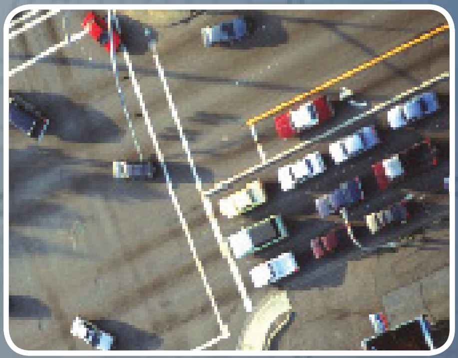
FINAL REPORT:
Vehicle Infrastructure Integration Proof-of-Concept Executive Summary — Infrastructure



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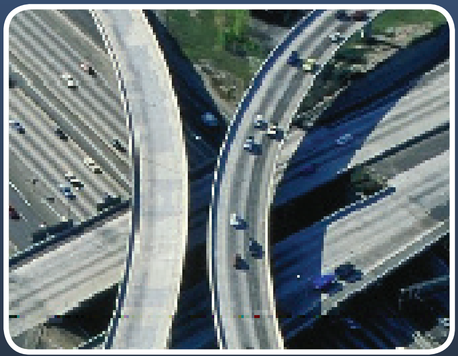

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16. Abstract

In 2005, the US Department of Transportation (DOT) initiated a program to develop and test a 5.9GHz-based Vehicle Infrastructure Integration (VII) proof of concept (POC). The POC was implemented in the northwest suburbs of Detroit, Michigan. This report describes the overall approach undertaken to prove the VII concept through a structured testing program and describes the overall experimental design utilized in proving the VII concept, by providing an overview of the system architecture and the design of systems, subsystems, and components, as well as the public sector applications developed to prove some of the system concepts. It outlines the purpose and procedures for various tests, identifies the test articles, and documents the results of that testing. It also discusses the implications of those test results relative to the overall viability of the VII concept and identifies recommendations for future work, including if and how designs and standards may need to be modified.

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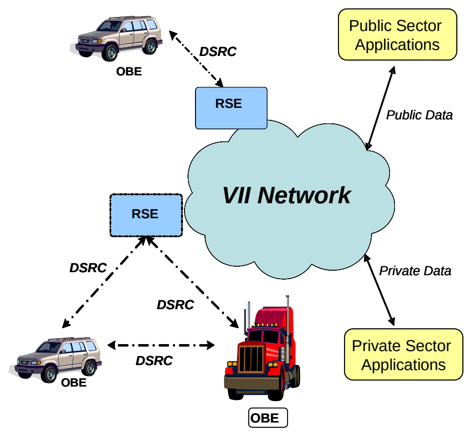
1.0 BACKGROUND

The Vehicle Infrastructure Integration (VII) program[1] is a joint government-industry research effort focused on developing standardized wireless vehicular communications for two primary purposes:

- Among vehicles (vehicle-to-vehicle)—mostly as a means of enabling advanced crash avoidance applications
- Between vehicles and various entities that notionally reside within the broader infrastructure (vehicle-to-infrastructure)—mostly as a means of collecting enhanced roadway condition information and broadcasting various alerts and related traveler information back to vehicles.



VII Concept

Under the VII concept (see figure), vehicles will be equipped with a dedicated short-range communications (DSRC) radio; a highly accurate on-board positioning system; and an appropriately configured on-board computer to facilitate communications, support various applications, and provide an interface to the driver (collectively, this equipment is called the on-board equipment—OBE). Vehicles would communicate with each other and with roadside transponders (or roadside equipment—RSE), which would be linked to the specialized VII network. RSEs would be positioned at major signalized intersections and along interstates and major arterials.

2.0 ORGANIZATION OF THE FINAL REPORT

The *Final Report: Vehicle Infrastructure Integration Proof-of-Concept* is organized into three volumes, as described below:

- ***Volume 1B – Final Report: Vehicle Infrastructure Integration Proof-of-Concept Executive Summary – Infrastructure*** (this document), provides an overview of the key findings and recommendations from the POC testing. This volume is intended for executives and managers of organizations interested in the deployment of VII.
- ***Volume 2B – Final Report: Vehicle Infrastructure Integration Proof-of-Concept Technical Description – Infrastructure***, describes the overall approach undertaken to prove the VII concept through a structured testing program. It describes the overall experimental design used in proving the VII concept by providing an overview of the system architecture and the design of systems, subsystems, and components, as well as the public sector applications developed to prove some of

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[1] The program name, Vehicle Infrastructure Integration (VII), was in official use at the inception of and during the execution of the work described in this report. The United States Department of Transportation (US DOT) has initiated a new program entitled "IntelliDrive^{sm}" which now encompasses all activities that were previously part of VII.

the system concepts. This volume is intended for engineering managers and practicing engineers interested in the design and development of VII systems and applications.

- ***Volume 3B – Final Report: Vehicle Infrastructure Integration Proof-of-Concept Results and Findings – Infrastructure***, outlines the purpose and procedures for various tests, identifies the test articles, and documents the results of that testing. It also discusses the implications of those test results relative to the overall viability of the VII concept and identifies recommendations for future work, including whether and how designs and standards need modification. This volume is intended for engineering managers and practicing engineers interested in the design and development of VII systems and applications. It assumes the reader has read and is familiar with the technical description in Volume 2.

