DSRC technology and safety features to the participants.
    - CAMP took each participant on a test drive in the vehicle type that the participant would be using during the SPMD.

5.2 Preparation of VAD Fleet

There were over 2,700 VAD installations completed for SPMD. The majority were on participants' personal vehicles, but also included installations on heavy duty, medium duty, and transit vehicles.

The final experiment plan intended to install VADs in 2,218 passenger vehicles, 100 UM light/medium duty vehicles, 50 heavy duty vehicles, and 82 transit vehicles. However, it proved difficult to equip that many UM vehicles. Additionally, some of the buses planned for the installation did not operate in SPMD area and were deleted from the program. In the end, the VAD installations below were completed for the fleet vehicles.

- Transit Fleet (75)
    - Gretchen House Childcare (2)
    - Ann Arbor Public Schools (20)
    - University of Michigan (53)
- Light Fleet (35)
    - 31 Metro Delivery
    - 2 Brewer's/Sakstrup's
    - 2 UM Plant and Facilities
- Medium Duty Fleet (23)
    - 2 Metro Delivery
    - 14 Brewer's/Sakstrup's
    - 7 UM Plant and Facilities
- Heavy Duty Fleet (47)
    - 8 Arbor Springs
    - 14 Brewer's Sakstrup's
    - 2 Domino's Pizza
    - 23 UM Plant and Facilities

Although over 2,700 VAD installations were completed, the most deployed in the field at once peaked at approximately 2,300 VAD-equipped vehicles. Due to the fact that as devices were repaired and re-deployed, there was no way to have 100 percent deployment. Many factors contributed to the lower than expected vehicle deployments and included the following:

- Attrition:
  - Participants left the study.
  - Participants purchased new vehicles or turned in lease vehicles and did not return to have the equipment installed in their new vehicle.
  - Participants were involved in an accident and totaled their cars.
  - Fleet operators decommissioned vehicles and did not replace them.
- A reduction in the number of articulated trucks operating in Ann Arbor to be equipped with VADs.
- Device repairs

5.2.1 VAD Supplier Selection

The original contract stipulated that USDOT create a VAD QPL prior to the selection of suppliers by the test conductor for SPMD. The basic premise was that the test conductor would select two or more suppliers from the QPL. However, the QPL was not finished before supplier selection was to occur. Therefore, the scope of the test conductor contract was modified to include VAD supplier selection.

The VAD supplier selection was done through the University of Michigan purchasing organization and employed a rigorous evaluation process for final supplier selection. An RFQ was sent to prospective suppliers (those that had submitted samples to USDOT for qualification testing). In parallel, USDOT continued qualification testing and submitted the test results to UMTRI as an input to the selection process.

The evaluation criteria used for supplier selection was broken down into two sections. The first set of criteria were "must haves," listed below. If the supplier did not meet those criteria, they were automatically eliminated.

- Enough detail in the manufacturing plan to be considered viable
- No external on/off switch
- Formatted BSM correctly as reported by USDOT during qualification testing
- No indication of the need for exceptions to the standard terms and conditions of a University of Michigan purchase order
- Major updates required to meet design intent for SPMD that would require an additional round of qualification testing by USDOT (as part of the USDOT QPL process)

The second category consisted of weighted criteria. The weight of each criteria was determined by the test conductor team prior to receiving responses from any suppliers. The following, in no particular order, is the list of criteria that were developed by the test conductor team.

- Financial evaluation from purchasing assessment of long-term company viability

- Test results from USDOT qualification testing (QPL process):
  - Bench
  - Security
  - GPS accuracy
  - Elevation positioning services
  - Connector specification
- Cost
- Logistics
- Compliance Specifications
  - Serial number
  - Antenna mounting robustness
  - State indicator
  - System event logs
  - Version control
  - Functions out of the box
  - DSRC antenna solution
  - GPS antenna solution
- Installation
  - Size
  - Installation robustness
  - Installation documentation
- Compliance with proposed delivery schedule
- Willingness to comply with the proposed agreement
- ISO 26262 compliance
- Proposed engineering support
- Removable media type
- Past experience
- Product maturity
- Perceived price risk (Probability of unit price increase.)
- Perceived performance risk (Probability of performance problems that may include poor quality devices of not meeting delivery schedule.)

Once the responses were received from the perspective suppliers, the test conductor team evaluated their proposals using the above-weighted criteria. Three of the suppliers did not meet all of the "must have" criteria. Even only considering the weighted questions, the two remaining suppliers scored significantly higher than the others. In the end, Cohda Wireless, located in Australia, and Savari Networks, located in California, were selected as the VAD suppliers. The volume was split equally between the two suppliers.

5.2.2 Process for Equipping Vehicles with VADs

The basic components for installing a VAD were the device, power, and DSRC antenna and GPS antenna placement. The VAD installation varied across the numerous vehicle platforms as documented in

Appendix E, which describe the basic components of the VAD installation and the VAD installation schedule.

As a result of the sheer volume of VAD installations, the installations were planned to begin well in advance of the August 21, 2012, launch date. The VAD installations included the 114 vehicles equipped in June 2012 for pre-model deployment testing. The VAD builds began ramping up August 6, 2012. The builds were completed by November 30, 2012. The original target was to ramp up and then complete 245 builds per week. However, it proved very difficult to contact and schedule the participants. In order to attract more participants, extended hours (7 a.m. to 7 p.m.) and weekends (both Saturday and Sundays) for installations were offered. Roush was hired as a temporary second shift crew for the extended hours. The actual installation rate is depicted in Figure 5-1below.

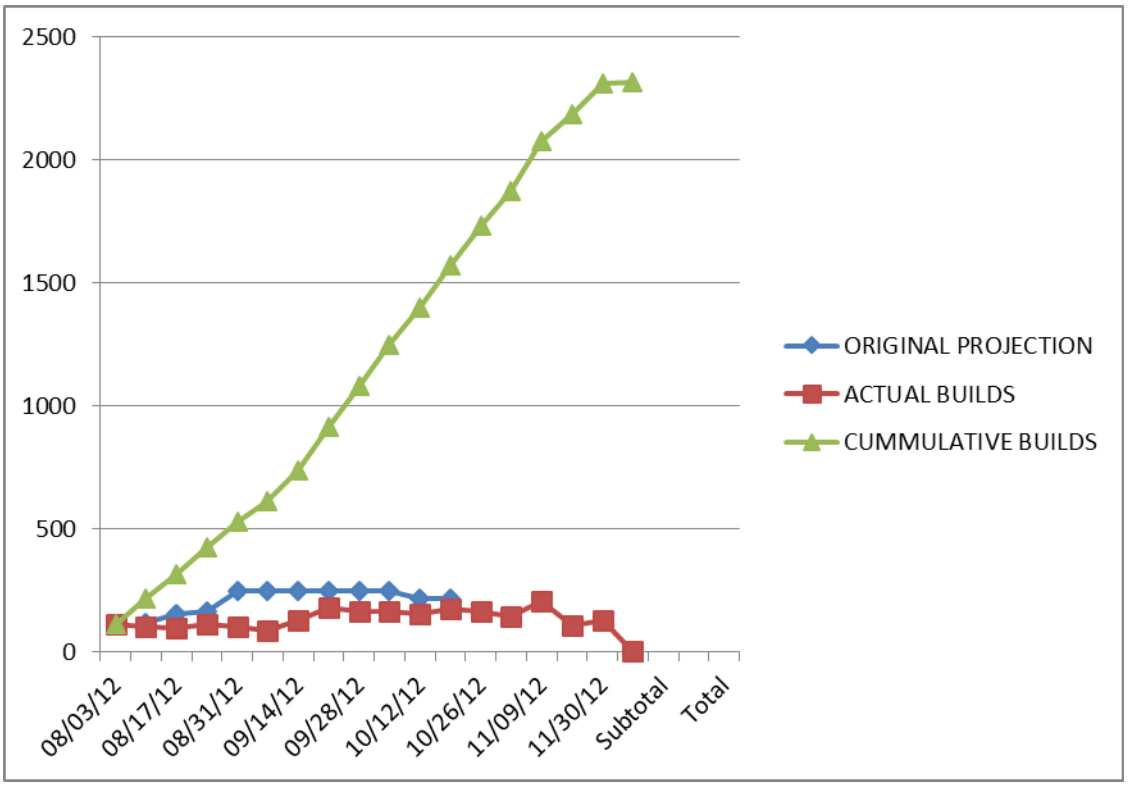


Figure 5-1: VAD Installations

In practice, VAD installations continued to address participant or device issues   As participants leave the program for various reasons, they are replaced by new participants. The reasons include getting a new car or lease expiring, accident where car is not reparable, VAD-caused water damage to the vehicle (our policy was to remove the device permanently), those that do not wish to continue participation (although that was a very small fraction), fleet vehicles going out of service, etc. The overarching goal was to keep the contractual amount of VADs in the deployment area. In addition, device repairs are required, and will also contribute to the need for continuing installations.

5.3 Preparation of ASD Fleet

There were 330 ASD installations completed for SPMD. The final experiment plan intended to install 300 ASDs on participants' personal vehicles – 200 with an ASD system only, and 100 with an ASD system plus an UMTRI DAS. At the peak of deployment, 281 ASDs were in the field – 196 with ASD only and 98 with ASD plus DAS. The attrition for participants was varied but included buying new cars, car accidents, changing their minds about being videotaped (for DAS installations), too much RF interference (described below), moving out of the area, or not willing to participate any longer (very low rate overall).

5.3.1 ASD Supplier Selection:

Similar to the VAD selection, the ASD supplier selection was conducted using a series of go/no-go decisions and weighted criteria. In addition to the VAD criteria, additional items were added for the Driver-Vehicle Interface (DVI), OTA security functionality, safety application performance, and the DAS interface.

Display: It was important for the display to have automotive temperature specifications. Some consumer electronic devices are known to overheat in high sun-load conditions. It also required robust vibration performance. These displays would be seeing loads outside the normal operating range of consumer-grade electronics. The proposed display installation was also important. The display should not obstruct the driver's field of view any more than a typical dash/window mounted nomadic device, such as a personal navigation device. The display should also be mounted in such a way as to not impact the crashworthiness of the vehicle. The display should not be a highly desirable device that was prone to theft since it would remain in plain sight at all times. Lastly, the display should not require any input from the driver. The display should turn on by itself and not require the driver to start any app on the device to enable the safety applications.

Security: The ASDs were required to implement OTA security management to request and receive security certificates and decryption keys. For security, two additional criteria were added to the supplier evaluation. First, the ASD had to have configurable batch parameters. This was important because it was unclear at the time how many certificates could be transferred from the SCMS server. Also, it was important that the supplier was capable of bootstrapping the device so that the test conductor did not have to maintain the passwords for the devices, as a security precaution.

Objective Test Performance: Volpe conducted objective test procedures to evaluate the performance of the safety applications for the ASDs. The safety applications tested were FCW, EEBL, and CSW. The test conductor supplier evaluation criteria were a measure of how well the devices performed during this testing.

DAS Interface: It was important to understand what information the ASD was capable of transmitting to the DAS. This criteria evaluated if the ASD met the minimum data logging requirements including alert type and pertinent information about the alert.

5.3.2 DAS-Equipped Vehicle Selection

To identify the vehicle models most likely to be represented in the subject pool, UMTRI compiled registration data from both Michigan as a whole, and from the 48105 ZIP Code where recruitment was focused. These data were used to identify the most prevalent models that met the overall criteria for DAS installation: (1) four door sedan, (2) recent model year, and (3) UMTRI experience working with the OEM to release CAN bus data. Once these models were identified, UMTRI worked to bring in vehicles for physical evaluation. These vehicles were identified among UMTRI staff, their colleagues, and friends and family.

Evaluation of the vehicle for DAS installation took about a day per model. Each model was assessed for the following:

- Room to mount a DAS, ASD, and associated equipment without interfering with the vehicle’s storage space or presenting a safety hazard to the driver.
- Suitable mounting locations for cameras and MobilEye that provide adequate field of view, yet do not affect driver visibility.
- Amount of disassembly required to complete installation.

Two vehicles that were quite common in the recruitment area that did not have adequate mounting room for a DAS were the Toyota Corolla and the Toyota Prius. Several crossover vehicles were also prevalent, but could not be considered as mounting the rearward facing cameras was not possible on the hatch.

In addition to the physical evaluation of the vehicle, UMTRI contacted the OEMs for vehicles under consideration to acquire CAN bus documentation. For all the candidate vehicles, UMTRI was able to complete a non-disclosure agreement and receive the necessary information. In some cases, though, this took several months as the University of Michigan and OEM legal staff came to agreement on the NDA language. UMTRI set up a secure folder on their server for this information, with access limited to only a couple of key staff members.

With the CAN documentation in hand, UMTRI brought the final candidate vehicles back in to confirm the key parameters of interest could be monitored. This was not always the case, as some CAN packets were not populated on mid or lower trim level vehicles. In general, this did not exclude many vehicles from consideration, but it did reduce the number of channels common across vehicle models. For example, steering wheel angle was available on all GM Epsilon models, but was only available on the top trim level of the Honda Civic, which was a low penetration option.

The final group of vehicles included in the DAS sample were Honda Accord, Honda Civic, GM Epsilon platform (Saturn Aura, Pontiac G6, and Chevrolet Malibu), Chevrolet Impala, Ford Fusion, and Ford Focus.

5.3.3 Process for Equipping Vehicles With ASDs

The process for equipping vehicles with ASDs without a DAS was identical to the VADs with the exception of a speaker that was used as the DVI for the warning system. The speaker was mounted under the driver side knee bolster. Although all supplier DVI proposals included some type of display, it was determined that none of them were ready for a model deployment. Most required some type of driver input, were high-theft items, or the display did not dim and was too bright at night. In the end, the test conductor opted for a speaker-only DVI. The readiness of the DVI was confirmed by a USDOT funded study conducted by Battelle.

The process for equipping vehicles with ASDs with a DAS was much more labor intensive. Whereas a standard ASD installation took from between 45 and 90 minutes, an ASD with DAS took several days. The DAS system consisted of the DAS module, a cabin camera and microphone, forward ranging system,[16] forward scene camera, two rear scene cameras, a dual GPS/cellular antenna, and the associated brackets and shroud to install and protect the DAS.

5.3.3.1 Vehicle issues

Installation of ASD and DAS equipment in most vehicles went smoothly. However, it was not uncommon for vehicles to arrive with one or more issues that took significant time to resolve. Some of these were:

- Large amounts of cargo. Some subjects did not follow the instructions of the recruiters to arrive with a minimum of items in the trunk or cargo area. On more than one occasion it took over an hour to remove boxes, bags, and miscellaneous items from a vehicle, then vacuum the cargo area so it was clean enough to begin installation.

- Batteries in poor condition. Technicians tested the condition of each vehicle's battery with a load tester when they arrived, and again after being on a charger if they tested low. For DAS vehicles, a battery in poor condition could result in undesirable restarts or shutdowns, as the voltage would sag at low idle. When batteries tested low on DAS vehicles, a replacement battery was purchased and installed.

- Wiring issues. On several occasions, vehicles arrived with intermittent electrical issues in the circuits where the equipment was connected. In some cases this was a result of poor quality installation of aftermarket radios or remote starters, in other cases the root cause was a manufacturing issue. In one instance the problem was found to be a manufacturing defect in the fuse block that caused the main ignition signal for the vehicle to drop out intermittently. Some vehicles also had poor grounds. Resolving these issues typically took at least an hour, and sometimes more.

[16] A system installed that looks forward of the vehicle that uses either a camera or rada sensor to measure the distance (changing distance) to a vehicle in front of the subject vehicle.

- Damaged windshields. On DAS-equipped vehicles, a stone chip or crack across the field of view of the forward scene camera or the MobilEye was present on several vehicles. The windshield was replaced before equipment installation.

- Water intrusion. Some vehicles arrived with clear evidence of an existing water intrusion issue in the area the equipment was to be mounted. If the technicians could find a clear source of the problem and correct it, they did. Otherwise they had to identify an alternate mounting location. Sometimes water intrusion was not noticed until the vehicle returned for data download, and the ASD was found to have suffered water damage. Seven ASDs were damaged beyond repair.

5.3.3.2 Interactions between Equipment and Vehicles
Some subjects found the level of radio interference (RFI) on the FM or AM bands caused from the installed equipment to be unacceptable. This was true for both ASD-only and DAS equipped vehicles. For ASD-only vehicles, this could often be resolved by making modest changes in the position of the DSRC antenna, particularly on SUV and crossover models where a glass-mount antenna was used. For DAS-equipped vehicles, resolving this issue could take most of a day, and in one case the RFI was not reduced to the subject’s satisfaction and the equipment was removed from their vehicles.

RFI also affected the operation of the remote function access module on some GM Epsilon vehicles; this module handled key fob access and tire pressure monitoring. We were unable to resolve this to the satisfaction of two subjects, who dropped out of the study.

5.3.4 ASD Installation Schedule
The original ASD schedule was based on the assumption that viable devices would be available in time for the SPMD ASD build schedule. However, all suppliers failed the USDOT certification testing. It was decided at that point to wait until after results were available from an additional round of USDOT certification testing. The revised plan was to complete supplier selection by June 12, 2012. This impacted the ASD installation schedule greatly. The original plan was to start installing ASDs immediately after pre-model deployment installations were completed and run from July 6, toOctober 5, 2012. The revised schedule moved to a start date of November 8, to January 28, 2013. After several issues identified with the devices, the ASD schedule was further revised to push out the end date to April 1, 2013. Figure 5-2 below shows the actual ASD weekly and cumulative installations.

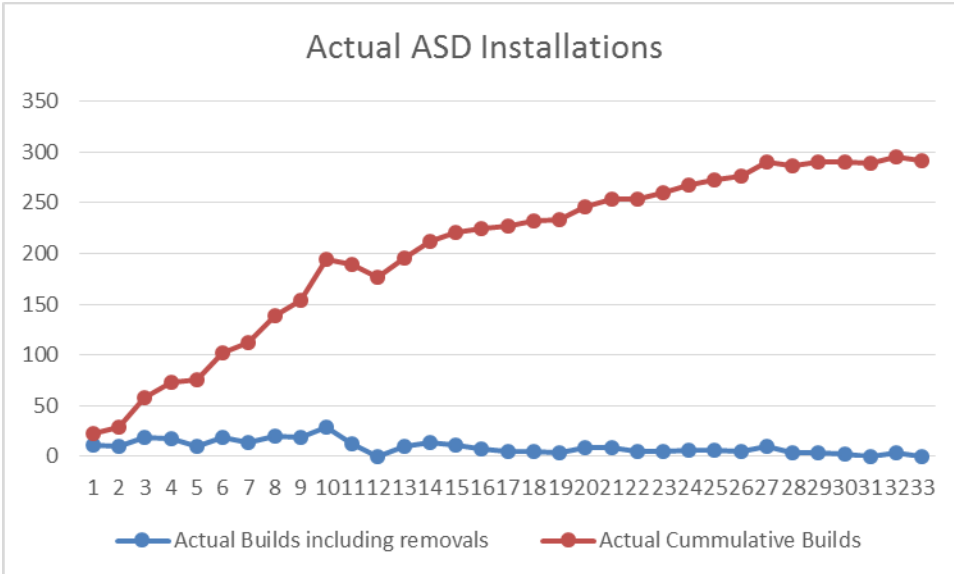


Figure 5-2: Weekly and Cumulative ASD Installations

5.4 Introduction of the Connected Commercial Vehicle – Integrate Truck Heavy Vehicle Fleet

Battelle, as a subcontractor to USDOT, delivered three CCV-ITs to the test conductor (UMTRI) for introduction into the SPMD. The test conductor was responsible for recruiting one or more fleets that would use the CCV-ITs in their existing operations.

Other Battelle responsibilities:

- Delivering documentation to support the IRB application as necessary
- Delivering two CCV-IT DSRC radios for the following stages of interoperability testing:
  - Stage 1 bench
  - Stage 1 field
  - Stage 2 bench
  - Stage 2 field
- Delivering the Blue Day Cab for pre-model deployment dry run
- Delivering the remaining two vehicles (red mid-roof sleeper and white high-roof sleeper) for SPMD
- Retrieving data on a monthly basis
- Transferring the following tractors and trailers to USDOT:
  - Three CCV-ITs
  - 53’ box trailer
  - 48’ box trailer
  - Gooseneck container chassis
  - 40’ intermodal container

UMTRI responsibilities included:

- Placing the tractors with Ann Arbor fleets
- Consenting the drivers
- Administering subjective questionnaires
- Facilitating a focus group
- Seeking IRB approval for the above
- Insuring vehicles
- Plating vehicles
- Transferring tractors and trailers from USDOT to UMTRI
- Decommissioning the vehicles

It was more difficult than originally anticipated to place the three tractors in existing fleets. One of the initial targets was Sysco for the smallest tractor (blue day cab). Sysco would have been a very good fit because it drives in the Ann Arbor area for the better part of the day. However, Sysco felt that the configuration of the blue tractor would not meet its needs because of the tractor's long wheelbase. Its deliveries in Ann Arbor require it to negotiate tight turns and alleys in the downtown area and felt the tractor would not practical for that use.

Subsequently, UMTRI identified an alternate Ann Arbor based trucking fleet to use the blue day cab during SPMD. Rightaway Delivery, LLC is an inventory management and logistics business that includes delivery and pick-up services to regional post offices in southeast Michigan and northern Ohio. For SPMD, Rightaway would use the blue day cab tractor in its Ann Arbor route to service post offices located on Green Road (northeast Ann Arbor) and the Stadium Boulevard post office (southwest Ann Arbor) with travel through Ann Arbor (and the SPMD area) on the Plymouth Road corridor (seeFigure 5-3). At that time, Rightaway serviced those facilities once each day, 6 days per week during the early morning hours (4 a.m. to 6 a.m.). Unfortunately, Rightaway lost the bid to continue its contract in March 2013. The last time it drove the Blue Day Cab was April 1, 2013.

The red mid-roof sleeper and white high-roof sleeper tractors were placed with an Ann Arbor-based trucking company, 4H. This trucking company is a small "for hire" long-haul trucking firm. It transports freight on an as-needed basis, rather than on prescribed routes or schedules. Unfortunately, 4H did not drive these vehicles in the SPMD very much as was originally expected. Much of the time, the tractors were in North Carolina. Not only was this disappointing, but it took some time to get the vehicles back to the Ann Arbor area. The last time the red tractors and white tractors were driven by 4H was June 30, 2013.

Because of the issues with both fleets, it was decided that UMTRI drivers would drive the tractors on prescribed routes twice daily during peak traffic hours. The routes adhered to the approved Ann Arbor truck route list. Four routes were identified. The drivers rotated through the routes and changed directions of the route weekly. Only two tractors were driven at a time. The blue tractor was driven daily. The red tractors and white tractors were driven daily every other alternating week. The UMTRI driving began in early August and continued until the tractors were decommissioned in late October 2013. The UMTRI driving provided 3 months of valuable data for the CCV-IT project.

Questionnaires were not given to the 4H drivers since they did not receive any warnings in the SPMD area. Only one Rightaway driver agreed to complete a questionnaire. No focus group was conducted.

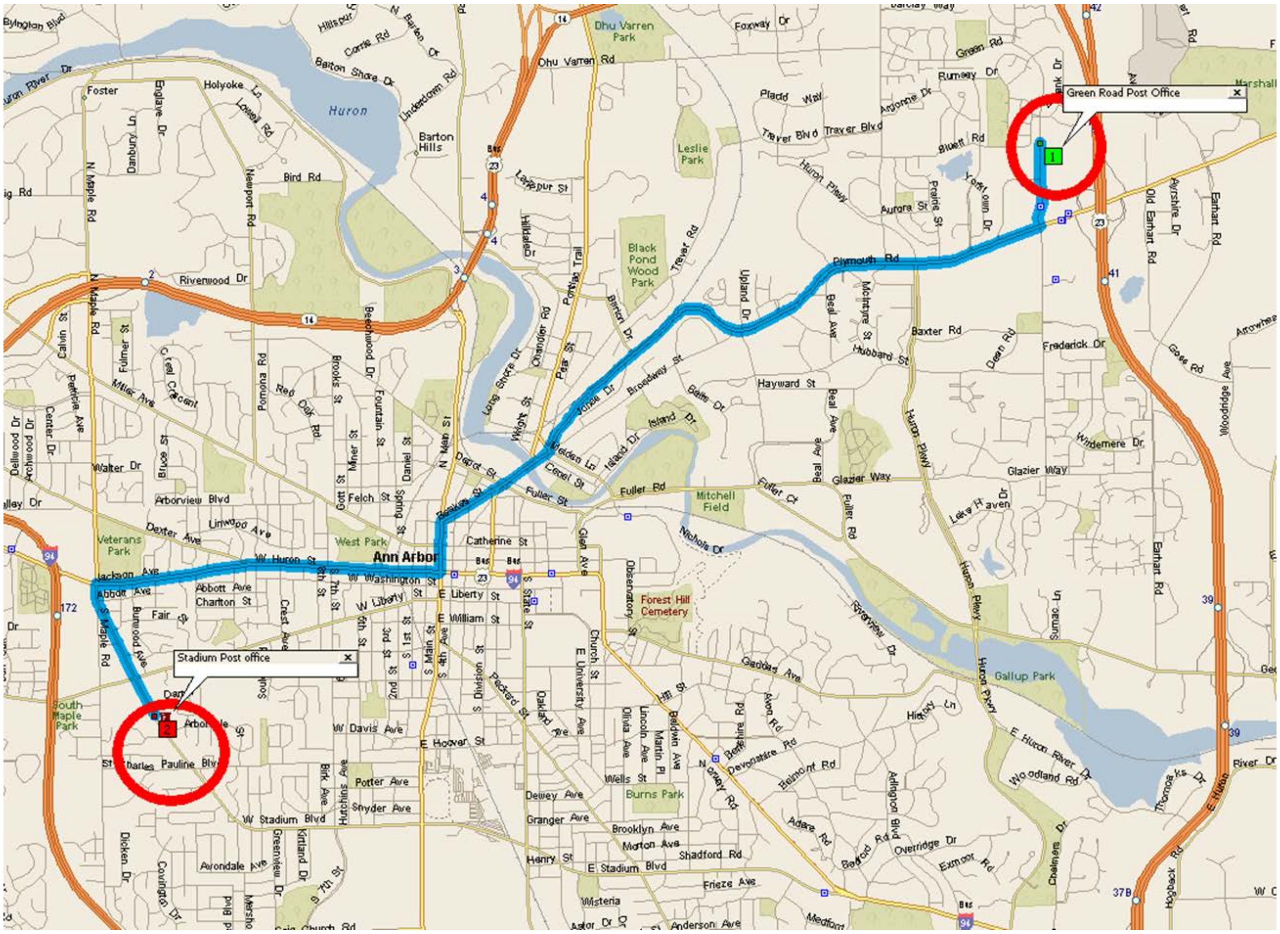


Figure 5-3: Rightaway CCV-IT Route

5.5 Introduction of the Retrofit Safety Device Heavy Vehicle Fleet

There were two USDOT subcontracts that supplied RSD kits to be installed by the test conductor – Battelle and Southwest Research Institute. Each subcontractor supplied eight RDS kits. Battelle supplied all of the eight kits with a DAS designed by UMTRI. Battelle also supplied two spare DASs. SWRI supplied eight RSD kits, four of which had a DAS (designed and fabricated by SWRI). The test conductor was responsible for recruiting one or more fleets that would allow the installation of the RSD kits in fleet-owned and operated commercial trucks operating in the SPMD area. Two fleets were selected. The Battelle RSD kits were installed on Sysco trucks. Sysco supplies food service products for restaurants, schools, healthcare facilities, and other organizations. It has a mix of straight-line tractors and articulated trailers. The Battelle RSD kits were installed on those Sysco trucks with routes primarily operating within the SPMD area. The SWRI RSD kits were installed on Con-way tractors. The Con-way tractors were fully articulated, Class 8 (GVWR above 33,000 lbs.) tractor trailers. They were less-thantruckload carriers operating in the daytime as pick-up/delivery and at nighttime as line-haul. Con-way has partnered with UMTRI on past USDOT projects.

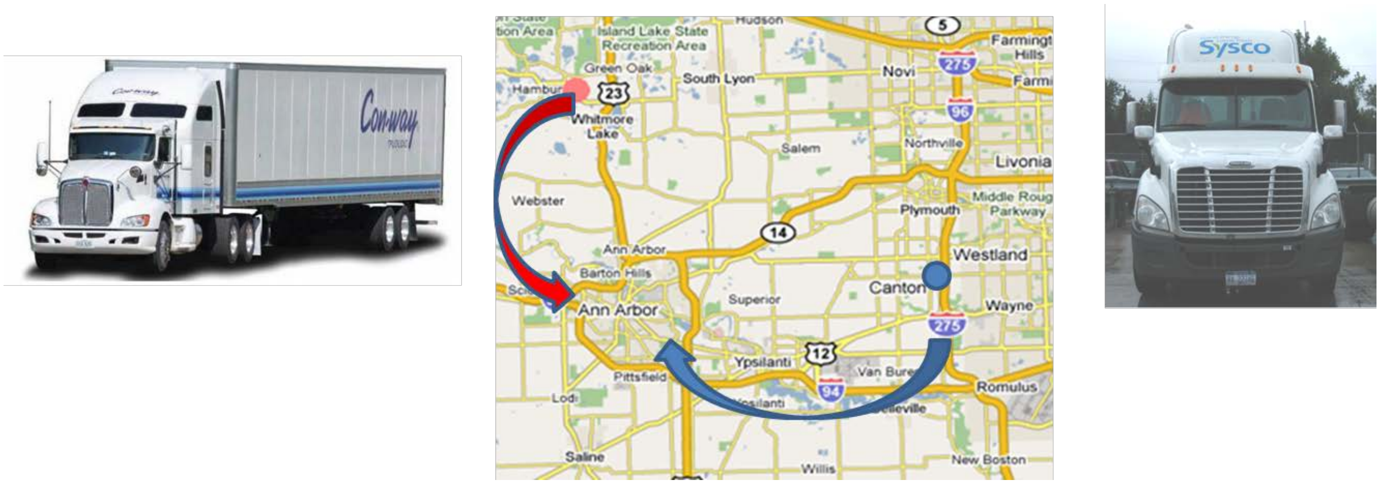


Figure 5-4: Con-way Truck (left), Relative Location of Distribution Terminals to Ann Arbor (middle), and Sysco Truck (right)

The tractors were brought to UMTRI where the RSD installations were completed. The tractors were taken out of service for two to three days during that time. Once the installation was complete, the tractors were returned to the fleet and were immediately deployed. The Sysco installations began on 10/16, 2012 and were completed November 19, 2012. The Con-way installations started on December 4, 2012 and were completed on January 10, 2013. The Sysco and Con-way distribution centers were used during SPMD for data downloads and to make any hardware and/or software updates that were required. Pictures of typical Con-way and Sysco tractors and a map of the relative position of the distribution centers are shown in Figure 5-4 above.

In preparation for SPMD, Battelle and SWRI were responsible for:

- Delivering documentation to support the IRB application as necessary,
- Delivering two RSD DSRC radios each for the following stages of interoperability testing:
    - Stage 1 bench,
    - Stage 1 field,
    - Stage 2 bench,
    - Stage 2 field,
- Providing final training material for the drivers,
- Supporting driver training, and
- Planning for data collection monthly at the distribution centers.

UMTRI responsibilities included:

- Coordinating with Con-way and Sysco fleets,
- Consenting the drivers,

- Administering subjective questionnaires,
- Facilitating a focus group,
- Seeking IRB approval for the above, and
- Decommissioning the vehicles.

5.6 Introduction of the Transit Retrofit Platform Fleet

Battelle was the USDOT subcontract responsible for delivering three TRP-equipped transit vehicles with DASs to the test conductor for deployment. University of Michigan hybrid buses were used for the TRP installations. The TRP plan, developed by Battelle and USDOT, was approached in stages. In the first stage, the TRP system was installed (August 2012). The next stage, the DAS was installed (October 2012), and the last stage, the TRP device was updated to include TRP-specific applications (December 2012). In January 2013, the TRP system was demonstrated to USDOT and approval was given to fully launch the TRP-equipped buses.

In preparation for SPMD, Battelle was responsible for:

- Delivering documentation to support the IRB application as necessary,
- Delivering two RSD DSRC radios each for Stage 2 bench interoperability testing,
- Delivering one TRP-equipped bus for Stage 2 field interoperability testing,
- Providing final training material for the drivers,
- Supporting driver training,
- Planning for data collection monthly at the main UM bus depot, and
- Calibrating the pedestrian detection sensors.

UMTRI responsibilities included:

- Consenting the drivers,
- Administering subjective questionnaires,
- Facilitating a focus group,
- Seeking IRB approval for the above, and
- Installing the pedestrian detection sensors.

Securing driver's consent to participate was more involved than originally anticipated. For the UM buses, a specific bus was on a specific route, but it was not guaranteed to have the same driver. Therefore, nearly all of the UM bus drivers needed to be consented. The consent process took several weeks and was completed on January 29, 2013.

After the deployment ended in September 2013, it was decided that the Battelle team would refine the TRP applications and re-deploy for one month. All bus drivers were re-consented and the deployment was conducted in February 2014.

5.7 Infrastructure Preparation

Once the design phase was completed for the network, network equipment selections were made and procured, and sites were identified, the next phase undertaken by the test conductor was the infrastructure site preparation. Preparing selected sites for infrastructure implementation included communication fiber splicing and network equipment upgrades by Ann Arbor. Then the cabinet interconnections were completed in combination with the cabinet switch upgrades to enable dual stack network deployment (IPv4 and IPv6). Next, the IPv6 device address design was completed. Then the equipment configurations were begun in combination with early field and network connectivity installations. During this site preparation the PCMS was designed, developed, tested, and deployed. In parallel, the test conductor team set up, configured, and began to use a Web-based system (Systems Development Lifecycle) to track, manage, and report issues, status, time spent, and resolutions for the deployment and operations and management of the SPMD infrastructure. The test conductor team implemented and configured the city hall core network equipment (router, firewall, and security appliance) and pre-tested the configurations in combination with the separate ISP connection into city hall to support the SPMD project.

5.7.1 RSE Supplier Selection

In parallel to the later phase design components, the RSE Request for Procurement was designed and forwarded to the research qualified provider list vendors for bid proposals. The test conductor team evaluated and ranked the RQPL vendor proposals and performed final selection/negotiation. The evaluation criteria were weighted based on several factors.

- Unit/bench and field testing support
- Equipment requirements and specifications adherence (USDOT RSE specification version 3.0)
- Data logging and offload via Secure Copy (SCP) methodology (a late design modification to the 3.0 specification)
- Equipment cost
- Delivery schedule/manufacturing schedule
- Design support
- Warranty
- Operations and maintenance support/software updates

After the design phase was completed, equipment purchase orders and competitive quotes were prepared as part of the RSE final selection and notification.

5.7.2 Roadside Equipment Installation

After the core network was implemented, the bench-tested roadside devices and configurations were field deployed in two Phases (Phase 1 – early deployment, initially tested/validated RQPL vendor equipment) and (Phase 2 – full infrastructure deployment). The Phase 1 RSEs were used from Arada and originally conceptualized to be a dual manufacturer deployment model for SPMD. During initial Phase 1 testing and evaluations, the Arada units were found to be unstable and a security risk. As part of Phase 2 deployment, the Arada units were removed from service.[17] Additionally, in a parallel installation process in Phase 2, Savari unit configuration, installation and testing were completed.