3.0 VII POC

In 2005, the US Department of Transportation (DOT) initiated a program to develop and test a 5.9GHz-based VII POC, in support of a nationwide deployment decision. The US DOT and its private-sector partner the VII Consortium (VIIC)—an organization consisting of several light-duty original equipment manufacturers (OEMs) and industry participants—executed the POC test. The US DOT has engaged Booz Allen Hamilton to design the national VII network architecture, act as system integrator, and implement the POC.

The POC Development Test Environment (DTE) was implemented in the northwest suburbs of Detroit, Michigan. Fifty-five RSEs were installed within 45 square miles, 27 vehicles were configured with OBEs, and a communications network was established. Further, a limited number of public- and private-sector applications were developed, primarily as a means of testing the end-to-end functionality and performance of the VII system.

4.0 POC GOALS AND OBJECTIVES

The primary goals of the POC include demonstrating the technical performance and functionality of the VII architecture and associated concept and proving that safety, mobility, and commercial (private) applications can be effectively implemented. Key among the technical and functional requirements is the need for vehicular users to maintain their anonymity, while the overall system ensures a high level of security.

The design of the POC test environment and associated system software and applications was completed based on objectives established to meet the aforementioned goals. The following are key objectives identified for the POC:

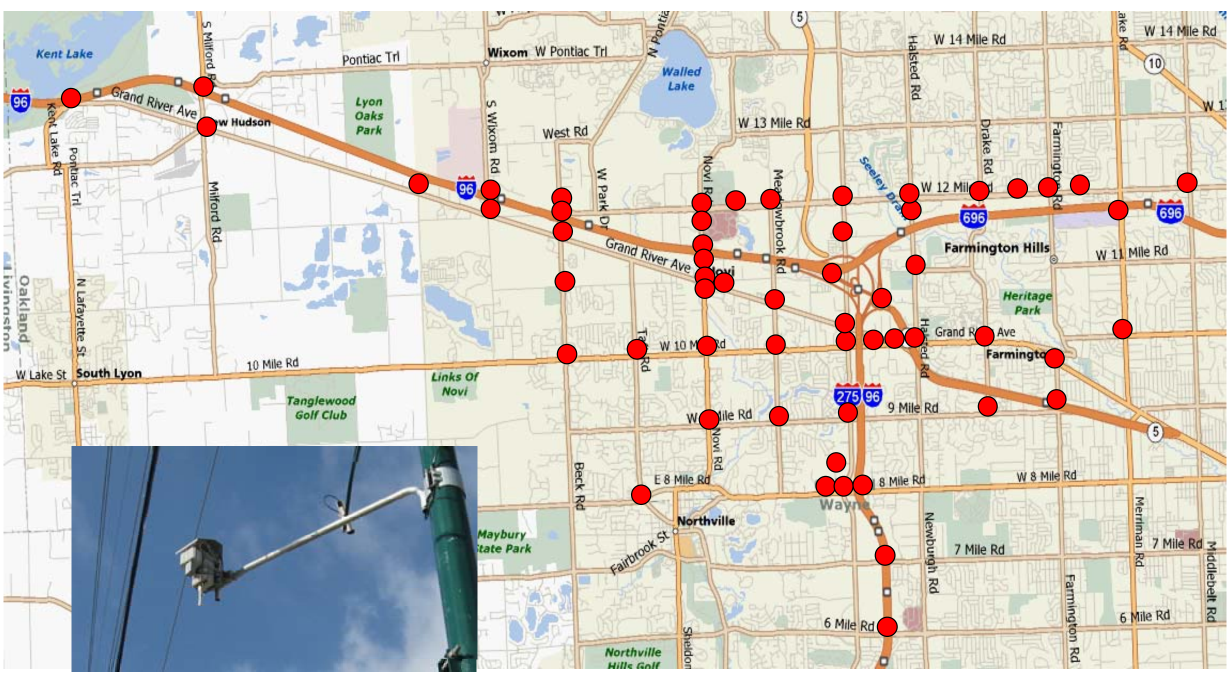
- ***Validate Standards*** – The IEEE (Institute of Electrical and Electronics Engineers) 1609 and 802.11p suite of standards was established for the vehicle-to-vehicle and vehicle-to-infrastructure communication paths used in VII. In addition, the SAE J2735 standard was established to provide a common message set for these communications. An objective of the POC was to validate that these standards properly function in the 5.9GHz band allocated for use with VII.
- ***Provide Core Services*** – A set of core services are part of the VII architecture. These include publish/subscription services, network management, mapping and positioning services, and a

Certificate Authority. An objective of the POC was to test these services to ensure that they function properly.

- ***Support Applications*** – Successful implementation of VII at the national level depends on the architecture's ability to support simultaneous operation of the safety, mobility, and commercial (private) applications expected to run on the system. An objective of the POC was to demonstrate that a basic set of applications, representative of those expected to be part of the initial set used on VII, can concurrently run on VII.
- ***Demonstrate Security and Privacy*** – The ability to protect against malicious intrusion, while maintaining privacy, is an essential part of the VII concept. An objective of the POC was to test the susceptibility of the system to intrusion (hackers), while ensuring the anonymity of users.

5.0 POC TEST SCOPE

The scope of the POC test was developed based on the goals and objectives described above. While the VII communication standards and technology (as originally envisioned) are based on existing Wi-Fi platforms, there are significant modifications made to enable high-speed, low-latency communications with moving vehicles. In addition, the envisioned public and private sector applications that would utilize VII technology require special provisions related to security, privacy, and reliability in order to ensure safety and anonymity of motorists. The realization of VII wireless standards and implementation of the roadside network that enables communications to and from vehicles required Booz Allen to address special challenges that have been unique to the VII program—and therefore required significant development and innovation as well as thorough testing of the concepts and technology solutions.



Booz Allen staff photo

VII Testbed in Michigan

By testing the VII concept and systems in a real-world uncontrolled environment in Michigan (see above figure), designers and developers were able to: 1) determine whether the new communication standards, technologies, hardware, and software solutions do in fact support the intended applications (i.e., that the VII system “works”); 2) obtain valuable information for refining the concept and solutions; and 3) demonstrate the potential value of this new wireless vehicular communications media to both government and private stakeholders.

The VII testing program was structured into three main phases—subsystem testing, system integration and test, and public and private applications testing. After completion of subsystem testing, the VII POC moved into the system integration and test phase. The goal of the system integration and test was to verify the VII National System Specification (NSS) requirements and demonstrate that the end-to-end VII system was functional and ready to support user application tests. The goal of the public and private applications testing phase was to demonstrate the ability of the VII architecture to support multiple public- and private-sector applications. Booz Allen conducted the public and private applications testing from May 2008 to September 2008.

6.0 FINDINGS FROM THE POC TEST

The following sections highlight the key findings from the POC testing led by Booz Allen. The findings from the POC testing led by the VIIC are documented in the VIIC’s final report. The reader is encouraged to also read the VIIC’s report to get a complete picture of the POC findings.

6.1 Dedicated Short-Range Communications

DSRC testing was performed during the system integration and test phase. The scope of this testing included showing DSRC interoperability between an RSE radio built by one vendor and an OBE radio built by another vendor. This testing focused on fundamental DSRC standards and included Wave Service Advertisement (WSA) testing, Wave Short Message (WSM) broadcasts, WAVE Basic Service Set (WBSS) generation and Internet Protocol version 6 (IPv6), and User Datagram Protocol (UDP) communications.

Finding Number	Finding
F-DSRC-1	Final range testing results showed solid radio communications from RSE to OBE up to 1100 meters, with multipath effects degrading communications at 660 meters, 850 meters, 900 meters, and 1,000 meters. These results also showed a link imbalance with OBE to RSE communications only available up to 400 meters.
F-DSRC-2	DSRC radio findings indicate that adequate range can be achieved in most conditions, although typical roadside link quality is significantly different from that measured in open field testing due to roadside furniture.
F-DSRC-3	Testing in situations where an OBE came within the overlapping range of multiple RSEs highlighted an issue involving prioritization and service selection. While the OBE successfully created a WBSS based on the highest priority service currently being advertised from the RSEs within range, it will not create a WBSS with any other RSE, and will miss any service channel messages or services offered on those RSEs.
F-DSRC-4	Testing throughout the VII program has shown that both OBE and RSE are interoperable and fully capable of transmitting and receiving traffic in accordance with the POC baselined DSRC standards. VII services and public and private applications have consistently utilized IPv6, TCP, UDP, and WSM message traffic throughout the DTE. With the notable exception

Finding Number	Finding
	of the OBEs “confirm before join” discrepancy, the OBE and RSE conform to the POC baselined DSRC standards. However, testing showed that the DSRC standards do not adequately address functionality for multiple overlapping RSE coverage areas.
F-DSRC-5	WAVE/DSRC-based security mechanisms generally work as intended and can effectively provide the authentication and authorization features required to meet stated privacy and security objectives.
F-DSRC-6	Communication quality was reduced by an “unbalanced link” situation whereby the OBE would commence transmission of data after coming in range of an RSE’s broadcast, but at a distance too far for the RSE to receive the OBE’s data.

6.2 Probe Data Service

Probe Data Service (PDS) testing was accomplished in all three phases of the VII test program. The scope of PDS testing was to show that OBEs could generate and send probe data messages to RSEs, and that network users could subscribe to all probe data elements or subsets of probe data elements and receive the data that accurately matched the subscriptions.

Finding Number	Finding
F-PDS-1	Initial PDS tests involving vehicles equipped with OBEs showed probe data loss rates greater than 60 percent. Implementation of V-DTLS greatly improved the probe data loss rates by requiring the OBE and RSE to set up a V-DTLS connection before transmitting probe data.
F-PDS-2	PDS testing showed that OBE-equipped vehicles can successfully generate and send probe data to RSEs and that Network Users can create, update, and delete PDS subscriptions and receive probe data snapshots in accordance with those subscriptions.
F-PDS-3	A small amount of probe data is lost between the SDN and Network User due to the need for sending an ARP message when sending the first probe data snapshot to a Network User and the use of UDP as the protocol for sending probe data snapshots.

6.3 Advisory Message Delivery Service

Advisory Message Delivery Service (AMDS) testing was accomplished in all three phases of the VII test program. The scope of AMDS testing was to show that network users could generate AMDS messages with varying broadcast strategies to send to RSEs and that OBEs could receive and correctly display those messages according to the message instructions.

Finding Number	Finding
F-AMDS-1	If an OBE enters an area with multiple RSEs broadcasting AMDS messages on the service channel, it may never receive the AMDS messages from one of the RSEs.
F-AMDS-2	Control channel messages that were advertised in the WSA caused instability in the OBE resulting in a software crash. Since WSAs should only contain service channel advertisements, a fix was developed for the RSE to that effect.
F-AMDS-3	During AMDS testing, multiple broadcast strategies were used which varied the broadcast

Finding Number	Finding
	region, presentation region, message activation time, and priority. All messages were correctly broadcast by the RSEs and displayed by the OBEs according to the message instructions. Additionally, already active messages were updated and deleted, and those changes were accurately reflected by both the RSE and OBE.
F-AMDS-4	As implemented in POC, an advisory message is not displayed by the OBE if the vehicle receives the message while already in the active region specified within the message, even if the vehicle is traveling in the direction to which the message applies.