5.7.2.1 Freeway Sites

The initial conceptualized freeway site locations planned for in Phase 2 deployment, were delayed until late in the project due to a combination of technical design choices/issues with MDOT regarding how and where to set up and use the IPv6/IPv4 dual stack equipment and CML/SSL data offloads needed for RSE operation. Once these design criteria were identified and finalized, MDOT was not able to set up their network in time for SPMD conclusion, so the test conductor team began evaluating alternate communications pathways to the sites (including MDOT cable ISP provider Comcast). A series of design options were completed and RSE devices were installed with Comcast service provisions to the sites. As part of initial testing it was discovered that Comcast delivery of IPv6 did not adhere to the IPv6 addressing requirements and therefore the RSEs would not function properly. This then required a separate design and communications methodology and series of equipment procurements performed under a separate MDOT ITS contract, which accounted for another project schedule delay. Once the contract task was set up, the additional wireless communications equipment was purchased, installed, and configured. This implementation allowed by Ann Arbor supported the backhaul extension of Ann Arbor's network for the freeway RSE sites.

5.7.2.2 Signal Phase and Timing Sites

There were a series of project schedule and cost impacts to the test conductor team resulting from the lab development, testing, and delivery of a functional SPaT software and "black box" communications transceiver. In addition, the initial design of the software did not support multiple network segments or the dual network interfaces (IPv4/IPv6) in the initial release, in combination with the single IP address device assignment broadcast (as opposed to segment/nearest neighbor network broadcast); all of these issues required software modifications and additional time prior to SPaT/GID bench testing, field testing, and production deployment. Once the revised software was turned over, the integration, configuration and design/deployment was set up by the test conductor team in conjunction with Battelle, TTI, and Ann Arbor. The bench testing and configuration evaluations were completed and the Econolite TSC SPaT/GID equipment was installed along the Fuller Road corridor.

Additionally, in parallel, the Econolite SPaT TSC firmware release was ready on time, however the Siemens version took an additional 18 months to release for use on SPMD. Prior to allowing SPMD to use the new Siemens TSC firmware, Ann Arbor required three months for bench testing to validate the

[17] During the Phase 1 Ann Arbor installation process, the test conductor team discovered several issues with the initial Arada units. Initially the units were not using a secured (user name and password) methodology for Communications Message Log and System Status Log file offloads. A secondary security issue was found in the directory file structure on the unit, as an authenticated user could place any random file/script in the file structure setup for offloads and the unit would automatically load the random file to the back office communication processing servers. If best practice security protocols on both the RSE and the back office were not implemented, data corruption could be propagated on RSEs, RSEs broadcast, and through the repository/data processing routines for the entire back office server storage. The file offloads and data processing were core requirements for the SPMD project, and as a result the Arada units were replaced with Savari RSE units throughout the infrastructure.

firmware interoperated with Tactics Central Office Control, SCOOT adaptive control, and core functions used throughout Ann Arbor for signalized intersections. Once this was completed, the Siemens SPaT/GID deployment was completed along the Plymouth Road corridor and design integration was completed with SCOOT and the field installed RSEs.

5.7.3 Local Certificate Distribution System Installation

The LCDS was used to generate two year batches of 5-minute security certificates and decryption keys for the VADs, as described in Section 4.4 Security Management System Concept of Operations. The first use of the LCDS was up and operational on July 2, 2012, for pre-model deployment testing. An issue was discovered prior to launch: the certificates in the batches were in the wrong order, making them unusable. An automated process was developed to verify that the certificates were valid before delivery. All 110 batches needed for pre-model deployment VAD installations were delivered by July 6, 2012. The process for generating and delivering the VAD certificates was:

- LCDS interfaced with SCMS to generate the certificates,
- LDCS validated each certificate,
- Certificates are transferred to a secure area for UMTRI retrieval,
- Certificates are securely stored at UMTRI, and
- Certificates are retrieved by the configuration management system during VAD installation.

For SPMD, the certificate batches were generated and delivered at a rate of 250 per week. A total of 2,750 certificate batches were delivered by September 12, 2012. Five hundred additional certificate batches were generated and stored at Leidos to be used as spares if the need arose.

6 Pre-Model Deployment Phase 3: Execution of the Pre-Model Deployment Tests

Phase 3 of pre-model deployment consisted of executing interoperability testing, ASD as host testing, antenna testing, and the pre-model deployment dry run; and developing the recommendations report and readiness checklist.

6.1 Interoperability Testing

The Interoperability Test Plan submitted to the USDOT addressed interoperability of DSRC devices prior to and during the pre-model deployment dry run. Interoperability testing focused on the ability of vehicle-based and infrastructure-based devices to exchange messages over DSRC and decode, log, and/or forward, where applicable, those messages or the data contained within those messages. Interoperability testing verified DSRC messages sent from multiple device types and multiple device suppliers can be received and decoded by other device types and other device suppliers.

All discrepancies discovered during testing were recorded in a PTRR and sent to the supplier for resolution. The supplier completed the root cause, corrective action, verification plan, and implementation plan sections of the form and submitted it to the test conductor for approval. Once the test conductor approved the corrective action and the verification and implementation plans, the form was submitted to the change control board for final approval.

The original plan for interoperability testing was to conduct the tests one time. However, since the RSEs were not available at the time that interoperability testing was to take place, testing was split into two stages. The first stage only included vehicle-based devices and the second stage included all devices to be deployed for SPMD, i.e., vehicle-based devices and RSEs.

Stage III and Stage IV were added after issues were discovered after the launch of SPMD. Descriptions of the issues can be found in Section 7.1. The Interoperability Test Reports are provided in Appendix F.

6.1.1 Stage I Interoperability Testing

This section provides a summary of Stage I interoperability Testing. The full results can be found in *Safety Pilot Stage I Interoperability Test Report, Appendix F.* Stage I Bench Testing was conducted May 1, 2012, through May 4, 2014, at UMTRI. Stage I Field Testing was conducted May 14, 2012, through May 18, 2012, in Ann Arbor.

6.1.1.1 Stage I Approach

Stage I interoperability testing, conducted from May 23, 2012, through May 18, 2012, consisted of both a bench test and a field test. The bench test was conducted in a controlled lab environment with the intention of resolving core issues before proceeding to the field test in which devices were installed in vehicles and vehicles were driven around the model deployment geographic area. Figure 6-1 is a map of the Stage I driving route.

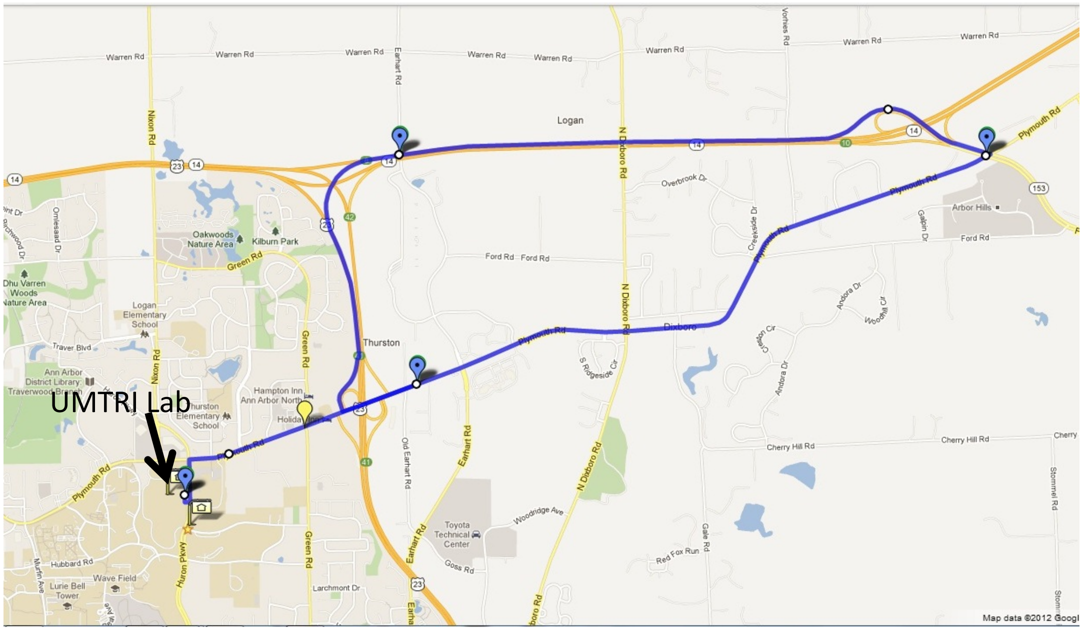


Figure 6-1: Stage 1 Field Test Drive Route

Both tests evaluated V2V BSM compatibility for the following devices:

- VADs (two each provided by Cohda Wireless and Savari),
- ASDs (two each provided by Delphi, Visteon, and Denso),
- Two integrated safety devices (ISDs), VSCA platform (two each provided by CAMP),
- Two integrated safety devices (ISDs), BSM proxy platform (two each provided by CAMP), and
- Two CCV-ITs platforms (provided by Battelle).

All suppliers provided two devices; however, only one device was operational at any given time. For each test all eight devices transmitted BSMs and, with the exception of the two VADs, all devices processed and logged received BSMs (VADs only transmit BSMs, they do not process received messages).

6.1.1.2 Stage I Results

From a core interoperability standpoint, all supplied devices passed Stage I testing. This indicated that all devices and device types could correctly decode BSMs from all other devices and device types. However, several discrepancies were observed resulting in six "Problem Trouble Reports" issued to four device suppliers for resolution. Also a few devices exhibited some seemingly minor stability issues[18] that needed to be addressed, all of which were targeted for resolution by pre-model deployment.

6.1.2 Stage II Interoperability Testing

This section provides a summary of Stage II interoperability testing. The full results can be found in *Safety Pilot Stage II Interoperability Test Report, Appendix F.* Stage II Bench Testing was conducted from June 25, 2012, to June 29, 2012, at UMTRI. Stage II Field Testing was conducted from August 27, 2014 through August 31, 2014 in the model deployment area (Ann Arbor).

6.1.2.1 Stage II Approach

As with Stage I, Stage II interoperability testing consisted of both a bench test and a field test. The bench test was conducted from June 17, to to June 29, 2012 and the field test was conducted from August 19, 2012, to August 31, 2012. Figure 6-2 is a map of the Stage II driving route.

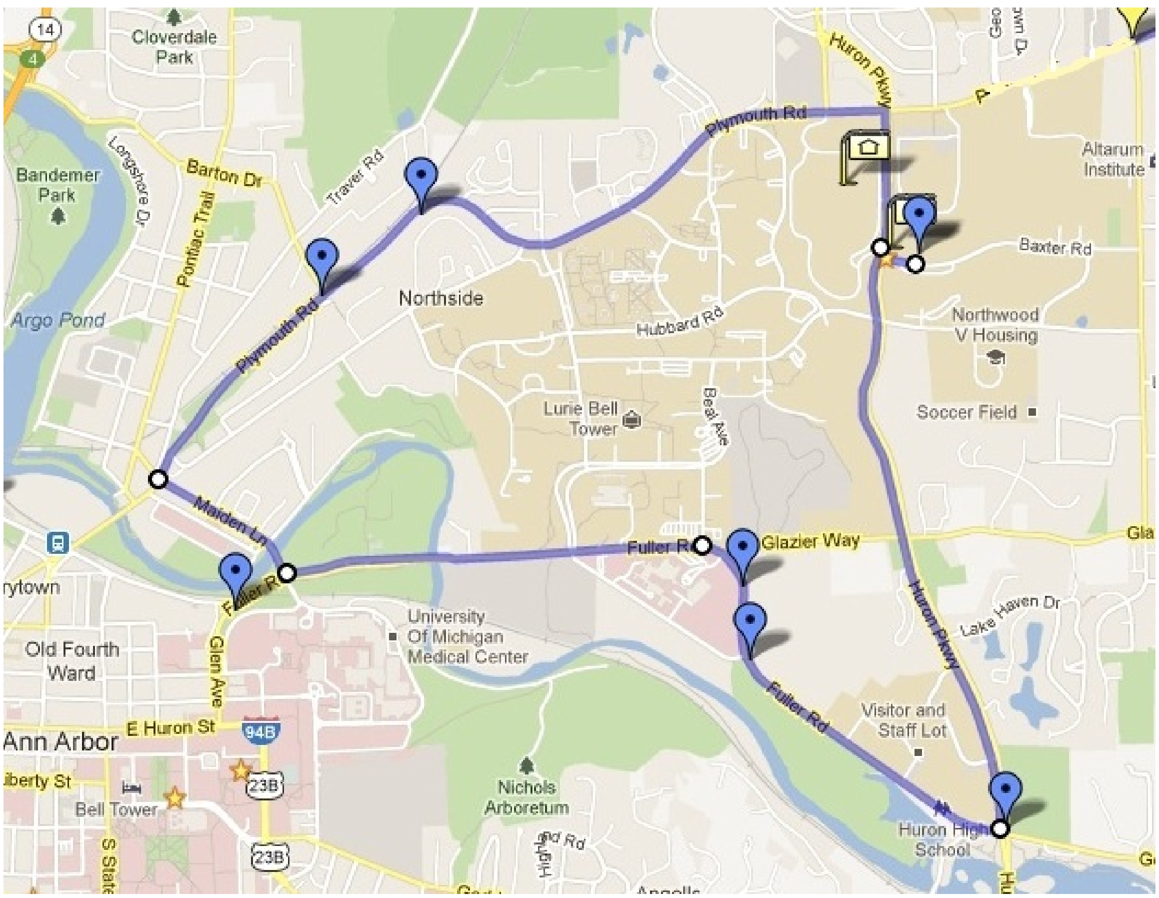


Figure 6-2: Stage II Field Test Drive Route

[18] Device experiences minor operational issues that causes temporary lapses in data processing or application computattions.

Both tests evaluated devices against the following test cases:.

1. BSM reception from multiple device suppliers (regression test)
2. CSW reception from multiple RSE suppliers
3. RSU logging of DSRC messages
4. ASD to remote server connection (RSU as gateway)
5. 1609.2 certificate revocation list (CRL) distribution to authorized vehicle
6. DSRC message rejection based on the CRL
7. Device misbehavior report generation and transmission to the SCMS

Test cases 5 to 7 were originally planned for execution during the pre-model deployment, however, none of the vehicle devices supported the functionality at the time of pre-model deployment.

The following devices were evaluated during the bench test.

- VAD (two each provided by Cohda Wireless and Savari)
- ASD (two each provided by Cohda-Delphi, Cohda-Visteon, and Denso)
- One ISD VSCA Platform (provided by CAMP)
- One CCV-IT platform (provided by Battelle)
- Two RSD platforms (one each provided by Battelle and SwRI)
- RSUs (two each provided by Arada and Savari)

The following devices were evaluated during the field test.

- VAD (two each provided by Cohda Wireless and Savari)
- ASD (two each provided by Cohda-Delphi, Cohda-Visteon, and Denso)
- One ISD VSCA Platform (provided by CAMP)
- One CCV-IT platform (provided by Battelle)
- Two RSD platforms (one each provided by Battelle and SwRI)
- One TRP (provided by Battelle)
- RSUs (five provided by Arada and 2 provided by Savari)

Most device suppliers provided two devices, however, only one device was operational at any given time. For each test, nine vehicle devices transmitted BSMs, up to eight vehicle devices processed and logged received BSMs, five vehicle devices processed and logged WAVE service advertisements and CSWs, and up to seven RSEs transmitted WSA and CSWs and received and logged BSMs, WSAs, and CSWs.

6.1.2.2 Stage II Results

All tested devices passed Stage II BSM regression testing, however, the following issues were observed:

1. Two ASDs failed the “DSRC message rejection based on the CRL” test case.
2. The RSDs and TRP did not support the security credential related test cases. The functionality was still under development.
3. Two ASDs did not provide alerts when the vehicle was traveling over the “advised speed” contained in the CSW message.
4. One ASD continued to have stability problems.

In total, seven problem trouble reports were issued to four device suppliers.

Based on the results of the interoperability Stage II field test, the test conductor recommended an additional round of interoperability testing to verify that observed failures were corrected as well as regression test on devices that did not support certain functionality at the time of Stage II Testing.

6.1.3 Stage III Interoperability Testing

This section provides a summary of Stage II interoperability testing. The full results can be found in *Safety Pilot Stage III Interoperability Test Report, Appendix F.* Stage 3 Interoperability testing was conducted from December 10, 2012, to December 14, 2012.

6.1.3.1 Stage III Approach

Since it was a regression test, Stage III interoperability testing consisted of only a field test. Testing took place from December 3 to December 14, 2012. The same test drive route was used for Stage III as was used in Stage II, and is shown inFigure 6-2.

Devices were evaluated against the following test cases:

1. CSW reception from multiple RSU suppliers.
2. 1609.2 CRL distribution to authorized vehicle.
3. DSRC message rejection based on the CRL.
4. Device misbehavior report generation and transmission to the SCMS.
5. RSU security credential boundary (WSA Verification).

The following devices were tested.

- ASD (two each provided by Cohda-Delphi, Cohda-Visteon, and Denso)
- Two RSD platforms (one each provided by Battelle and SwRI)
- One TRP (provided by SwRI)

Most device suppliers provided two devices, however, only one device was operational at any given time. For each test, up to two vehicle devices transmitted BSMs, up to two vehicle devices processed and logged received BSMs, up to two vehicle devices processed and logged WSA, CSW messages, and up to seven RSUs transmitted WSAs and CSWs and received and logged BSMs, WSAs, and CSWs.

Since Stage III was a re-assessment of specific devices against specific test cases, not all devices were tested against all test cases.

6.1.3.2 Stage III Results

All tested devices passed Stage III regression testing, with the exception of the following:

- Two devices failed the RSU security credential boundary (WSA Verification). The ASDs did not verify WSAs from an RSU because the ASD system time and the RSU system time were not synchronized. Since the ASDs did not verify WSAs, they did not join the WBSS. All remaining V2I tests were conducted with security disabled on the two devices. WSA verification was not relevant for the other tests.

In total, two problem trouble reports were issued to two device suppliers.

6.1.4 Stage IV Interoperability Testing

Stage IV Interoperability Testing was conducted to re-assess devices after multiple firmware updates were applied to resolve various issues discovered throughout the course of the project.

This section provides a summary of Stage IV interoperability Testing. The full results can be found in *Safety Pilot Stage IV Interoperability Test Report, Appendix F*. Stage IV Bench Testing was conducted from February 2 to February 7, 2014, at UMTRI. Stage IV Field Testing was conducted February 18 to February 21, 2014 in Ann Arbor.

6.1.4.1 Stage IV Approach

Stage IV bench and field testing was conducted from February 3 to February 7, 2014, and February 17 to February 21, 2014, respectively. The Stage II test drive route was used for Stage IV testing and is shown inFigure 6-2.

Bench testing evaluated devices against the following test cases (test case codes are included in parentheses).

1. BSM reception from multiple device suppliers (SP-BSM-BNCH-01)
2. CSW decode (SP-INT-CSW-BNCH-01)
3. RSU logging of DSRC messages (SP-INT-MSG-RSU-01)
4. ASD to remote server connection (RSU as Gateway) (INT-IPGAT-BNCH-01)
5. BSM populated with correct vehicle length data element (SP-DE_VehicleLength--BNCH-01)
6. BSM Part I Position3D is the reference point for Part II PathHistory Offsets (does not contain FullPositionVector) (SP-PathHistory_Offsets --BNCH-01)

7. BSM populated with correct "Year" data Eeement (SP-BSM-year Value-BNCH-01)

8. RSU WAVE service advertisement security verification (SP-WSA Certificate Verification-BNCH-01)

9. Device boots up properly after shutting down while GPS is writing to log file (SP-Shutdown while GPS is writing to file -BNCH-01)

10. Correct implementation of z-offset (SP-Antenna Z-Offset -BNCH-01)

11. Device stability with varying lengths of BSM Part I dSecond Data Frame (SP-BSM dSecond data length-BNCH-01)

Field testing evaluated devices against the following test cases.

1. BSM reception from multiple device suppliers (SP-INT-BSM-FILD-01)

2. ASD to remote server connection (RSU as Gateway) (SP-INT-IPGAT-TRANS-FLD-01)

3. CSW Alert (SP-INT-CSW-FLD-02)

4. ASDs send misbehavior report to SCMS (SP-MD-MSBEHV-RPT)

5. ASDs reject BSMs based on CRL (SP-MD-RV_CERT-01)

6. ASDs request and download security certificates (MD-SCMS-Cert Download-01)

7. RSUs broadcast SPaT and map messages (SP-INT-SPaT-FLD-01)

8. VAD certificate root rollover (SP-MD-CA-Rlovr)

The following devices were evaluated during both the bench and field tests.

- Two VADs (one each provided by Cohda Wireless and Savari)
- ASD (one each provided by Cohda-Delphi, Cohda-Visteon, and Denso)
- One TRP (provided by Denso)
- One ISD VSCA Platform (provided by CAMP)
- One ISD BSMP Platform (provided by CAMP)[19]
- One RSD platform (provided by Denso)
- One RSU (provided by Savari)

For each test, nine vehicle devices transmitted BSMs, up to seven vehicle devices processed and logged received BSMs, five vehicle devices processed and logged WSAs and CSW messages, and up to seven RSEs transmitted WSA and CSWs and received and logged BSMs.

[19] CAMP support for SPMD was broken into two groups of OEMs. The VSCA group participated in past research and had common V2V devices and safety applications. The BSMP group were new members that individualy developed and implemented V2V devices and safety applications into their vehicles.

6.1.4.2 *Stage IV Results*

With a few exceptions, all devices successfully passed all test cases. Firmware updates seemingly introduced several issues not observed in previous tests.

A total of six problem trouble reports were issued to four device suppliers for resolution at the end of Stage IV testing.

The test conductor recommended that device manufactures update their internal test procedures/processes to ensure firmware updates did not affect existing functionality as well as that devices be regression tested whenever a firmware update was applied to confirm previous problems were resolved and new problems had not been introduced. Not all suppliers were required to be on site during these regression tests, only the supplier for the device under test.

6.2 ASD as Host Testing

CAMP tested the ability of its ISDs to respond to potential threats based on BSMs from the SPMD selected ASDs (i.e., ISD as host vehicle and ASD as remote vehicle). However, the reverse case also needed be tested to verify full interoperability between the two device types. The SPMD ASD functional testing focused on the ability of the selected ASDs to respond to potential threats based on BSMs from ISDs and VADs (i.e., ASD as HV with ISDs and VADs as RVs). Testing was conducted the week of 0June 04, 2012 at the Michigan International Speedway.

The following five application scenarios were tested.

- EEBL
  - RV in 1st adjacent lane-alert (EEBL1)
  - RV in 2nd adjacent lane-no alert (EEBL2)
- FCW
  - RV Stopped in same lane-alert (FCW1)
  - Slow moving RV in same lane-alert (FCW2)
  - Stopped RV in adjacent lane-no alert (FCW3)

The following three antenna configurations were tested on sedans and SUVs (see Figure 6-3).

- Sedan (ASD\VAD)
  - Hirschman dual band: rear cargo shelf
  - DSRC: Hirschman dual band, rear cargo shelf; GPS: Hirschman window mount, center rear window
  - DSRC: Hirschman dual band, rear cargo shelf; GPS: Ublox, center rear window

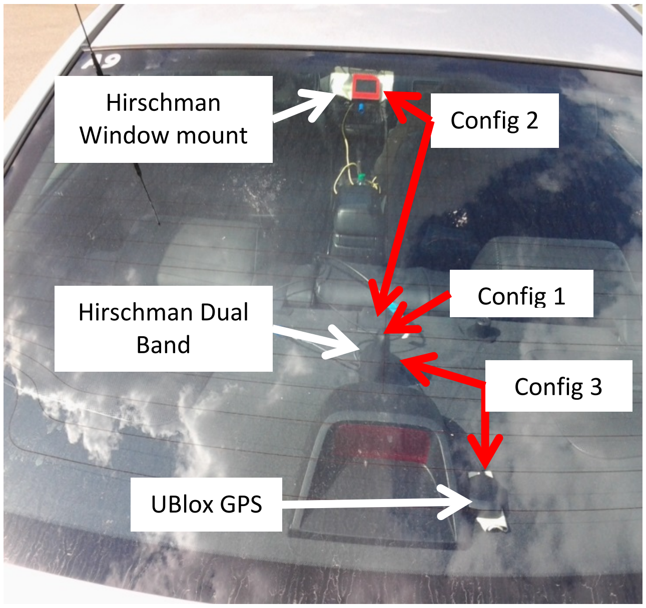


Figure 6-3: ASD as Host Antenna Configurations

- SUV (VAD only)
    - Mobile Mark dual band: center low rear window
    - Mobile Mark dual band: driver’s side window

The following devices were tested:

- Two VADs (one each provided by Cohda Wireless and Savari)
- ASD (one each provided by Cohda-Delphi, Cohda-Visteon, and Denso)
- One ISD VSCA platform (provided by CAMP)
- One ISD BSMP platform (provided by CAMP)

Table 6-1 contains the device and antenna configuration test matrix.

Table 6-1: ASD as Host Device and Antenna Configuration Test Matrix

		RV							SUV as RV	
		BSMP	Savari VAD			Cohda VAD			Savari VAD	
HV	Antenna Configuration	Baseline	1	2	3	1	2	3	1	2
Denso ASD	1	x	x			x			x	x
	2	x	x			x				
	3	x	x			x				
Cohda-Delphi ASD	1	x								
	2	x								
	3	x				x				
Cohda-Visteon ASD	1	x	x						x	x
	2	x							x	
	3	x	x			x				

For each test, two vehicle devices transmitted BSMs with one vehicle acting as the RV (threat) and one vehicle acting as the HV (application).

6.2.1 ASD as Host Test Procedures and Results

Testing consisted of installing ASDs in an HV with one of the three antenna configurations and installing VADs in an RV with antenna configuration #1. CAMP provided vehicles with VSCA and BSMP ISDs pre-installed. UMTRI and Leidos provided drivers for all vehicles. The vehicles were driven through the test station depicted in Figure 6-4 in accordance with each application scenario using each of the three antenna configurations on the HV.

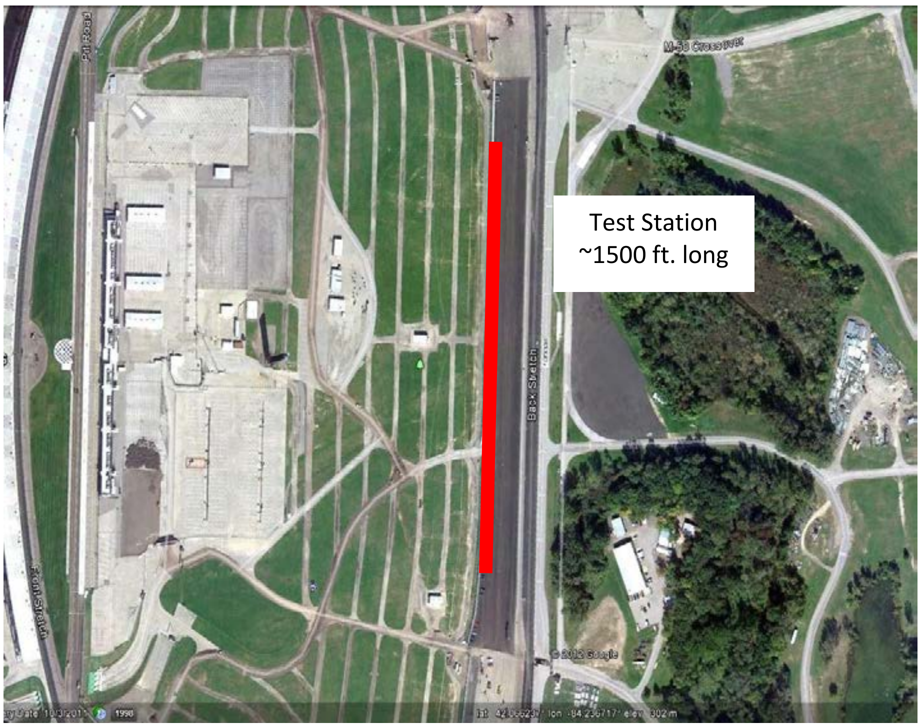


Figure 6-4: ASD as Host Test Station

Baseline tests were conducted for each host device with both the DSRC and GPS antennas on the outside of both the host and remote vehicles. Each scenario was run four times with the results of each run recorded and the average of the four runs calculated to determine the overall pass percentage.

For adjacent lane scenarios, two runs were conducted with the RV on the right side of the HV and two runs were conducted with the RV on the left side on the HV. Table 6-2 depicts the overall pass percentage for each host ASD versus each remote ISD and VAD.

Table 6-2: ASD as Host Pass % Host Versus Remote

Device	BSMP	VSCA	C-VAD		S-VAD				
	Baseline	Baseline	Baseline	1	Baseline	Sedan1	SUV1	SUV2	**Pass %**
Cohda-Visteon	89%	100%	100%		100%	89%	75%	100%	96%
Cohda-Delphi	85%	80%	100%		60%	100%	100%		85%
Denso	85%	100%	67%	75%	80%	90%	75%	0%	71%
Pass %	86%	93%	89%	75%	80%	93%	83%	50%	

6.2.2 ASD as Host Testing Conclusion

For the baseline, Denso preformed the best with a 90 percent passing rate and Cohda-Delphi preformed the worst with a 75 percent passing rate.

For the antenna configurations 2: DSRC-Hirschman dual band; GPS-Hirschman window mount, performed the best with a passing rate of 93 percent and configuration 3: DSRC-Hirschman dual band; GPS-Ublox, performed the worst with a passing rate of only 80 percent.

Overall, Cohda-Visteon preformed the best with a passing rate of 93 percent and Denso preformed the worst with a passing rate of only 71 percent.

6.3 Antenna Testing

The initial paradigm for the antennas to be used for VAD and ASD installations was to use a dual-band magnetic mount DSRC/GPS antenna. However, this configuration was not suitable for a one-year deployment on participants' personal vehicles. The types of damage that could occur included uneven fading, pitting and scratching of painted surfaces, broken leads, water intrusion that follows the antenna leads, and the potential for body panel damage as a result of antennas that come loose. In an attempt to compromise between an interior- and exterior-mounted antennas, the test conductor collaborated with CAMP to test various antenna mounting locations for both GPS and DSRC antennas. The test plan consisted of the following:

- Oakland University: testing on the gantry (an elevated three-dimentional movable platform) to evaluate potential mounting locations to generate a viable "short list" of GPS and DSRC antenna mounting locations. Testing was conducted May 1 to May 4, 2012.

- VAD certification testing: piggy-back USDOT certification testing to evaluate the short-list of potential mounting locations, and eliminate any potential mounting locations, if possible. Testing was conducted at Millville from June 5 to June 8, 2012.
- ASD as host testing: piggy-back the ASD as host testing to evaluate the short-list of potential mounting locations, and eliminate any potential mounting locations, if possible. Testing was conducted June 4 to June 8, 2012.
- Testing at UMTRI: first pass testing evaluate the final list of potential antenna mounting locations. Testing was conducted by both the test conductor and CAMP from July 30 to August 1, 2012.
- CAMP naturalistic testing: naturalistic drive from Detroit to Traverse City to evaluate the final candidates for GPS and DSRC antenna mounting locations.

The final result of the testing was that the GPS antenna was mounted externally. For sedans it was mounted on the trunk lid and for SUVs it was mounted on the roof. The DSRC antennas could be mounted in the interior of the vehicle. For sedans, it was mounted on the rear package shelf and for SUVs a window mount antenna was used and was mounted on one of the rear windows.

6.4 Pre-Model Deployment Dry Run

The pre-model deployment dry run took place from July 9 to July27, 2012. It focused on verifying that all deployed hardware and software components functioned as a complete system. It tested connectivity between vehicle-based devices, RSEs, and the SCMS and the connectivity between RSEs and the back office servers. It exercised retrieving log files from the various devices and transferring the data to the independent evaluator and the data capture management team for processing and analysis. It also exercised system monitoring and driver training procedures. Nineteen test cases were exercised during pre-model deployment.

During pre-model deployment, 125 vehicle devices were installed and tested.

- 8 ILVs (1 from each CAMP OEM) equipped with a DAS
- 2 ASD-equipped vehicles with DAS, owned and operated by UMTRI
- 114 Cohda Wireless and Savari VAD-equipped vehicles
  - 13 UMTRI employee-owned and operated vehicles
  - UMTRI-owned development vehicles
  - 70 vehicles selected from the recruitment pool with “naïve drivers”
  - 13 light-duty Metro fleet delivery vehicles
  - 10 heavy-duty fleet delivery vehicles
  - 3 UM buses (transit vehicles)
- 1 CCV-IT (blue day cab)

Additionally, 6 Arada RSEs[20] were installed in the SPMD area.

- UMTRI
- Fuller Road/Geddes and Huron Parkway
- Washtenaw and Huron Parkway
- Fuller Road and Glen Avenue
- Main Street and Depot Street
- Plymouth Road and Green Road

6.4.1 Dry Run Results

- Successfully downloaded and decrypted six months' worth of security certificates on ASDs
- LCDS generated and delivered 550 batches of VAD certificates
- Network operations and maintenance verified
- Data successfully collected and transferred to the Independent Evaluator
  - Log files from ASDs and VADs
  - Data from ASD DAS
  - Data from CCV-IT DAS
  - Data from ILVs (by CAMP)
  - RSE log files
- Successfully trained ILV, ASD, and CCV-IT drivers
- Verified process for equipping ASDs and VADs
- Successfully monitored the RSE network state of health
- Successfully monitored the vehicle-installed DSRC device state of health

6.4.2 Dry Run Conclusion

The pre-model deployment dry run assessed the overall performance of several vehicle-based devices, Stage I RSEs, the backhaul network, and various processes and procedures. Test results indicated that all Stage 1 SPMD functionality was operational.

6.5 Recommendations Report

Upon the completion of the Safety Pilot Pre-Model Deployment, the SPMD test conductor made the following recommendations for SPMD, and delivered to USDOT in the Recommendations Report.

- The test conductor and all associated USDOT contractors have completed all tasks required to begin model deployment. Therefore, the test conductor and all USDOT contractors should continue with plans for the SPMD launch on August 21, 2012.
- The outstanding items on the model deployment Readiness Checklist version 4.9 should be completed by the dates indicated. However, not all outstanding items are critical to SPMD launch.

[20] Arada units were initially installed; however because of security performance issues were later replaced (see section 5.7.2).

- All open PTRR issues should be in the “resolved” state. This constitutes that the following has been completed:
    - Identify the root cause
    - Agree on the implementation plan
    - Agree on the verification plan
    - Agree on the configuration management tracking
- The following refresh activities should have occurred prior to the launch, but were not completed until after the start of model deployment.
    - Update the Savari Pre-Model Deployment Fleet (55 vehicles total).
        - Savari VADs had two issues that were identified that required updates:
            - Savari pre-model deployment VADs did not meet transient voltage requirements. There was a hardware update required. SPMD units were built with the updated hardware and were not affected. The risk of failure in the field was very low. The occurrences of transient voltages at this level were very rare.
            - Savari pre-model deployment VADs did not correctly implement the unique ID. The unique ID was in the wrong location in the BSM. The SPMD units were built with the software update and were not affected.
        - The Savari pre-model deployment units were removed and replaced with SPMD units when the vehicles were returned for their first data download at UMTRI.
    - Update the DSRC and GPS antennas on the pre-model deployment Fleet (114 vehicles total).
        - As a result of the limited availability of the Hirschman shark fin dual band antenna at the onset of pre-model deployment builds, several sedan vehicles were built with an alternative DSRC antenna with a temporary mount.
        - As a result of the limited availability of the Mobile Mark window mount antenna at the onset of pre-model deployment builds, the majority of SUVs were built with an alternative DSRC antenna with a temporary mount.
        - None of the pre-model deployment dry run vehicles were built with the separate GPS antenna. The GPS testing and selection was completed after the pre-model deployment fleet was built.
    - Update the DSRC and GPS antennas on the VAD SPMD fleet.
        - The Hirschmann shark fin dual band DSRC antenna was not available until September 7, 2012. Until then, sedans were built with the Mobile Mark window mount dual band antenna.
        - The Hirschmann GPS antenna was being installed in the interior of the vehicle on the window near the dash and passenger side A-pillar. These needed to be relocated to the location agreed upon by CAMP, USDOT, and UMTRI.
- Continued rigorous change control to address any problems that occurred after launch.