6.4 Communications Service

Throughout the system life cycle of the VII POC, various backhaul technologies were employed to provide VII RSE and OBE devices as well as VII partners and stakeholders with access into the VII POC environment. Infrastructure-to-infrastructure and vehicle-to-infrastructure communications benefited from the use of multiple communication mechanisms such as T-1 data circuits, a closed WiMAX network, and various 3G connections. Each technology was leveraged to support infrastructure where the other means of communication were impossible or cost prohibitive.

Finding Number	Finding
F-COMM-1	Communication technologies supported the dual stack IPv4/IPv6 nature of VII architecture.
F-COMM-2	Management of network communications resources for multiple simultaneous applications is more complex than expected.

6.5 Map Element Distribution Service

Map Element Distribution Service (MEDS) testing was primarily accomplished during the subsystem testing phase. The Booz Allen team conducted this testing at the CNSI Lab. VIIC and Nissan conducted tests using the MEDS Geometric Intersection Description (GID) distribution functionality in the DTE.

Finding Number	Finding
F-MEDS-1	GIDs could be imported into MEDS and sent to RSE, via the AMDS service.
F-MEDS-2	Lane-level positional accuracy is needed to test automated GID updates made from probe data (e.g., Stop Bar Update).
F-MEDS-3	Inaccurate or null vehicle dimensions, both size and shape, within probe data, mitigate the effectiveness of geo-statistical processing of probe data for developing or validating the accuracy of GIDs.
F-MEDS-4	Knowledge of the location of the GPS antenna on the vehicle is critical to determine the vehicle's exact location on the roadway and in relation to other vehicles.

6.6 Positioning Service

Positioning service testing was accomplished during the subsystem testing and system integration and test phases. The VIIC and Booz Allen teams conducted this testing at the CNSI Lab and at the Battelle and VIIC test track facilities. The VIIC conducted extensive testing of the OBE and vehicle positioning systems, while Booz Allen testing focused on receiving a HA-NDGPS feed at the SDN and re-broadcasting that feed to RSEs in the SAE J2735 defined format.

Finding Number	Finding
F-POS-1	Currently, commercially feasible positioning technologies in vehicles do not support lane-level accuracy, which is required for some applications. Commercial products from two different vendors were used in the testing, and neither one met the lane-level accuracy requirement.
F-POS-2	The SDN was able to receive HA-NDGPS data over an Internet Protocol (IP) network, and forward the relevant Real-Time Correction Messages (RTCM) positioning correction data to RSEs. Testing done at the VIIC Battelle test track showed that RSEs were able to receive this RTCM data and broadcast the HA-NDGPS corrections in the SAE J2735 format, and that the OBE would receive those corrections and enter into differential correction mode.
F-POS-3	While the end-to-end delivery of the RTCM positioning corrections was successfully tested, limitations of the OBE's GPS receiver resulted in HA-NDGPS positioning corrections actually degrading the accuracy of OBE positioning data. Consequently, positioning accuracies resulting from application of the corrections was not fully tested.

6.7 Security

VII POC security service provides secure management of VII assets, network services, and the security of data transmitted across the network. The VII Security service provides for "defense-in-depth" protection of hardware, software, and information components against attackers, unauthorized users, and physical or electronic sabotage.

Finding Number	Finding
F-SECU-1	The VII POC security IdAM service successfully provided VII network access account lifecycle management for RSE devices, Network Users (data subscribers, advisory providers, and transaction service providers), administrative users, and service provider management systems.
F-SECU-2	VII service provisioning (AMDS) using the 1609.3 Provider Service ID (PSID) demonstrated the successful interoperability of the 1609.3 (network) and 1609.2 (security) protocols for providing POC security services using WAVE.
F-SECU-3	1609 Security Configuration Management of multiple devices (certificate authority, Lightweight Directory Access Protocol, RSE, OBE) requires the training of multiple stakeholders on the use of 1609.2 cryptographic libraries.
F-SECU-4	By provisioning "anonymous certificates," the VII POC certificate authority enabled anonymity and privacy for vehicle-to-vehicle communication. Anonymous certificates remain outside the current definitions provided by the 1609 Security Protocol standards.

6.8 Enterprise Network Operations

Enterprise Network Operations (ENOC) testing was accomplished during the subsystem testing and system integration and test phases. The Booz Allen team conducted this testing at the CNSI Lab, and the

ENOC monitored all SDN, ENOC, and RSE equipment at the DTE. The scope of the ENOC testing was to demonstrate that all VII equipment, with the exception of OBEs, can be remotely monitored, updated, and maintained at a separate operations center.

Finding Number	Finding
F-ENOC-1	Installing, configuring, and maintaining the RSE was a more complex and difficult task than originally envisioned. It relied on multiple custom-developed applications to provide the VII services, and a COTS network management product extensively custom configured to interact with the RSE. It was found that the most efficient way to manage RSE configurations and software updates was to make changes to each RSE individually. However, on a larger scale, this approach may not be feasible, and support from COTS manufacturers may be necessary to help develop tools to manage large deployments of RSEs.
F-ENOC-2	A central operations center can monitor, update, and re-configure RSEs in the Detroit DTE remotely using an ENOC. Additionally, an ENOC can monitor and maintain the SDN remotely.