6.6 Model Deployment Readiness Checklist

The purpose of the model deployment readiness checklist was to provide evidence of sufficiency to USDOT that the model deployment site was ready to launch model deployment. One hundred twenty-five items were identified in various categories including planning, security, communications, data, applications, devices, certification, and governance. For each item, an owner and scheduled completion date was identified. The readiness checklist was reviewed during the program coordination meetings. Detailed reviews of the readiness checklist were also conducted at the July 2012 working group and the August 7-8, 2012, working group meetings. At the first meeting, all items were reviewed and the status documented. At the second meeting, only the remaining open items were reviewed.

It was a requirement that all items needed to be checked off prior to USDOT approval to launch model deployment.

7 Model Deployment

The model deployment stage consisted of maintaining devices, vehicles, and infrastructure; data collection, storage, and transfer; and introducing other applications. All of these aspects of the model deployment are described below.

7.1 Maintain Devices, Vehicles, and Infrastructure

Once the SPMD was launched, the infrastructure and vehicle fleets needed to be maintained. The following sections describe how the devices were monitored in the field, what types of issues were discovered, and how they were corrected (refresh report).

7.1.1 State of Health Monitoring

State of health monitoring was conducted for both vehicle-based devices and infrastructure-based devices. For purposes of the SPMD, each vehicle-based device was assigned a unique ID that was broadcast as part of the BSM. As a vehicle drove by an RSE, the BSMs that were transmitted from the vehicle were automatically stored as part of the RSE log file. These log files were scanned on a regular basis, and a list of the unique device identifiers that were recorded was produced. From this list, UMTRI looked for the absence of specific devices. When UMTRI had not recorded the unique device identifier from specific vehicle for a period of several days (perhaps a week), UMTRI contacted the participant associated with the device to find out whether the vehicle has been recently driven in the SPMD test area. This process was also employed for ASD-equipped vehicles without a DAS.

Vehicles equipped with the UMTRI DASs (ASD-equipped vehicles, TRP-equipped vehicles, some RSD-equipped vehicles, and the CCV-ITs) were also monitored daily via cellular data link with UMTRI. For the monitoring of devices and the DAS equipment, a file was sent to UMTRI via cellular link using DAS battery power when power from the vehicle to the DAS was terminated, i.e., when the vehicle was turned off. The file contained small snippets of data and some diagnostic information. From the diagnostic information, it was easy to obtain the state of health of the DSRC device.

The state of health for the vehicles equipped with the SWRI RSD kits were not monitored in the field. However, the vehicles were functionally verified during the data downloads, which occurred approximately every three months.

The 64 ILVs had cellular-based health monitoring that was handled by the CAMP VSC3 consortium under a separate contract with the USDOT.

The infrastructure was also monitored. The RSEs sent a state of heartbeat message to the back office once every minute. If the heartbeat was not received, the RSE warranted further investigation. The RSE also offloaded the stored BSM, SPaT, TIM, and MAP files once every hour, or sooner if the RSE storage capacity was full. This was also monitored by the back office. The back office organization (Mixon Hill) generated a report twice daily that provided the status of all deployed RSEs and distributed it to the test conductor team as well as USDOT stakeholders.

7.1.2 Maintain the Integrated Light Vehicle Fleet

Although CAMP was responsible for maintaining the ILV fleet, support was required from the test conductor. The two main areas were support for the monthly data harvests and deploying the ILVs with a second round of participants.

For the monthly data harvest, the test conductor was responsible for contacting the 64 participants and scheduling them over a 3- to 4-day period to bring their vehicles to UMTRI. The specific dates were designated by CAMP. If it was a hardship for the participant to bring the vehicle in for their scheduled appointment, UMTRI would pick up the vehicle at their place of employment or from their home. Once at UMTRI, the CAMP team would harvest the data, clean the drive, and verify full functionality for each vehicle before re-deployment. The first data harvest was scheduled for two weeks after initial deployment to disable the baseline. During the two-week baseline period, the driver did not receive any warnings. Subsequent data harvests were conducted monthly.

At the end of the first 6-month deployment, the vehicles were inspected by the test conductor and CAMP and repairs were approved and prioritized. The test conductor made arrangements for the vehicle repairs. The test conductor detailed the vehicle to prepare them for the second deployment. CAMP transported the vehicles to their facilities for updates and upon completion transported the 64 vehicles back to UMTRI.

In parallel with the vehicle preparations, the test conductor recruited the second round of drivers. Again the drivers were balanced by age and gender. However, for the second round the drivers were selected from the existing VAD fleet. The data from the sent BSM database (see section 7.2.1, OTA Sent BSM Message Archive, below) were analyzed to recruit drivers that spent the most time in the model deployment area. This was a much better measure than using the questionnaires completed by the prospective participants for the first round of ILV deployment.

The training was conducted in the same manner as for the first deployment. The test conductor scheduled the participants in groups of four, two groups for each OEM. The test conductor made arrangements with Ann Arbor and the University of Michigan to close roads necessary for the CAMP training. During the training session, the test conductor gave an overview of SPMD and consented the drivers. CAMP gave an overview of DSRC technology and the safety applications that they would be testing. CAMP then took the participants for a demonstration drive on the “closed course” established and elicited the warnings that were implemented by the OEM for the vehicle type that the participant was assigned to.

During the SPMD one vehicle was “totaled” and subsequently scrapped (Nissan Infiniti). The crash was not related to the V2V system under test. CAMP removed all SPMD equipment from the vehicle and UMTRI stored the vehicle and worked with USDOT to dispose of it. A second vehicle was severely damaged and was not repaired at the direction of CAMP and USDOT. This vehicle was returned to CAMP. All other repairs that were made were relatively minor.

Although both rounds of ILV deployment were planned to be for a six month period, the second round of deployment was only five months because the turnover from round 1 to round 2 took longer than initially planned.

7.1.3 Maintain the Heavy Vehicle and Transit Fleets

The test conductor was responsible to interface between the RSD fleet operators (Con-way and Sysco), as well as the transit fleet operator (University of Michigan Transportation Services). In this capacity, the test conductor scheduled on-site visits as required by Battelle and SWRI, as the USDOT subcontractors for those fleets.

7.1.4 Refresh Report

Originally, the refresh report was intended to document any updates made as corrective actions for issues found in pre-model deployment. The updates were to be made before the start of model deployment. However, there was not enough time between pre-Model and model deployments for the updates to occur. Furthermore, numerous issues were found in the field over the course of model deployment. Because of those two facts, the refresh report evolved into documenting all issues and corrective actions that occurred during model deployment (year 1). When the SPMD extension was approved, it was decided to add a second refresh report that would document all issues and corrective actions that were completed during the extension.

The sections below give an overview of the issues encountered for each device type. The full description of the issues and the corresponding corrective actions can be found in Appendix G.

7.1.4.1 Vehicle Awareness Devices

- Savari Vehicle Awareness Devices
    - GPS parameters are not optimal and may affect safety application performance
    - Unique ID broadcast in wrong location in the temporary ID field of the BSM
    - Transient power suppression does not meet USDOT VAD spec
    - Transmitted without a GPS lock, in violation of the USDOT VAD spec
    - Security certificates expired May 31, 2014
- Cohda Wireless Vehicle Awareness Devices
    - May broadcast incorrect dsec value, causing other devices to lock up
    - Broadcast an incorrect initial position in the BSM
    - Broadcast incorrect vehicle width/length in the BSM, even though the configuration file is correct
    - Units lock up because of an allocation failure
    - Units do not boot up properly
    - Security Certificates expired May 31, 2014
    - Transmitted without a GPS lock, in violation of the USDOT VAD spec
    - Difficult to verify that a software load was completed successfully
    - Hex ID was in a different format than expected by CAMP
    - Z-offset was not implemented
    - Power cable connector had a high failure rate
    - GPS coin cell battery failed
- VAD-Equipped Vehicle Installations and Repairs

    - Initial installations did not have the final antenna mounting design
    - Small amount of vehicles did not have GPS antenna connector properly seated

7.1.4.2 Aftermarket Safety Devices

- Cohda Wireless Aftermarket Safety Devices
    - Requested incorrect batch size of security certificates
    - Requested wrong decryption key for security certificates
    - Truncated log files detected by the DAS
    - May broadcast incorrect dsec value, causing other units to lock up
    - Broadcast incorrect initial position in the BSM
    - Broadcast incorrect vehicle width/length even though the configuration file was correct
    - Units lock up because of an allocation failure
    - Units do not boot up properly
    - Units lock up because of a race condition (see appendix G for definition)
    - Intersection Movement Assist application was enabled, although not approved for the program
    - Would not release the IPv6 connection with the RSE when the vehicle drove out of range
    - Hex ID not in the format expected by CAMP
    - Z-Offset not implemented
    - Fallback certificate expired May 31, 2014
    - Issues introduced as a result of a software update
        - Rolling unique ID
        - CSW disabled
        - Test tone enabled
    - Power cable connector had a high failure rate
    - GPS coin cell battery failed
- Denso Aftermarket Safety Devices
    - ASD hung on power down
    - Flash memory corrupted
    - Improper synchronization after security certificate change
    - Projected that the device could connect to the wrong RSE
    - Connection setup reliability could be improved
    - Security Credential Management System (SCMS) connection logic could be improved
    - ASD crashes under certain conditions:
        - Continuous packet stream
        - WSA reception during system initialization
    - Z-offset was not in the format expected by CAMP
    - Hex ID was not in the format expected by CAMP
    - Fallback security certificate expired May 31, 2014

7.1.4.3 Roadside Equipment Devices

- Savari Roadside Equipment
  - During specific events and BSM announcement handling with interoperability testing the RSE had misreported messaging or failed the message exchange.
  - Support text tag and channel numbers was not supported.
  - Process designated “monitord” that is responsible for collecting and offloading system logs and PCAP files from the RSE to the Mixon-Hill servers crashes.
  - Process “gpsd file” made process “monitord” (offload process) crash
  - “Monitord” process bug was reported to cause buffer overflow in firmware update (version 0.94-1556).
  - Process “gpsd” crashes
  - During specific events the offload process and gpsd would conflict
  - Process “DSRCproxy” crashes
  - Heartbeat status did not report that the unit was not successfully offloading
  - Process “heartbeat” crashes
  - Process “monitord” & “DSRCproxy” crashes
  - Process “TIMmain” crashes
  - Unit would hang during firmware update process
  - Firmware update did not repair all of the state and process issues reported from the prior release.

7.2 Collect, Store, and Transfer Data

A significant amount of data were collected in the SPMD and the processing, handling, parsing and storage of these data was a significant task. To comprehensively explain and understand all the data elements is beyond the scope of this report. However, at a high level, the data collected fell into four broad categories or groups that are illustrated in Figure 7-1and labeled Message, Driving, Contextual and Subjective. Although the figure shows these data collections as single databases, in reality they were stored in many databases and electronic files on multiple servers at UMTRI and on servers maintained by test conductor partners in the SPMD.

Also shown in the figure are arrows indicating the transfer of data to the independent evaluator (Volpe Center) and the Research Data Exchange program administered by the USDOT. With over 2,800 vehicle and infrastructure installations in SPMD, monitoring and tracking problems and defects with the technology was also an important role of the test conductor. This effort is illustrated rather simplistically in the lower left of the figure. In addition to defining the “data sets” collected during SPMD, the transfer of data and health monitoring of the fleet are discussed in more detail below.

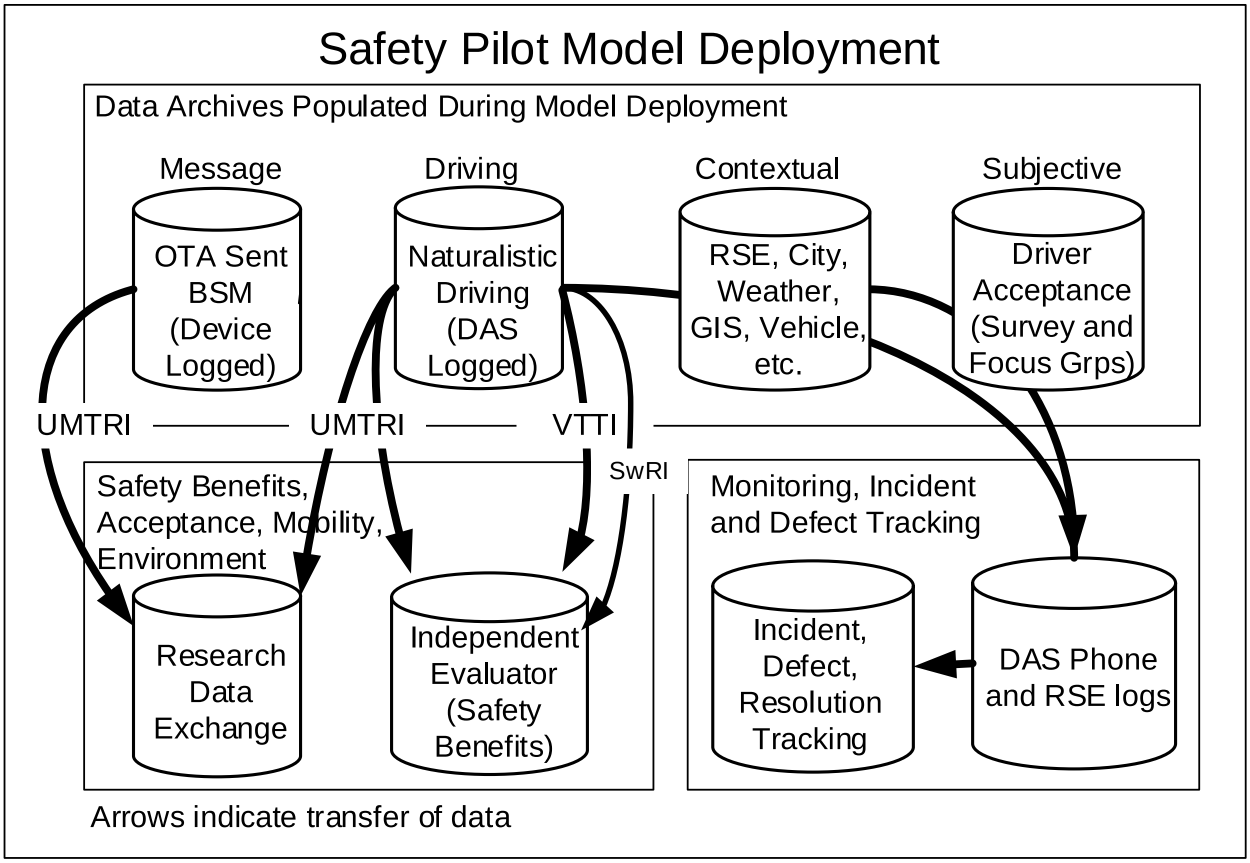


Figure 7-1: Overview of SPMD Data Collection, Storage, and Transfer

7.2.1 OTA Sent BSM Message Archive

In terms of quantity, the OTA sent BSM archive was the largest collection of data in the SPMD with tens of billions of records. The BSM was defined by the Surface Vehicle Standard for DSRC Message Set Dictionary (SAE J2735). This message was broadcast by every vehicle in SPMD at a nominal rate of 10 Hz or 10 messages per second. With nearly 3,000 vehicles in the SPMD being driven in a naturalistic manner for over a year, the volume of this data set was considerable.[21] To understand the content of this archive requires a brief definition of the content of a BSM.

7.2.1.1 Definition of a BSM

The BSM is 1 of 15 messages defined by the Surface Vehicle Standard for DSRC Message Set Dictionary (SAE J2735). The message contains two parts. Part I is required in every BSM and contains the following data elements: Time; GPS location and heading; speed; acceleration; yaw-rate; brake pedal status; vehicle length and width; and accuracy estimates of the GPS location measures.

[21] UMTRI continues to deploy, maintain, download, and archive BSMs from vehicles being driven in the SPMD area. The exposure numbers reported cover the time period from August 2012 to June 2014. The contractual end to data collection was Feb. 2014. However, because decommissioning of vehicles was eliminated in preparation for the transition to the Ann Arbor Vehicle Communication Test Environment, data collection was continued.

Part II of the BSM contains the “vehicle safety extension” and “vehicle status optional” structures. The vehicle safety extension contains a series of event flags (hard braking, anti-lock brake system active, air bag deployment, traction control loss, stability control activated, etc.), vehicle path history and path prediction and radio technical commission for maritime services messages that are used to improve the accuracy of GPS location and heading estimates. In SPMD, every BSM was required to include the event flag element and the path history and prediction data structures of the vehicle safety extension at a rate of at least 1 Hz.

The vehicle status structure contains information about the state of peripheral elements of a vehicle and other facts related to the vehicle. For example, exterior lights, wiper state, throttle position, vehicle height, weight and type are defined in the vehicle status frame of Part II of the BSM. For BSMs broadcast in SPMD, no elements of the vehicle status structure were required. However, some device suppliers and the ISD populated some elements of the vehicle status structure.

7.2.1.2 Exposure Summary for the Sent OTA BSM database

To understand the scope of the sent OTA BSM database, consider the exposure summary given in Table 7-1. Although UMTRI continues to populate the BSM database, the summary given in Table 7-1reflects data collected from the beginning of the SPMD, August 2012 to June 2014. During this 23 month period, almost 4 million trips were driven by the fleet covering over 25 million miles in nearly 900,000 hours. Average trip statistics are also shown in the table. On average, each trip distance was 6.3 miles, had a duration of 13.3 minutes and an average speed of 28.6 mph. Other data summary values are shown in the table. A total of 24 tables are in the database, having a cumulative record count of 70 billion and a database size of 5.6 TB. There was no associated video collected for the sent OTA BSM database.

Table 7-1: Exposure Summary of the OTA Sent BSM Database as of June 2014

Basic Driving Database (Sent OTA BSM)

Exposure			Per Trip Average			Database and Video Archive			
Trips Count	Distance miles	Duration Hours	Distance miles	Duration minutes	Speed mph	Tables Count	Records Count (BN)	Obj. TB	Video TB
3996611	25350335	887686	6.3	13.3	28.6	24	69.2	5.66	0

7.2.1.3 Database Structure for the Sent OTA BSM database

The structure of the OTA BSM database consists of two table formats. An overview of the structure of these tables is shown inTable 7-2. The first format is time-history and the database contains two tables with this format. The tables are called BsmMD and BsmP1 (MD = MetaData; P1 = Part 1 of the BSM definition). The primary index for these tables is:

- RxDevice: [two-byte signed integer] the unique device Id for the receiving device;
- FileId: [four-byte signed integer] a unique file number assigned to all files downloaded from every device in SPMD;
- TxDevice: [two-byte signed integer] the unique device Id for the transmitting device;[22]

[22] In the Sent OTA BSM database the sending and receiving devices are ideally the same number. See Data

GenTime: [eight-byte integer] message generation time as defined by IEEE STD P1609.2 Standard for wireless access in vehicular environments (WAVE); number of microseconds since January 1, 2004.

The fields of the table are shown under the column headings indicating the source of data, i.e., did the data originate from the BSM (multiple parts) or from the security and authentication layer wrapped around the BSM payload.

The second table type is called a transition table. Transition tables store data in a concise format and are ideal for measures that do not change frequently. As the name suggests, measures using this structure are stored when they transition to a new value. A good example of transitionally logged measure in driving data is the PRNDL.[23] The state of PRNDL does not change frequently and is not a function of the length of a trip that makes it ideal for logging only on change. Other measures that are logged transitionally include: turn-signal, head lamps, cruise control settings, and in some cases wiper. Since the time and state of a transitionally logged measure are stored, the content of the measure is identical to recording it as a time-history but can involve far less computer memory since the same value of the measure is not being logged continuously. However, transitionally logging measures do have limitations, which include the following:

- To combine multiple measures into a single table, some form of unique identification is needed to identify each measure in the table. This unique id then requires a look-up table that maps the value to each measure.
- The primary key to the table can be much larger than the data being stored. In the PRNDL example, the state of the measure can be adequately covered by a single byte (which allows 256 values). Driving data is typically indexed by driver, trip, and time, which might be sized as one, two, and four bytes, respectively. Also, given multiple measures in the transition table requires that the identification field also be part of the key, adding an additional byte. So for each transition of PRNDL, eight bytes (not including the storage requirements of the index itself) are required to uniquely key the table for every byte value of PRNDL. An eight-to-one ratio for each transition of PRNDL will explode the size of a database if PRNDL changes frequently. For this reason, it does not make sense to transitionally log continuous measures (like speed and acceleration) that change frequently.
- Finally, most transition tables are created for a single value type. That is, measures that are a byte will be logged together in the field of a table sized as a byte. Hence, an additional table is needed for every distinct value type collected. The alternative to this approach is to define single field value type that is “big enough” to accommodate all measures, thus wasting memory when a byte measure is stored in double or float field. This approach also has adverse implications when memory usage is considered.

Anomalies section for exceptions to this convention.

[23] Standard automatic transmission drive indicators: Park(P), Reverse(R), Neutral(N), Drive(D), Low(L)

The middle set of definitions in Table 7-2 ("Transition:") shows the signals stored transitionally in the sent OTA BSM database. Each of these measures is stored in its own table with a similar name. The key to these tables is similar to a time-history table with the exception that a start and end generation time is specified for each value of a given signal.

Finally, the bottom of Table 7-2 shows data culled from each BSM for path-history. These data were not added to the sent OTA BSM database because of space concerns, but exist in files that will be loaded when needed. The path-history data also requires an additional index variable to accommodate the fact that there are multiple path points for each BSM (a one-to-many relationship with any given time-history record).

Table 7-2: Field and Indexes for the OTA Sent BSM Database

Basic Safety Message Parsing/Database Table Definition

		Part I	***Part II***	***Part III***	***MetaData***
Table Format	***Table Key***	***Blob***	***Vehicle Safety Ext***	***Vehicle Status***	***(1609.2 Layer)***
Time History:	RxDevice	MsgCount	PathCount		Certificate (8-byte)
(one record for	FileId	TxRandomId	RadiusOfCurve		GenTime
each BSM)	TxDevice	TxDevice	Confidence		FrameOffset
	GenTime	DSecond			FrameSize
	(16 bytes)	Lat, Long, Elev.			BsmIRelOffset
		Speed			BsmIIRelOffset
		Heading			BsmIIIRelOffset
2 Tables: BsmMD		Ax, Ay, Az			GenTimeRelOffset
and BsmP1		YawRate			PsIdByte
		Part I	***Part II***	***Part III***	***MetaData***
Table Format	***Table Key***	***Blob***	***Vehicle Safety Ext***	***Vehicle Status***	***1609 Layer/File***
Transition:	RxDevice	PosAccurByte1	EventFlag	VehicleHeight	
(one record for	FileId	PosAccurByte2		FrontBumperHgt	
each change in	TxDevice	PosAccurByte3		RearBumperHgt	
value)	StartTime	PosAccurByte4		VehicleMass	
	EndTime	TransState		VehicleType	
	(24 bytes)	SteerAngle		ExteriorLights	
		BrakeByte1		ThrottlePosition	
20 Tables:		BrakeByte2		WiperStatusFront	
one for each measure		Width, Length		WiperRate	
		Part I	***Part II***	***Part III***	***MetaData***
File Only	***Key Design***	***Blob***	***Vehicle Safety Ext***	***Vehicle Status***	***1609 Layer/File***
Time History:	RxDevice		PathPointNumber		
(multiple records	FileId		PathLatOffset		
for each BSM;	TxDevice		PathLongOffset		
one-to-many)	GenTime		PathElevOffset		
	PathPtNo		PathTime		
RxDevice = UMTRI Assigned Device Id					
FileId = Unique Integer, similar to trip					
StartTime=Min(GenTime)					
EndTime=Max(GenTime)					

7.2.2 Naturalistic Driving Data Archive

The second substantial collection of driving data in SPMD comes from vehicles instrumented with the UMTRI DAS. Nominally, during SPMD, a total of 115 vehicles across four platforms were instrumented with an UMTRI DAS. A matrix showing vehicle platform, manufacturer, number of different models, and device suppliers is shown inTable 7-3.[24]

A major challenge in SPMD was the design and implementation of DAS software customized for twelve different model vehicles and the two device suppliers. From a data collection perspective, the differences in vehicle models manifest themselves in connecting and parsing messages from the vehicle CAN interfaces. Other differences, albeit more minor, came from the installation orientation of the inertial-measuring unit (IMU) installed with every DAS in SPMD and the different data being delivered to the DAS from the two device suppliers. Communication between the DAS and device was done using an Ethernet connection with message packets defined by each supplier. The UMTRI approach was to make the DAS software capability independent of the device type and vehicle model. This was done by implementing every combination of vehicle model and device supplier. This made it possible to have a single DAS program and operating structure across all vehicles. At installation, an UMTRI technician simply selected the vehicle platform and device type from a drop down-list. The effectively changed pointers within the DAS program turning on and off signals customizing the data collection for the specific vehicle. As much as possible, changes to the definition of a signal or code in the DAS software applied to all vehicle configurations making it relatively straightforward to update vehicles when they were at UMTRI for data downloads. All versions of the signal definition metadata and DAS collection programs were managed using versions numbers that are part of the data archive.

Table 7-3: Matrix of DAS-Equipped Vehicle and Device Suppliers for SPMD

Vehicle Platform	Vehicle Manufacturer	Model Count	Device Count	
			Cohda	DENSO
Light Vehicle	Honda	3	15	30
	GM	3	15	15
	Ford	2	20	5
Heavy Truck	Freightliner	1	0	8
Bus	Gillig	1	0	3
Motorcycle	BMW	1	2	0
	Honda	1	2	0
Total		12	54	61

7.2.2.1 Exposure Summary for the Naturalistic Driving Database

To understand the scope of the naturalistic driving data database, consider the exposure summary given inTable 7-4. Although UMTRI continues to populate the driving database, the summary given in the table reflects data collected from the beginning of the SPMD, August 2012 to June 2014. During this 23-month

[24] Table 7-3 represents UMTRI DASs. The DASs in the integrated light vehicles are not included in the table.

period, 221,000 trips were driven by the fleet covering over 1.7 million miles in nearly 64,400 hours. Average trip statistics are also shown in the table. On average each trip distance was 8.0 miles, had a duration of 17.4 minutes and an average speed of 27.6 mph. Other data summary values are shown in the table. A total of 25 tables are in the database, having a cumulative record count of 15 billion and a database size of 656 GB. For SPMD, each UMTRI DAS collected video from four cameras. These video files constitute an archive 13 TB in size.

Table 7-4: Exposure Summary of the Natural Driving Database as of June 2014

Enhanced Driving Database (UMTRI DAS)

Exposure			Per Trip Average			Database and Video Archive			
Trips Count	Distance miles	Duration Hours	Distance miles	Duration minutes	Speed mph	Tables Count	Records Count (BN)	Obj. TB	Video TB
221901	1777361	64422	8.0	17.4	27.6	25	15.3	0.656	12.8

7.2.2.2. Database Structure for the Naturalistic Driving Data Archive

In general, data collected by the DAS fell into three categories, namely: numerical, video, and audio. This section describes how data from each of these categories was structured and explains the terminology and naming convention used to identify these structures in the overall data archive. In general, the examples given below are based on an archive derived from vehicle driving data, that is, it shows measures typically used to describe vehicle dynamics, driver control, and measures from sensors typically found in safety applications for the traffic environment. However, the UMTRI DAS is used in a variety of applications and the discussion and the conventions outlined below apply to other data collection activities as well.

Numerical: In its simplest form, all data are simply a collection of bits and bytes, but for this discussion the definition of numerical data are numbers that have been processed into a human readable format. These numbers typically fall into two general types of floating point and integers. Going a step further, the floating point numbers are designated as either single (four byte) real, or double (eight byte) real; while integers are a single byte, a small integer (two bytes), and long integer (four bytes) and a big integer (eight bytes). Although additional criteria, like byte order (endian-ness) and signage, are needed to fully process all input data types by the DAS, the number types used about in this document are typical of a database application and therefore, somewhat limited in scope. Each of the sections below describes the structure of different collections of numerical data as they are created and stored by the DAS.

Fact Tables: Fact tables and structures have numerical (and sometimes alphanumeric) representations that distinctly characterize a person, place, or thing in an experiment. These numbers are static and do not change for the duration of the data collection process or the life of the data archive. Typically, fact tables are derived from key elements of the experiment, such as: subjects, vehicles, sensors, devices, and instrumentation. In many cases, a fact table has a primary key that is identical to the first keyed field in more descriptive tables. For example, in a naturalistic driving experiment, each subject will be assigned a unique integer identification number. The first field of the subject fact table will be this identification number, along with numbers, enumerations, and descriptions that are unique and descriptive of the subject such as; age, gender, estimated annual mileage, years driving, etc. Hence, each subject would have one row of data in the subject fact table. Other tables in the archive might also have subject number in their index in order to uniquely identify each data record and keep the database fully normalized.

In addition to these descriptions, reference numbers to other fact tables would be included in the subject table to allow the joining of different fact tables relevant to each subject.

In general, the UMTRI DAS does not create fact tables. They are usually generated manually during an experiment and are based on data entered by subject coordinators, engineers and technicians in the build and up-fit of vehicles and the interview process with subjects.

Summary and Event Tables: Summary and event tables are functionally the same. Both these data structures are defined by a start and end time as part of primary key into the table. In the case of the summary table, the start time is defined as when the test was started or the DAS began to collect data and the end time is the time when data collection ended. Typically, when the DAS collects data in a turn-key fashion, the start and end time coincides with a vehicle ignition on/off event. Event tables are similar to summary tables with the exception that they begin and end anytime during the data collection period. While the summary table is used to summarize a trip, an event table is used to summarize events that occur during a trip.

Both summary and event tables contain aggregated and summary numbers that characterize the time between the start and end time specified for each event. Examples include distance traveled, which is the integration of the speed signal over the time resolution of that signal, and the count of brake applications by a driver. Summary and event tables can also contain fields that are not aggregated. When this happens, the last value for the field is recorded in the table. Examples of non-aggregated fields are latitude, longitude, speed, heartbeat and state, etc.

Event tables are always associated with a trigger. This measure is typically a byte and an event is triggered when the state of the trigger changes from zero to one. In some cases, a trigger is latched for a pre-set amount of time. In these cases, the trigger becomes the latched measure and the fields of the event table are calculated when the latched field is high.

The time fields in summary and event tables are generally at the same resolution as the DAS internal clock. That is, if the DAS main calculation loop is at 100 Hz and time is represented in centi-seconds, the resolution of time in the event table will be in centi-seconds. In some database operations where a join is made between the event table and a deci-second resolution time-history table, the time fields of the summary table will have to be cast into a deci-second-resolution time. In SQL, the command to make the cast is: Cast((Time/10.)+0.5 as Int)*10. Generally, however this is not necessary since most queries are looking for what happened during the event in which the records of a 10 Hz time-history are culled between the start and end time of the event.

Summary tables are usually named summary, diagnostic, or in some cases summary2. For SPMD, event tables will be prefaced with the word “Evt,” for example, EvtInform and EvtWarning.

Transitional Tables: See Section 7.2.1.3 for the definition of a transition table format.

Time-history or Series Tables: See Section 7.2.1.3 for the definition of a transition table format.

Video: Four video cameras were installed on all UMTRI DAS-equipped vehicles in SPMD. The camera mounting locations varied based on platform and vehicle model but generally included a forward, cabin, left and right scene as shown inFigure 7-2. The cameras are grey-level (“black-and-white”) to provide better night-time imagery and to produce a more manageable volume of data. The camera frame rates are 10 Hz for the cabin and forward video streams and 2 Hz for the right and left views. Images from each camera are collected continuously. The images are compressed spatially and temporally using an mpeg-4 compression technique and are time-stamped for synching with the other DAS data.

Figure 7-2: Sample Camera Views from DAS Equipped Vehicles in SPMD

Audio: Audio was also captured by the DAS during SPMD. The audio is triggered based on warnings given to the driver. The audio events were 12 seconds long and buffered such that the audio content starts four seconds prior to the warning and last eight seconds after the start of the warning. The purpose of the audio is to confirm that the warning was given to the driver and to record any initial verbal response to the warning by the driver.

7.2.2.2 Standardization of Common Data Elements

Another important aspect of the UMTRI data collection architecture is the standardization of common data elements across different vehicles and device suppliers. For example, many vehicle suppliers use an enumeration to represent the different states of a vehicle transmission commonly referred to as the

PRNDL. However, the enumeration may not be the same across different manufacturers, or even across models by the same manufacturer. To manage this from a data archive perspective, UMTRI maps the enumeration from each vehicle model into a common enumeration.[25] This common enumeration is then stored in the database, making it possible to query across different models and platform types without having to change the conditional statement of the query. Another good example is turn-signal. Regardless of the original definition created by the manufacture, a value of 1 for turn-signal indicates a left turn, 2 a right turn, and 3 both left and right or hazard. Other common data elements include:

- Wiper,
- Head lamp,
- Antilock brake,
- Electronic stability control, and
- Warning type (EEBL, FCW, BSW, IMA, CSW, etc.).

7.2.3 Message and Safety Application Data from Devices

Data from the device suppliers was communicated to the DAS via an Ethernet connection using user datagram protocol (UDP) structure. The content of these data vary as a function of the device supplier. However, for SPMD the device data falls into four general categories:

- Host-vehicle—these signals include GPS location, heading, speed, and quality along with vehicle CAN information (only the devices in CCV-IT program had a CAN interface) like speed, yaw-rate, throttle, steer, brake, wiper, and turn-signal state.
- Remote-vehicle—these signals include all the content of the BSM, namely: GPS location, heading, speed, quality, path-prediction and path-history.
- Target classification—these signals include information that about the relative position and kinematics of a remote-vehicle.
- Threat assessment—these signals indicate if a warning is given to the driver usually indicating the type of warning, its priority and level.

7.2.4 RSE, Contextual and Fact Archive

A third, mixed set of data collected during SPMD included archives from RSEs, the city of Ann Arbor, facts and characteristics of all vehicles in the study, and other data sources such as weather and GIS related to the SPMD area. A description of these data collections are given below. Since these data elements exist in a variety of formats, the focus of this discussion is on the content of these archives, as opposed to a description of the data structure.

SPMD Vehicle and Device Tracking

To track, monitor, and inventory devices and vehicles during the SPMD, a custom and flexible property management system was developed by the test conductor team using relational database concepts to relate activities done to vehicles and equipment to the data collected by the UMTRI DAS and in the OTA

[25] As a rule, UMTRI also saves the original enumeration in a platform-specific table for each vehicle model.

BSM database. A form-driven interface to the property management system was developed to provide users access to the underlying data structures to ensure that for a given work procedure all necessary information was logged in a consistent and thorough manner. The form development also included data integrity algorithms to reduce the possibility of erroneous entries into the dataset. The core of the system is the sessions table, which contains a unique identifier, date/time stamp, and session type for each entry. The most common session types include activities like: data download, new VAD Install, VAD removal, device repair, installation repair, etc. Each of these activities required any new information to be entered into the system, while in the case of a repair, the user created a link between the activity and existing data records. For example, if an antenna was replaced on a vehicle, the user did not enter any facts related to the vehicle and module (WSU) installed in the vehicle but related this session with an existing vehicle and module. This approach leveraged the relational nature of databases to ensure that facts related to equipment and vehicles are only defined in one place. For example, a vehicle never changes model, color, VIN, etc. so this information was defined once and then simply referenced through pointers within the property management data structure. The same was true of all other equipment, be it modules, antennas, DASs, cameras, etc. Information that may have changed as a function of time, like odometer, software version, installed equipment supplier changes (e.g. choda device replaced with a denso device) module supplier, or different antenna, were logged for each session, if applicable, creating a traceable complete history of how parts and equipment were used in the study.