6.9 Certificate Authority

Both the Booz Allen team and the VIIC support team conducted the certificate authority testing. The Booz Allen team tested the X.509 Certificate Authority, which issues certificates to network users for access to the VII services. The VIIC support team tested the 1609.2 Certificate Authority, which provides the certificates to both OBE and RSE for DSRC communications. X.509 Certificate Authority testing was accomplished at the CNSI Lab, and 1609.2 Certificate Authority testing was accomplished at Telcordia facilities, the CNSI Lab, and VIIC test track facilities.

Finding Number	Finding
F-CA-1	The X.509 certificate authority testing showed that the SDN and ENOC can issue and revoke certificates to network users. Additionally, testing showed that without a valid certificate, Network Users were unable to access and use VII services.
F-CA-2	The 1609 certificate authority testing demonstrated that the certificate authority can issue 1609.2 certificates (anonymous, identified, CSR signing, and WSA) and distribute to RSEs and OBEs. The certificate authority can also revoke any of these certificates and distribute via certificate revocation lists.

6.10 Test Bed Deployment

The VII network was primarily tested during the subsystem testing and the system integration and test, but was utilized by all services during all phases of testing. The scope of the VII network testing was to demonstrate the ability of the network to support IPv6 and demonstrate a range of backhaul technologies. The VII network testing was conducted in the CNSI Lab and at the DTE.

Finding Number	Finding
F-TBD-1	The VII WiMAX backhaul network experienced periodic interference using the public unlicensed 5.8 GHz spectrum. Sources of interference were not always able to be determined; however, in one instance, a local radio station broadcasting at 100MHz did interfere with the WiMAX intermediate frequency band of one base station.
F-TBD-2	3G backhaul performance was dependant on the proximity to the closest cell phone tower and the number of users on the 3G service at any given time.
F-TBD-3	There is a requirement to suspend an OBE to TSP transaction session when an OBE leaves the range of an RSE, and resume the transaction session when the OBE subsequently comes within range of the same or a different RSE. An experimental V-HIP protocol was successfully tested; however, it was a qualified success, because it could not be supported as implemented by the COTS network equipment used in the VII backhaul and backbone network. Workarounds, in the form of IPv4 "SIT" tunnels, were required to successfully route V-HIP traffic through the POC infrastructure.
F-TBD-4	The VII network successfully demonstrated that T1, 3G, and WiMAX backhauls can be fully supported. Of the three backhaul technologies, T1 was the most reliable and consistently provided 1.544 Mbps of bandwidth, although it required long lead times to set up and was the most expensive. WiMAX was the second most reliable and provided an average bandwidth of 6 Mbps, but was not available in the DTE and required a private WiMAX network to be installed. Initial set up of the WiMAX network was costly; however, there were no month-to-month costs. Although 3G was the least reliable, those connections were still active the majority of the time. Maximum bandwidth of 3G was 800 Kbps; however, bandwidth varied throughout the day. Overall, 3G was the cheapest of the backhaul technologies, provided adequate performance for most of the VII testing activities, and was the simplest to deploy.
F-TBD-5	The current mounting location of the RSE compute platform and power supply made servicing the hardware difficult and required an RCOC/WCDR bucket truck.

6.11 Network User

Network user testing was accomplished in all three phases of the VII test program. The scope of this test was to show that network users can successfully subscribe to and receive probe data, send advisory messages to vehicles, alter the way that vehicles generate probe data, and receive trip path data from the vehicles.

Finding Number	Finding
F-NU-1	Network Users could send traveler advisory messages (based on a mixture of ITIS phrases and free text, as specified in SAE J2735) to the SDN, and query the delivery status of their advisory messages.
F-NU-2	Network Users could cancel advisory messages; however, if a vehicle had already received the message, it would still display it.
F-NU-3	When message deliveries failed, Network Users could send advisory message sync requests to the RSE.
F-NU-4	Network Users could subscribe to probe data by choosing the RSE where the probe data was received, the time of the probe data reception, and the desired probe data elements

Finding Number	Finding
	included in each snapshot.
F-NU-5	Network Users could place multiple subscriptions and receive probe data in real time, which matched their subscriptions.
F-NU-6	Network Users could cancel and modify their subscriptions before its expiration time and the modified subscription would take effect immediately.
F-NU-7	Network Users could send and cancel PDM messages, and receive probe data in real time, which matched their PDM messages.
F-NU-8	Network Users could receive all trip path data from vehicles transmitting such data through an opt-in service.

6.12 Privacy

The scope of the privacy testing was to demonstrate the ability to protect against malicious intrusion, while maintaining privacy, which is an essential part of the VII concept. It also included testing the susceptibility of the system to intrusion (hackers), while ensuring the anonymity of users.

Finding Number	Finding
F-PRIV-1	POC was designed not to collect personally identifiable information (PII). As documented in the VII Privacy Impact Assessment (PIA), the POC test environment demonstrates that it does not collect PII.
F-PRIV-2	The VII PIA provides adequate guidance for privacy protection in a scaling national deployment.
F-PRIV-3	Inspection of probe data during testing provided a means of validating the absence of PII content in POC.

6.13 Standards

Booz Allen conducted the standards testing during all three phases of the VII test program. The scope of this testing included validating that the IEEE 1609 and 802.11p suite of standards as well as the SAE J2735 standards (POC DSRC Message Sets) function properly throughout the VII network, including in the 5.9GHz band allocated for use with VII.