Road Side Equipment Messages and Device Health Monitoring

During SPMD, there were 29 RSE installations. Of the 29, 6 were located at the entrance and exit of three road curves (2 per curve) identified in the SPMD area. The CSW safety application used TIM broadcast from these units to issue speed advisories to a sub-set of the drivers in the SPMD. The remaining 23 RSEs were installed at signalized intersections along two major corridors in Northeast Ann Arbor. The majority of these devices did not broadcast messages but did receive and record BSM messages broadcast by all equipped vehicles in the SPMD. Three RSEs were equipped to broadcast SPaT and map (geographical intersection geometry description) messages.

Messages received and broadcast by all RSE devices were captured and stored on servers housed and maintained by the test conductor team. During the SPMD study, all received BSM messages by the RSEs were given to the test conductor on a continuous basis nominally within hours of being received by each RSE. To monitor the health of vehicles in the study, the test conductor parsed and loaded these messages into a database. (The structure of the RSE BSM database is similar to the Sent OTA BSM database described in this report.) Then by joining the property management database to the RSE BSM database, the test conductor could determine when each deployed vehicle was last “seen” by an RSE and if the sent GPS messages from the vehicle were consistent with the location of the RSE. Vehicles not “seen” recently were added to a list for investigation and possible recall for repair or removal.

Traffic Volume Data From Ann Arbor

For instrumented corridors within the SPMD, Ann Arbor provided estimated traffic counts at intersections on a per lane basis and as a function of time. For the intersections equipped with vehicle detectors (mainly, inductive loops) that use SCOOT for signal timing, the city traffic engineers provided 765 files containing over 2.2 million intersection and lane specific traffic counts at 15-minute intervals for years 2008 to 2013.

Intersection and Map Mapping Data From GIS

To enhance the Driving and Sent BSM databases, the test conductor team used GIS data from the HPMS to enhance the dataset. By overlaying a vehicle's geographical path (latitude and longitude) onto the GIS information for to the road network in Michigan, additional attributes related to every trip taken in SPMD were added to the database. These attributes included road-type, road-name, signalized and grade criteria for intersections, number of roadway lanes, and annual average daily traffic.

7.2.5 Subjective Archive

The subjective archive includes the following elements, which are detailed below: driver identification, driver questionnaires, ILV focus groups, and TRP focus groups.

Driver Identification

Drivers in the SPMD were primarily identified via a driver ID number assigned to them when they enrolled. This was true for VAD, ASD, RSD, and ILV drivers. TRP drivers were not given a unique driver ID until after some preliminary analysis to determine which drivers actually drove the buses. Each driver ID was linked to the participant through either e-mail address (preferred) or if no e-mail was available, through a phone number. For VAD and ASD participants, the driver ID was also linked to a specific vehicle through its VIN. For the RSD drivers, their driver IDs were linked to specific tractors. These driver IDs were then used to match participants' data with their subjective questionnaire responses.

Driver Questionnaires

Subjective questionnaires were administered to participants in the ASD, TRP, RSD, CCV-IT, and ILV portions of the SPMD. ASD Drivers were all surveyed from March to May 2014, while participants in other portions were given the questionnaires immediately at the end of their participation. TRP drivers participating in both phases of the TRP deployment (if they participated) would have received two similar but different subjective questionnaires, one at the end of each phase.

The subjective questionnaires primarily asked participants for their opinions of the wireless warning systems. Questions covered participant acceptance of the warning systems, the functionality of the warning systems, the accuracy of the alerts, and generally their opinions on wireless communication between vehicles. Responses were tabulated and aggregated and sent to the independent evaluator for analysis.

Integrated Light-Vehicle Focus Groups

Focus groups were conducted with a subset of the drivers from the ILV portion of the SPMD. Eight focus groups were conducted, one for each OEM that provided ILVs. Participants could have been from the first or second round of ILV deployment and each group had at least one member from each round. The focus groups were held in the evening at UMTRI, lasted two hours, and all participants were paid $80 for their participation. The focus groups were recorded for later viewing and analysis and the videos were shared with the independent evaluator.

Transit Retrofit Platform Focus Groups

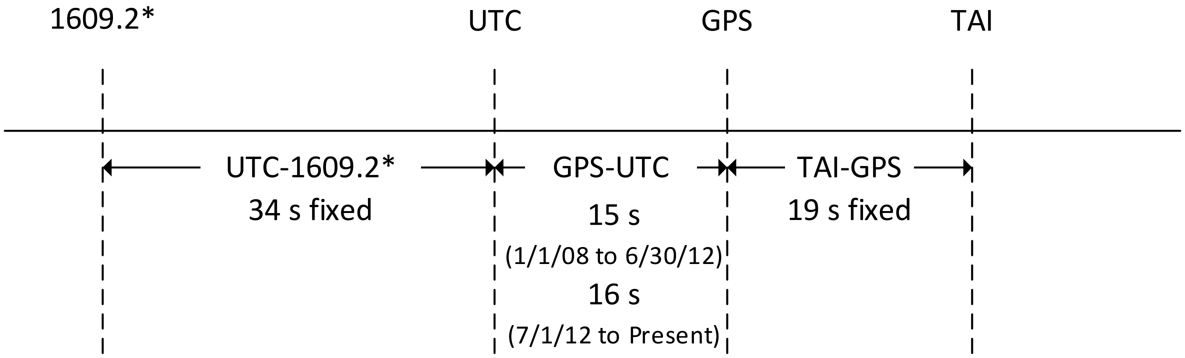
Two TRP focus groups were held, one after each round of data collection. The first included five drivers and the second only three drivers, however two drivers attended both groups and provided good "before and after" feedback on the changes to the TRP system between data collection rounds. These focus groups were held at UMTRI, lasted approximately two hours and drivers were paid $80 for attending. A live video feed was provided for on-site viewing and recordings were made for later analysis.

7.2.6 Data Anomalies Discovered during SPMD

A variety of time measures are present in the data collected during the SPMD and, in general, all time is referenced to coordinated UTC per the requirements developed specifically for SPMD and existing standards for message generation time as defined by IEEE STD P1609.2 Standard for Wireless Access in Vehicular Environments (WAVE).

One time reference anomaly is known in the derivation of the generation time that is part of the 1609.2 layer. Generation time is defined as the number of microseconds since Jan 1, 2004. In SPMD, devices receive very accurate GPS time messages that include the current leap second (a non-constant time offset between UTC and GPS time that accounts for the fact that the earth's rotation rate changes with time) and a pulse-per-second signal used to set the internal device clock to UTC with sub-millisecond accuracy. Furthermore, since all devices in SPMD are running a Linux operating system, they use a Linux epoch (reference date) of January 1, 1970.

However, generation time that is part of the 1609.2 security layer uses a reference epoch of January 1, 2004. The constant between Linux and 1609.2 epoch times is 1,072,915,200 seconds. Unfortunately, the 1609.2 standard (v2-d9_3) Section 6.2.11 defines the number of seconds from the Linux epoch to the 1609.2 epoch as 1,072,915,234 seconds. This constant includes 34 additional seconds (probably derived by including number of leap seconds between TAI and UTC at the time the standard was written). In short, this means that all generation time values have a 34 s offset from UTC. This offset is shown pictorially in Figure 7-3.



Time Reference		Epoch
International Atomic Time	TAI	Jan 1, 1958
GPS Time	GPS	Jan 6, 1980
Linux Time/UTC	UTC	Jan 1, 1970
1609.2 Generation Time	1609.2*	Jan 1, 2004

Conversion Offset	Value, s
Jan 1, 1970 to Jan 6, 1980	315964800
Jan 6, 1980 to Jan 1, 2004	756950400
Jan 1, 1970 to Jan 1, 2004	1072915200

Figure 7-3: Time Reference and Conversion Offset Values Common in SPMD

7.2.7 Data Transfer to the Independent Evaluator and Research Data Exchange

Monthly deliveries of data to the independent evaluator and FHWA's research data exchange were done by the test conductor during Safety Pilot model deployment. These transfers were done using remote 2-TB harddrives, shipped between UMTRI and designated officials at FHWA and the Volpe Center. Data shipments were incremental and only included newly added data since the previous shipment. All PII data was encoded in an UMTRI-specified format to ensure confidentiality of the study participants. In general, each shipment consisted of the following:

- Sent OTA BSM Database—The collection of sent over-the-air BSM messages downloaded from all SPMD during the previous month. Each transfer contained time, GPS location and heading, speed and acceleration, yaw-rate, brake status and vehicle length and width. Aggregated, this entire data set contains 24 tables and over 74.7 billion records.
- Enhanced Driving Database—The collection of data downloaded from vehicles instrumented with the UMTRI DAS during the previous month. Each transfer contained time; GPS location, heading, quality; speed and acceleration; yaw-rate; brake and cruise control status; forward object detection; lane tracking; inform and imminent warnings; remote vehicle BSM data and classification; forward, cabin, rear-left, rear-right video and triggered audio. Aggregated, this entire data set contains 25 tables and over 15.9 billion records.

- Device and Vehicle List— This list allowed researchers to make the association between vehicle identification flags in the data set with details about each vehicle, such as color, make, model, etc. and what equipment was installed in the vehicle, such as a VAD supplied by Cohda Wireless.
- Property Management Activity Web Pages—a Web browser interface to the activities done by the test conductor to all participating vehicles in the study. With this tool, researches can select any vehicle in the study to view all activities related to a vehicle, such as the date and time of initial device installation, details about how the device was configured, pictures of the installation process, historic and current device supplier and software versions, etc.
- Problem Trips Database—Issues related to the quality of the data or circumstances that are important to the analysis of data were captured in the Problem Trips Database. The list of reasons for identifying potently invalid or problematic data is given inTable 7-5. From the list of problem trips, a valid trips table is generated. This allows a direct join with other data tables to exclude trips flagged as problematic.

Table 7-5: Problem Trip Identifiers

UMTRI Driver
None Subject Driver
Video Data Lost Due to DAS Full
CCV-IT: Netway and Ipad Removed for Battery Problem
CCV-IT: System Not Working Due to Software Update for Security
No UDP Packets From WSU and Distance > 100
No Pcap Packets From WSU and Distance > 100
Spurious Warnings Due to Broken Antenna
Testing of System After Software/Hardware Update
UMTRI CCV-IT Driver
Wrong Vehicle Type: No CAN Data
No Gps Data on TRP
Vehicle CAN Bus Errors
Cabin Camera Misaligned or Obstructed
Trips Excluded for RSD/Battelle Operational Analysis

7.3 Introduction of Other Applications

7.3.1 Motorcycles

The motorcycle portion of the SPMD included six motorcycles provided by their manufacturers that were driven by test participants in the field for approximately four weeks each. Four Honda NC700Xs and two BMW F800Rs were used in the data collection, each being equipped with an ASD similar to those installed on the ASD-equipped light vehicles (cars and trucks). Four of the motorcycles, two of each make, also had an UMTRI DAS installed on-board to augment the data collected by the ASD. Two of the Honda motorcycles had only an ASD installed.

The deployment of the motorcycles was done in two phases, one in 2013 (from May to November) and then a second phase in 2014 (from May through August).

Participants were recruited both from the larger SPMD participant pool, but also through word-of-mouth through the informal Ann Arbor motorcycle rider community. Each motorcycle was provided to the participants for a four-week exposure. When they arrived to pick up the motorcycle, they were given instruction on the operation of the motorcycle by trained UMTRI motorcycle riders with experience on these specific motorcycles. At the end of the exposure, they simply returned the motorcycles to UMTRI. Each participant was paid $200 for his/her participation.

The ASDs on the motorcycles were functioning while they were in the field, however, the warnings generated were not presented to the drivers, only recorded in the background for later analysis. The warning systems on the motorcycles were FCW, IMA, EEBL, and CSW.

The UMTRI DAS was the same as used on other platforms of the SPMD, and enabled the collection and assimilation of video and CAN bus with the signals sent and received by the ASDs. This allowed for more in-depth analysis of the warnings and the performance of the motorcycles. Four cameras were integrated into the body of the DAS-equipped motorcycles, two facing backwards to each side, one capturing the forward scene, and another on the driver's face.

Table 7-6 below presents the amount of data collected in both phases, the completed 2013 deployment phase and the on-going 2014 phase. Upon the writing of this, five of the six motorcycles are deployed in the field collecting data that will be added to the 2014 data set.

Table 7-6: Motorcycle Data Collection Periods

Data Collection Period	Participants	Trips	Miles
2013 (complete)	14	885	4730
2014 (incomplete)	6	195	1225

7.3.2 Bicycle

In 2009, there were 2,334 cyclists who died while riding bicycles in Europe. Many of these fatal accidents occurred at road intersections where only one vehicle and one bicycle were present.[26] To investigate this type of scenario and other interactions between a bicycle and vehicular traffic, a bicycle was introduced into the Ann Arbor model deployment area as part of the SPMD.

7.3.2.1 Bicycle Integration

A bicycle was integrated with a Cohda Wireless ASD by Marco Dozza at Chalmers University of Technology located in Gothenburg, Sweden. This effort was a derivation of the BikeCOM studies conducted by Dozza at Chalmers. BikeCOM was a study to implement a cooperative application to warn driver and cyclist of imminent threat. Figure 7-4 shows the ASD and DAS equipped bicycle.

[26] http://publications.lib.chalmers.se/publication/174772-bikecom-a-cooperative-safety-application-supporting-cyclists-and-drivers-at-intersections

Figure 7-4: Bicycle with ASD

Bicycle with ASD Legend:

A: Data logger, camera
B: ASD box w/battery
C: Event flag button
D: Seat w/sensor to turn on electronics
E: Brake force sensors
F: Handlebar IMU

7.3.2.2 Bicycle System Design

The bicycle system consisted of the following elements.

- Forward looking video provided by a Go-Pro camera
- Cohda Wireless ASD that recorded to removable media
  - Received BSMs
  - BSMs that would have been transmitted but were suppressed (see below)
- Bike DAS that measured and recorded
  - Brake force
  - Acceleration, angular rate, magnetic field
  - GPS time, position

Because of concerns expressed by CAMP about interference that may be caused by the introduction of an ASD equipped bicycle without previous testing with ILVs, the following restrictions were placed on the application.

- ASD did not transmit
- Locally recorded data that would have been transmitted
- Recorded received DSRC transmissions
- Safety warning applications were not implemented

7.3.2.3 Bicycle Results
Analysis of the data collected was not completed at the time of this report.

7.3.2.4 Bicycle Recommendations
Because the Go-Pro camera does not have GPS time encoded with the recorded video, this made it difficult to synchronize the video recorded with the BSMs recorded by the ASD for analysis. A future implementation of a vehicle communication technology should include this capability.

7.3.3 Ice Warning System
One of the most common winter weather hazards to vehicular traffic is the formation of ice / black ice on the road surface. To counter this hazard, the RIWS ice warning application was developed to evaluate the utility of transmitting a traveler information message using I2V communication. In general the RIWS was to:

1. Perform environmental measurements,
2. Analyze measurements, and
3. If conditions favor ice formation, broadcast a TIM from the local RSU.

The project goal was to develop a low-cost road ice warning/detecting system, in which the road conditions (ice/wet/dry) can be detected without using high-priced active devices but with combined information measured from a series of low-cost sensors. In particular, a wireless data collecting system was the building block of the RIWS to enable communication from remote sensors to a TIM message control server.

7.3.3.1 Ice Warning Site Location
The location for the application test was Murfin Road northbound into the intersection of Plymouth Road and Murfin Road (seeFigure 7-5). This site was selected to use the existing RSU located at the intersection and access to existing service poles and controller cabinets to house equipment required for the application.

Figure 7-5: Location of RIWS

7.3.3.2 Ice Warning Sensor Suite

The sensor suite for the RIWS consisted of a water detection sensor, pavement temperature sensors, and a humidity sensor. The pavement sensors were installed in pairs, one being approximately 0.5 inches below the pavement surface, and the other approximately 1.5 inches below the pavement surface.

7.3.3.3 Ice Warning Operation

The signals from all of the sensors were collected by the wireless sensor node that was programed to collect data during 30-second periods, once every 30 minutes. The sensor data was then transmitted from the wireless sensor node to the wireless TIM server. Looking at the relationship between air temperature, relative humidity, pavement temperature, and the presence of water, the determination was made if the conditions were right for the formation of ice on the roadway surface. Once the determination was made that ice may be present by the TIM server, a message was sent to the RSU, and the ice warning TIM message was broadcast. When the ice warning TIM message was received by the properly configured ASD, and the vehicle was travelling north bound (see Figure 7-6) an icon was displayed to the vehicle driver on an LCD display embedded in a rear view mirror along with a warning tone.

Once the environmental conditions no longer indicated that ice formation was expected, the TIM ice warning message was cancelled and no longer transmitted by the local RSU.