Finding Number	Finding
F-STD-1	V-DTLS allows only one vehicle to send probe data to an RSE at a time.
F-STD-2	The probe data message, as specified in the POC DSRC message set, can successfully accommodate sending vehicle sensor data to network users.
F-STD-3	The PSN, as specified in the POC DSRC message set, can successfully be generated randomly and changed at predetermined times and conditions.
F-STD-4	The PDM message, as specified in the POC DSRC message set, can successfully accommodate directing vehicles to change probe data collection policies.
F-STD-5	The start/stop strategy for probe data collection, as specified in the POC DSRC message set, can successfully accommodate suspension of collection and sending of probe data while the vehicle is stopped.

F-STD-6	The start gap for probe data collection, as specified in the POC DSRC message set, can successfully accommodate prolonging the collection of probe data until a distance traveled threshold is met.
F-STD-7	The traveler information message, as specified in the POC DSRC message set, can successfully accommodate sending relevant information/signage to vehicles.
F-STD-8	Java, as implemented in POC, is not suitable for sending/receiving low-latency messages such as SPAT/GID and heartbeat, as it has too much overhead.
F-STD-9	The trip path message, as implemented in POC, can successfully provide the route a vehicle has traveled.

7.0 RECOMMENDATIONS FOR FUTURE WORK

The following sections provide high-level recommendations for future work, based on the POC testing led by Booz Allen. Detailed recommendations are included in Volume 3 of the final report. Recommendations based on the POC testing led by the VIIC are documented in the VIIC's final report. The reader is encouraged to also read the VIIC's report to get a complete picture of the POC recommendations.

7.1 Dedicated Short-Range Communications

Overall, the VII POC system successfully demonstrated the core DSRC-based vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications functions. However, POC testing identified issues with the prototype WAVE/DSRC radio implementations, mostly due to limitations and shortcomings in the 1609 WAVE protocol standards suite. The majority of these shortcomings result from the dynamic nature of the mobile radio relative to the stationary radio and to other mobile radios. The WAVE/DSRC standards and the next-generation radio implementations need to be refined to include signal quality measures, enhanced service processing logic (unbalanced links), and multi-RSE service arbitration logic. The two secure communications protocols (V-HIP and V-DTLS) developed for the POC, and optimized for use with the WAVE/DSRC 1609 protocols, need to be further developed with the end goal of submission to the appropriate standards bodies.

7.2 Probe Data Service

The PDS adequately met the requirements of the VII system after the implementation of V-DTLS, throughout the VII POC testing. Once probe data was received by the RSE, losses throughout the system were minimal. Those losses that did occur were found between the SDN and network user interface, and were due to the use of UDP as the transport protocol. A review of alternative protocols to use for this interface and an analysis of increased bandwidth required for a new protocol should be conducted to determine whether there are viable options other than the UDP. Additionally, changes to the structure of ASN.1 Probe Data Messages should be reviewed due to the complexities found designing the parsing and data extraction mechanisms resident in the PDS. Although the parsing functionality proved adequate for the POC, increased message throughput could adversely impact future performance with larger-scale probe data tests.

7.3 Advisory Message Delivery Service

Overall, the AMDS met the basic requirements of the VII system; however, due to deficiencies in the DSRC standard regarding overlapping RSEs, there were instances of message loss. As a result, the DSRC standards should be revisited and a study conducted to determine what mechanisms can be put in place to allow vehicles to receive messages from multiple RSEs with overlapping coverage. Additionally, the POC testing found a gap in functionality that should be further explored. In the current architecture, once an AMDS message is received by a vehicle, there is no way to tell that vehicle that the message has been canceled or revoked by the user who created it. Further study to determine a mechanism to allow RSEs to broadcast a message canceling or revoking AMDS messages should be conducted.

7.4 Communications Service

In general, the VII POC communications service met the basic requirements of the dual-stack IPv4/IPv6 nature of the VII architecture. However, prior to national rollout, the conventional Internet mobility and security protocols need to be refined and modified to support dynamic and anonymous mobile users.

7.5 Map Element Distribution Service

Vehicle dimensions, both size and shape, have significant impact on the MEDS geostatistical processing. These dynamics need to be more adequately addressed to increase the accuracy of updated intersection geometries. Continued work on MEDS should also include closer coordination with other organizations across the intelligent transportation system (ITS) community. Many industry organizations, academic institutions, and commercial vendors are actively performing research into the use of probe data for map updates. Leveraging these efforts in combination with continued MEDS development will facilitate the development of MEDS' capability to support multiple VII use cases.

7.6 Positioning Service

The POC positioning service design was based upon delivery of standard RTCM corrections through the VII infrastructure using the Networked Transport of RTCM via Internet Protocol (NTRIP) standard. Future positioning service development and testing phases should evaluate alternative positioning solutions and emerging technologies, enabling enhanced delivery of RTCM corrections through the VII infrastructure or other delivery mechanisms, including use of alternative correction sources besides the HA-NDGPS.

7.7 Security

The VII POC security subsystem has demonstrated the ability to provide trusted data to the vehicle operators and to prevent the misuse of vehicle information by unauthorized users of the system. RSEs and OBEs equipped with strong identity credentials have rejected bad messages and avoided threats from would-be attackers. The "defense-in-depth" model deployed for the VII POC security architecture should be used as a baseline and assessed against the National ITS Architectures for information security, operational security, and threat mitigation criteria. The analysis and reporting of quantifiable metrics regarding VII POC security services should be developed to further demonstrate the secure management of VII assets and network services, as well as the security of user data transmitted across the VII POC system, from misuse by attackers, unauthorized users, and physical or electronic sabotage.