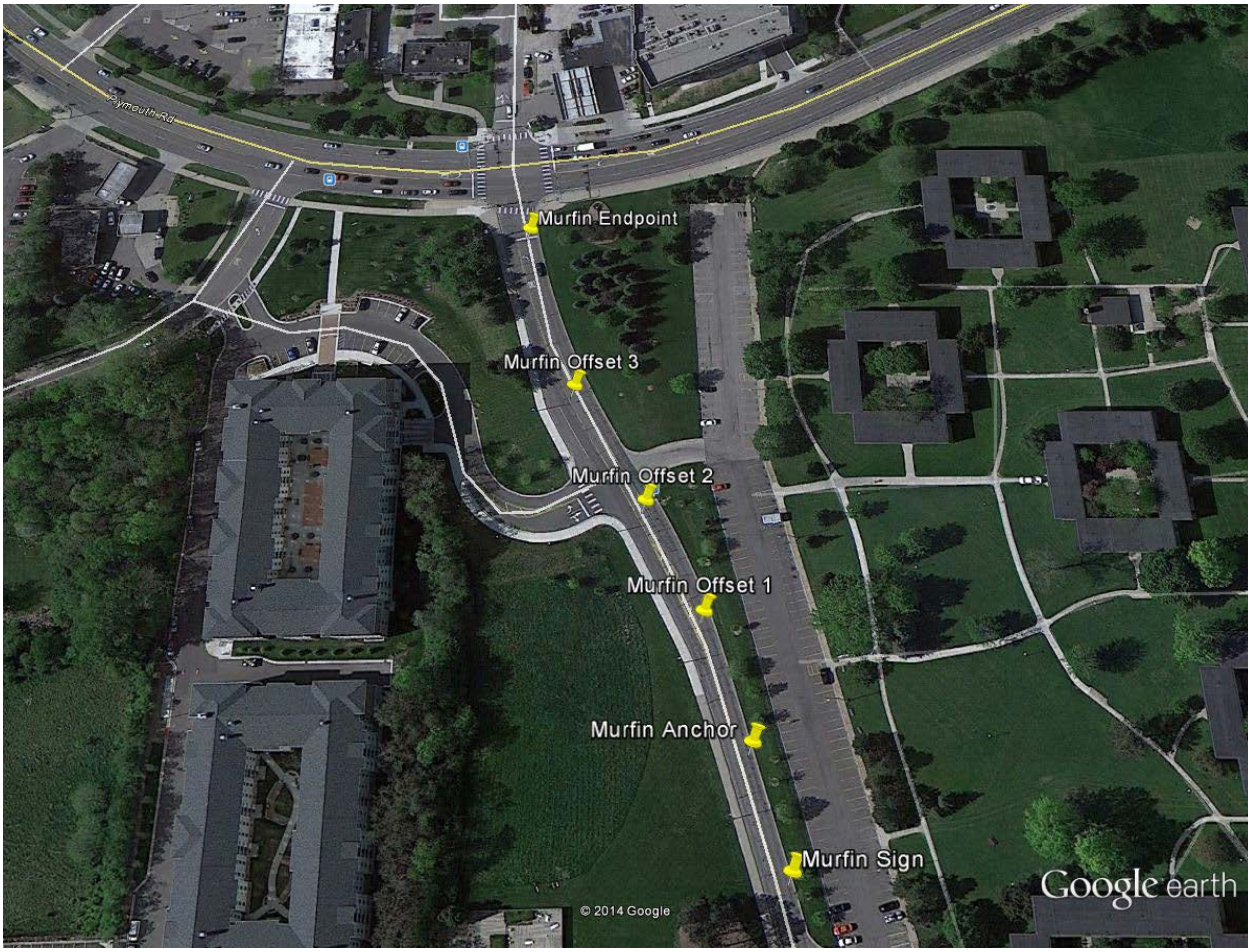


Figure 7-6: Ice Warning Geo-fence Region North Bound Only

7.3.3.4 Ice Warning Monitoring Results

Figure 7-7 and Figure 7-8 show data collected during January 3 to January 8, 2014. The areas of the chart that are circled in Figure 7-9 show the conditions that indicate a possible icing condition is present on the pavement.

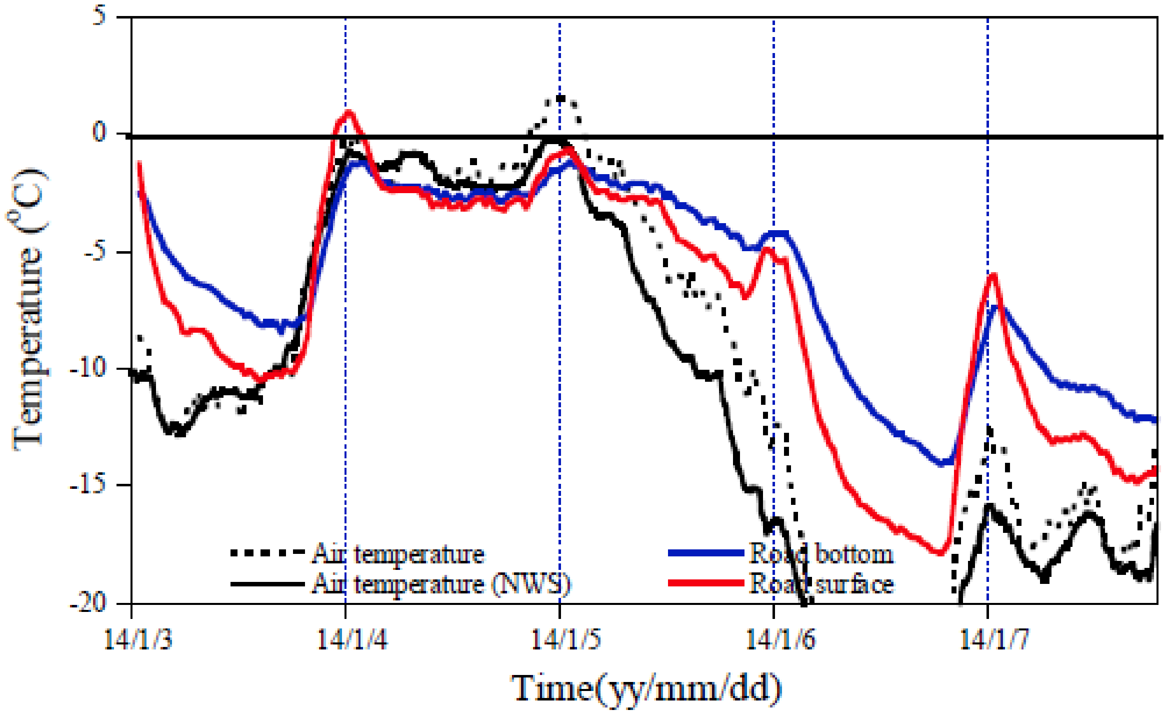


Figure 7-7: Temperature

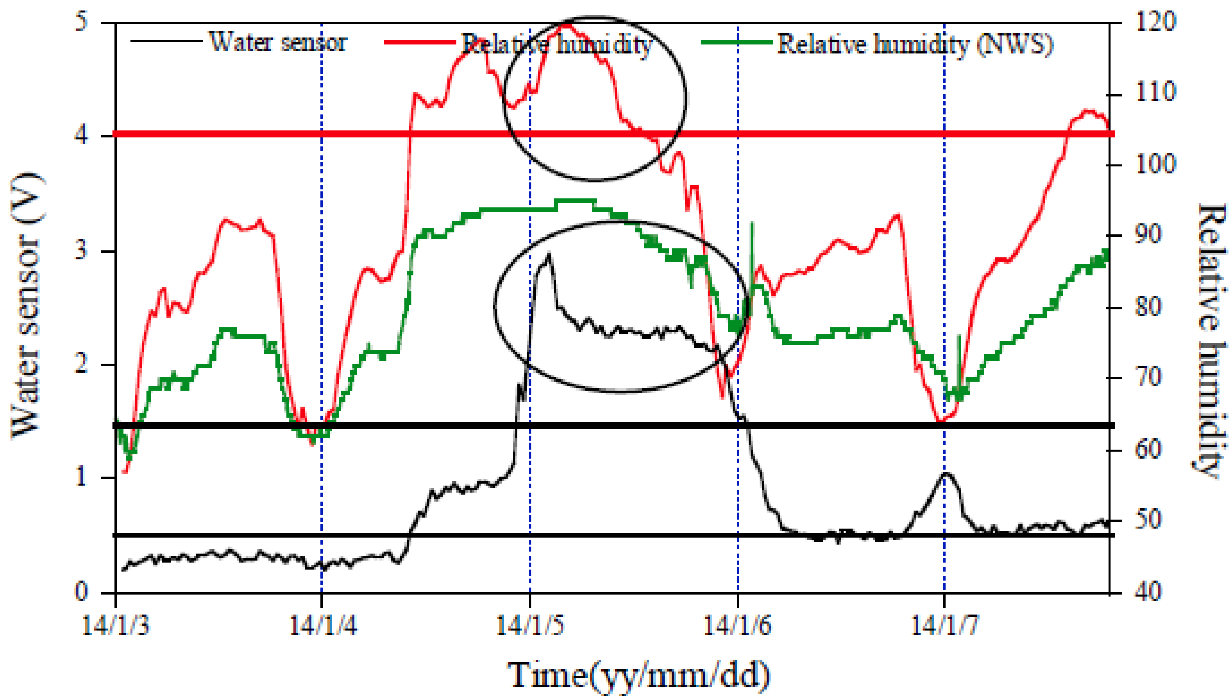


Figure 7-8: Relative Humidity / Water

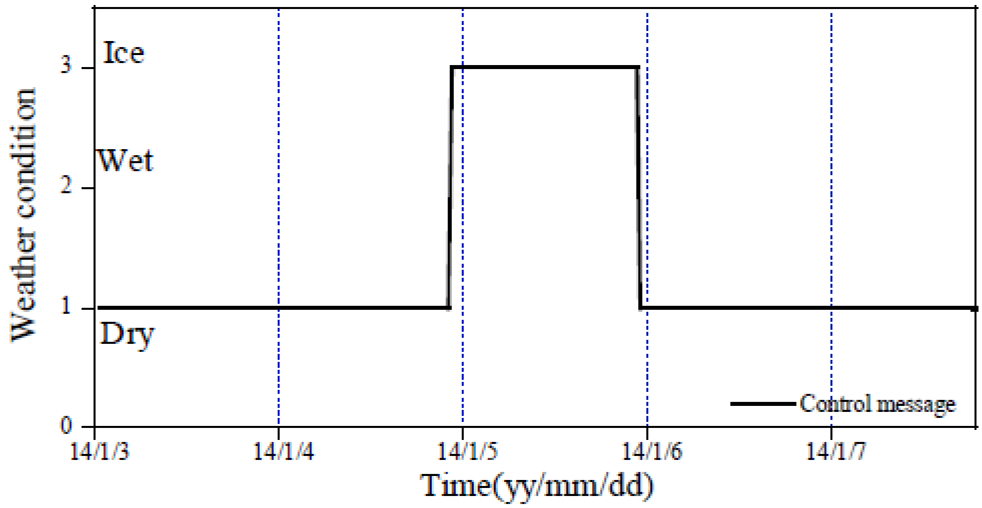


Figure 7-9: TIM Control Message

7.3.3.5 Ice Warning Issues Identified

One of the issues that was identified during the winter was how to identify when snow was falling. With the low cost moisture sensor installed above the pavement (for both security reasons and to protect the sensor from inadvertent damage), moisture could be present on the roadway, but not noted by the moisture sensor. This condition could occur when during snowfall, snow did not melt on the moisture sensor (as a result of the temperature well below freezing) and no heating element was present in this particular sensor.

The quality of the relative humidity can affect the accuracy of detecting ice formation. As illustrated in Figure 7-8, there were times where a high relative humidity present caused the relative humidity sensor to go into saturation (reporting a relative humidity greater than 100%). Under saturation conditions, the sensor may indicate a much higher relative humidity than was present. As a result of this saturation, the sensor can also take longer to return to proper operation tracking of relative humidity when coming out of a saturation condition.

Other ice conditions identified during the testing of this application was ice formed from compacted snow and the effect of deicing (salting the road). The sensors used in this study could not detect either of these conditions.

7.3.4 Applications considered, but not deployed

One application that was considered (and worked on) was the “student competition.” The objective of the student competition was to stimulate student contribution to, and experience with, DSRC through the development of new and innovative applications that benefit road users in the areas of safety, mobility, and sustainability. The scope of the student competition was to engage six or more teams of undergraduate students, from a minimum of three colleges and universities based in Michigan, in a competition to develop and demonstrate DSRC-based applications. These applications were to be both technically sound and capable of making a positive impact. Ford Motor Company purchased a van for use in the project. The competition was introduced, but there were no students that responded. After examining the structure of the competition, it was determined that the prize was inadequate to generate any real interest. However, the van remained for use of the SPMD program. It was equipped with an ASD device and DVI and is now used for demonstrations.

Another application that was considered for SPMD was a railroad grade crossing warning system. This is a safety application intended to warn drivers of the presence of a train approaching an at-grade railroad crossing, either gated or un-gated. The system is a low-cost supplement to the current grade crossing warning systems that uses wireless communications at the crossing to deliver in-vehicle warning messages for equipped vehicles included in the SPMD. Specific objectives of the system would have been to reliably detect the presence of an approaching train using low-cost devices, and to warn equipped vehicles as they approach about the presence of a train in the crossing area. There were three locations on or immediately adjacent to the SPMD site where grade-crossing warnings were considered; Plymouth Road and Barton Drive intersection (signalized), Pontiac Trail at Maiden Lane (signalized), and Traver Road and Bowen Street (two un-signalized crossings). All crossings are over a line operated by Ann Arbor Railroad, on which there are at least two trains per day. Drivers who regularly travel over the crossings would have been selected to operate vehicles equipped with this particular application.

However, no agreement with the Ann Arbor Railroad could be reached to install and deploy the system. At the time, the Ann Arbor Acquisition Corporation, the owner of the Ann Arbor Railroad, was unresponsive, mainly as a result of negotiations they were having with Watco Railroad Company Holdings to sell the railroad. The purchase was agreed to in December 2012 and the sale finalized in early 2013, after approval from the Surface Transportation Board.

8 Post-Model Deployment (Decommissioning)

Although most of the decommissioning tasks were removed from the test conductor contract to allow for the transition from SPMD to the Ann Arbor Connected Vehicle Test Environment, some tasks remained for specific fleets.

Administering subjective questionnaires and conducting focus groups were part of post-model deployment. For each fleet type, except the VAD fleet, a subjective questionnaire was developed that was directed at that specific type of driver. The subjective questionnaires were developed with input from the independent evaluator and the corresponding stakeholder organization. For example, the TRP questionnaire was developed with input from the FTA. The focus group material was developed in the same way. Both the subjective questionnaire and focus group materials required IRB approval.

8.1 Decommissioning the Integrated Light-Vehicle Fleet

Upon return from the field, the test conductor cleaned the ILVs. The test conductor and CAMP inspected all of the vehicles and agreed upon repairs. The test conductor then made arrangements for the repairs. The test conductor removed all traces of personal information from the vehicles including any documents or items in the glove box and all information stored in the navigation or other on-board telematics devices. Once complete, the ILVs were transferred from UMTRI to USDOT to CAMP. CAMP transported the vehicles to their facilities with the exception of three vehicles that the repairs were incomplete – those vehicles were delivered to the CAMP facility by the test conductor.

Subjective questionnaires were given to all ILV participants. A secondary questionnaire was given to the Toyota participants at the request of Toyota and the USDOT. The results for both were tabulated and submitted to the independent evaluator. Focus groups were also conducted. There was a separate focus group for each OEM. These results were compiled and submitted to the independent evaluator.

8.2 Decommissioning the Commercial Connected Vehicle – Integrated Truck Fleet

The three CCV-ITs were returned to factory setting and delivered to USDOT at the VRTC test track in Ohio. A subjective questionnaire was given to one of the two Rightaway drivers. The second Rightaway driver declined to complete the questionnaire or receive compensation for participation. The 4H drivers were not given a subjective questionnaire because they did not drive enough in the Ann Arbor area to elicit any alerts.

8.3 Decommissioning the Retrofit Safety Device Fleet

Only the Con-way RSD fleet was decommissioned. The SWRI RSD kits were removed from the vehicles. The DASs were shipped back to SWRI for the final data harvest. The RSD kits were stored at UMTRI, awaiting further instruction from USDOT. The Con-way drivers were given the subjective questionnaire and the results were compiled and submitted to USDOT.

The Sysco RSD fleet equipped with Battelle RSDs remained in service. The Sysco drivers were given the subjective questionnaire and re-consented for continued deployment. The results of the subjective questionnaire were submitted to the independent evaluator.

Focus groups were not conducted for the RSD fleet.

8.4 Decommissioning the Transit Retrofit Platform Fleet

After the second TRP deployment, the TRP fleet was decommissioned in stages. The equipment remained on one TRP bus for display at the UMTRI Global Symposium. At the end of each deployment, the consented bus drivers were given the subjective questionnaire, the results of which were compiled and submitted to the independent evaluator and the FTA. For each deployment, focus groups were also conducted. Each focus group targeted the highest mileage bus drivers that had the most exposure to the SPMD geographic area. The results were submitted to the independent evaluator and the FTA.

8.5 Decommissioning the Aftermarket Safety Device Fleet

The ASD fleet was not decommissioned. However, subjective questionnaires were given to the participants at the end of their one-year period. The results were submitted to USDOT. Focus groups were not required for the ASD fleet.

8.6 Decommissioning the Vehicle Awareness Device Fleet

The VAD fleet was not decommissioned in preparation for the transition from SPMD to the Ann Arbor Connected Vehicle Test Environment. Subjective questionnaires and focus groups were not required for the VAD fleet participants.

9 Summary

Over 2,800 vehicles and 25 Infrastructure sites were deployed for the SPMD program. The vehicles consisted of several different types of fleets of vehicles.

- ILVs (provided by CAMP)
- CCV-IT – Integrated truck fleet (supplied by Battelle)
- RSDs heavy truck fleet (kits provided by Battelle and SWRI for test conductor installation)
- TRP fleet (provided by Battelle)
- ASD fleet
- VAD fleet

The deployment lasted for one year, but was subsequently extended through the end of the SPMD contract.

The objective of the SPMD was to support the evaluation of dedicated short-range communication technology for V2V safety applications, which operate at 5.9 GHz in a real world, concentrated environment. The main focus was to collect data to support (1) the functional evaluation of V2V safety applications, (2) the assessment of the operational aspects of messages that support vehicle-to-infrastructure (V2I) safety applications, and (3) comprehension of the operational and implementation characteristics of a prototype security operating concept. All of this equated to an assessment of a real-world deployment of V2V technology.

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