In particular, the use of IPv6 security services should be evaluated for further enhancements to the VII POC "defense-in-depth" model.

7.8 Enterprise Network Operations

The VII ENOC subsystem was the epicenter of the VII POC. Its role was to provide network management and security information services to the underlying VII subsystem architecture. As the primary entry point for access into the VII enclave, the ENOC was responsible for tracking the network health, system security, while providing a centralized location for investigation and remediation of VII-related component issues. In the future, large-scale build outs should take into account all aspects of a network operations implementation. Identification of the correct people, creation of tested processes, and adherence to established security policies, as well as incorporating the right technologies, are paramount to the deployment of a successful ENOC capability.

7.9 Certificate Authority

The certificate authority requirements of the VII POC System were met though independent linked certificate authority servers, providing a small-scale public key infrastructure (PKI) service, deployed to securely manage the different classes of messages, applications, and services traversing the VII system. These certificate authority capabilities included lifecycle management for public and private keys, digital signatures, and a variety of encryption mechanisms. This certificate authority model (which included both X.509 and 1609 certificates) was proven to be a viable security design given the limited number of RSEs, OBEs, and services deployed in the various VII test beds utilized during the POC testing. As a follow-on to the VII POC program, this security architecture should be assessed in terms of providing a scalable solution for enterprise-wide deployment. Performance modeling and quantitative analysis of the certificate authority are suggested as a means for looking at network throughput, hardware encryption devices, certificate revocation lists (CRLs), and digital signature verification operations.

7.10 Test Bed Deployment

Overall, the VII backhaul infrastructure satisfied the basic requirements of the VII POC. In concept, the resilient and redundant failover mechanisms employed for the architecture provided adequate support of the VII subsystem architecture. Through the use of traditional T1s, 3G technologies, and the internal WiMAX network, the VII architecture maintained the various interfaces, devices, and communication paths for the VII POC. However, implementations of these technologies were a challenge and at times were cost prohibitive. For the most part, the T1 and WiMAX network provided the most availability and ease of use due to VII engineering having administrative control. The traditional T1 and WiMAX services offered the stability that the RSE and OBE devices required. However, they were also the most cost prohibitive. Additional issues revolved around the lack of IPv6 vendor support. Moving forward, the ITS steward should work with its partners to push IPv6 maturity in its technical roadmaps.

7.11 Network User

Overall, most of the network user needs were met by the public applications. However, POC tests revealed some areas in need of further development. Most of these relate to additional features that would greatly enhance the network users' ability to make better-informed decisions. For both AMDS and PDS, the network users need more fine-tuned control to better manage advisory messages and probe data subscriptions. Specifically, for PDS, further customization of subscriptions would need to be added, and for AMDS, the network user should have the ability to further limit the affected vehicles for a given message.

7.12 Privacy

For the VII POC, privacy requirements have been assessed in both the V2I and V2V segments of the network. The term "anonymity" describes the POC design goal that, as far as possible, broadcast transmissions from a vehicle operated by a private citizen should not leak information that can be used to identify that vehicle to unauthorized recipients. While V2I privacy requirements were met by examining traceability and identity in probe data transmission, the V2V privacy aspects of the VII POC suggest broader operational requirements beyond existing standards (IEEE 1609 Security). As such, technical innovations to protect the anonymity of the driver and vehicles necessitate further examination of VII POC privacy protection technology (use of protocol innovations and anonymity protection mechanisms). To meet the privacy requirement of the VII POC, further assessment of available trust models (privacy by design, privacy by trust) are needed to evaluate certificate management, "bad actor" and scalability factors for the network. Privacy constraints in the V2V segment need further research to consider various issues, including how the system can sustain more compromised vehicles with reasonable overall system performance, how we can eliminate misbehaving vehicles without compromising their privacy, and how we can maintain consistent or predictable levels of privacy.

7.13 Standards

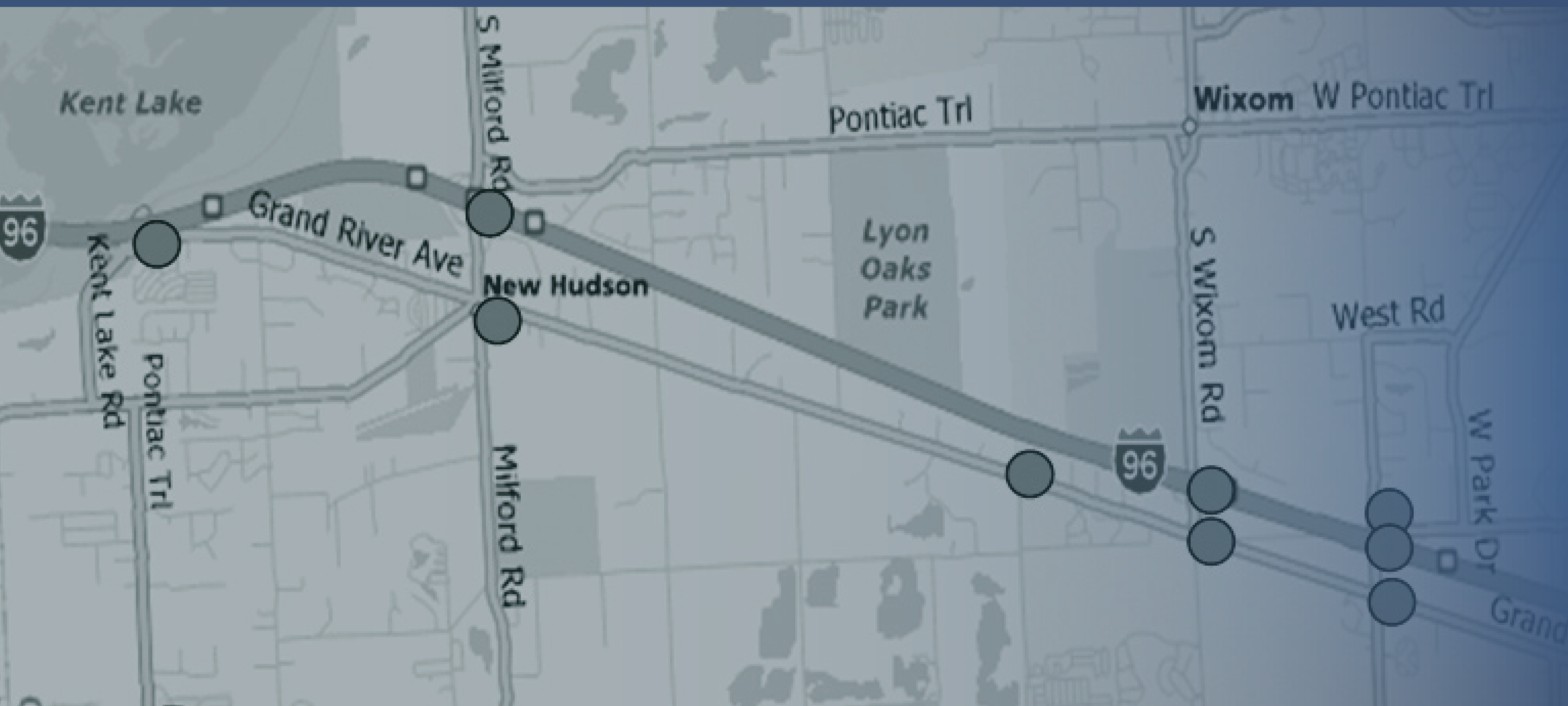
Some refinements are required to the DSRC standards implemented for the POC (e.g., SAE J2735, IEEE 1609.2, 1609.3, 1609.4, and IEEE 802.11p) based on lessons learned during the POC testing. The usage descriptions and content of some J2735 messages need to be updated to avoid uncertainty during development and implementation. A constant line of communications was open between POC developers and the SAE during development, resulting in the majority of the issues being addressed in J2735 version 2.0. Refinements to the IEEE standards are required to better accommodate the nature of the vehicular environment. Improvements need to be made in the area of vehicle-to-vehicle communications, where both the transmitter and receiver are moving simultaneously and overlapping RSE coverage areas where multiple RSEs are broadcasting the same PSIDs.

APPENDIX A: ACRONYMS

AMDS	Advisory Message Delivery Service
ARP	Address Resolution Protocol
BSP	Bootstrap
CA	Certificate Authority
CICAS	Cooperative Intersection Collision Avoidance System
CNSI	Center for Networks and System Innovation
COMM	Communications Service
COTS	Commercial Off the Shelf
CRL	Certificate Revocation List
CSIRC	Computer Security Incident Response Capability
CSP	Credentials Service Provider
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications Link
ENOC	Enterprise Network Operations Center
EPS	Electronic Payment Service
FHWA	Federal Highway Administration
GID	Geometric Intersection Description
GPS	Global Positioning System
HA-NDGPS	High-Accuracy National Differential GPS
HIF	Hardware Interface
HIP	Host Identity Protocol
HMM	Health Management Manager
IdAM	Identity and Access Management
IDD	Interface Design Description
IEEE	Institute of Electrical and Electronics Engineers
ILS	Information Lookup Service
IP	Internet Protocol
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IRS	Interface Requirements Specification

ITIS	International Traveler Information Systems
ITS	Intelligent Transportation System
LAN	Local Area Network
LCS	Life Cycle Service
LDAP	Lightweight Directory Access Protocol
LSS	Local Safety System
MIB	Management Information Base
MEDS	Map Element Distribution Service
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
NAP	Network Access Point
NTRIP	Networked Transport of RTCM via Internet Protocol
OBE	Onboard Equipment
OEM	Original Equipment Manufacturer
PDS	Probe Data Service
PFM	Platform
PIA	Privacy Impact Assessment
PII	Personally Identifiable Information
PKI	Public Key Infrastructure
POC	Proof of Concept
POS	Positioning Service
PRXY	Proxy
PSOBE	Public Service Onboard Equipment
RFC	Request for Comment
RIS	Roadside Infrastructure Service
RSE	Road Side Equipment
RSR	RSE Subsystem Requirements
RSU	Road Side Unit
RTCM	Real Time Correction Messages
RTG	Routing Services
SDN	Service Delivery Node
SEC	Security Service
SNMP	Simple Network Management Protocol

TAM	Transportation Area Maps
TCP	Transmission Control Protocol
TOC	Transportation Operations Center
TSR	Transaction Service Router
UDP	User Datagram Protocol
US DOT	US Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V-DTLS	Vehicular Datagram Transport Layer Security
V-HIP	Vehicle-Host Identity Protocol
VII	Vehicle Infrastructure Integration
VIIC	Vehicle Infrastructure Integration Consortium
VPN	Virtual Private Network
WAN	Wide Area Network
WAVE	Wireless Access in Vehicular Environments
WBSS	WAVE Basic Service Set
WSA	Wave Service Advertisement
WSM	Wave Short Message



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