Enabling Accelerated Installation of Aftermarket Onboard Equipment for Connected Vehicles

TASK 3: PROCUREMENT GUIDANCE DOCUMENT

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Prepared by
Industrial Technology Research Institute
California PATH of the University of California at Berkeley
Visteon Corporation

for
University of Virginia
Cooperative Transportation System Pooled Fund Study

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Executive Summary

The Procurement Guidance Document is the third milestone in the University of Virginia's Enabling Accelerated Installation of Aftermarket Onboard Equipment (OBE) for Connected Vehicles Project, conducted under the umbrella of Cooperative Transportation System Pooled Fund Study. This guidance document is based on findings reported in the first two deliverables of the Pooled Fund Study, the State of the Industry and Vendor/Market Readiness Reports, and is enhanced with additional contents to specifically address the considerations for OBE procurement. The purpose of the guidance document will be to assist Pooled Fund Members and other interested Government Agencies in developing procurement proposals for dynamic configurable multi-band aftermarket OBE.

1 Introduction

1.1 Project Goals

The goal of this project is to evaluate the potential approaches for accelerating the introduction of aftermarket OBE units to the vehicle fleet. Without a rapid deployment, the safety, mobility, and convenience benefits of the USDOT Connected Vehicles Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the market penetration required for maximum benefit. Therefore, aftermarket deployment is critical. The combination of aftermarket and new vehicle sales equipped with 5.9 GHz DSRC or other communication technologies will more effectively produce benefits to the consumers. Furthermore, from the consumer perspective, only a system that provides immediate benefits will offer value. Without value, the envisioned USDOT Connected Vehicles systems and applications will not be accepted by consumers on its own merits.

This procurement guidance document is built upon insights shared in the State of the Industry and Vendor/Market Readiness Reports and developed with additional contents to discuss the needs and considerations of aftermarket OBE procurements. The purpose of the document is to assist government agencies in developing a procurement document to solicit the development of a dynamic configurable multi-band aftermarket OBE.

1.2 Report Layout

The following will offer a brief summary of chapters 2 thru 5 as an introduction to the more in-depth assessment provided in the remaining chapters of this report.

Chapter 2 will summarize the available literature on the requirements of the USDOT Safety Pilot Model Deployment project; the characteristics of and lessons that can be drawn from OBE developed for the Japan Smartway program; as well as similar devices developed by industrial players. This briefing ought to give the reader a cursory glance at the current capabilities of systems that have been used elsewhere and how they have informed our current expectations for system standards as we proceed.

Chapter 3 will discuss the OBE system definition and requirements in terms of intended usage by varying target users, components and subsystems, dynamically configurable multi-band wireless communication technologies and how the selection of wireless communication is dependent on the desired functionality of the OBE. This chapter is intended to give the contour of the technologies enmeshed in the OBE system and the ways they affect the concerted functionality of the composite design.

Chapter 4 will discuss the preliminary preparations that need to be managed in order to define the requirements of the OBE and ensure successful procurement processes. An outline of a procurement document that is in tune with the OBE definition in the context of this project will be offered as an example. Furthermore, functional blocks of a typical OBE module will be examined.

Chapter 5 will summarize the presented material and provide our suggestions on how to proceed with the procurement of an OBE module.

2 OBE Development Review

Many research projects in recent years have advanced the utilization of wireless communication technologies in Intelligent Transportation Systems (ITS). These projects have proven to be instrumental in leading to the developments of most requirements documented in current on-going projects like the USDOT Connected Vehicles program and the Japan Smartway program. Furthermore, industry has advanced their research efforts from development boards to prototype vehicle modules. This chapter will highlight OBE requirements and capabilities from the USDOT Safety Pilot Model Deployment and Japan Smartway program, as well as other industry developed modules.

2.1 Safety Pilot Model Deployment [1]

The USDOT Research and Innovative Technology Administration (RITA) has defined a significant test and evaluation effort—the Connected Vehicle Safety Pilot. The Connected Vehicle Safety Pilot Program is a scientific research initiative that features a real-world implementation of connected vehicle safety technologies, applications, and systems using everyday drivers. The effort will test performance, evaluate human factors and usability, observe policies and processes, and collect empirical data to present a more accurate, detailed understanding of the potential safety benefits of these technologies. This empirical data will be critical to supporting the 2013 National Highway Traffic Safety Administration (NHTSA) agency decision on vehicle communications for safety.

The vision for the Connected Vehicle Safety Pilot Program is to provide the world with a model deployment that demonstrates the transformative nature and benefits of connected vehicle technologies for safety and that can be further extended to support non-safety needs relating to mobility and environmental impacts. Safety Pilot is a major research initiative that involves several modes within the U.S. DOT, several vehicle manufacturers, public agencies, and academia.

The goal of Safety Pilot Model Deployment is to create a highly concentrated connected vehicle communications environment with vehicles "talking to each other." The onboard devices to be tested include embedded, aftermarket, and a "simple" communications beacon. All of these devices emit a basic safety message 10 times per second, which forms the basic data stream that other in-vehicle devices use to determine when a potential conflict exists. When the wirelessly transmitted data is further combined with the vehicle's own data, it creates a foundation for cooperative, crash avoidance safety applications. The details of such devices will be described in this section.

2.1.1 HIA (Here I Am) Device

HIA [2] device is an automotive grade electronic module capable of sending a "Here I Am" message based on the Basic Safety Message defined in SAE J2735-200911. The message is to be transmitted over a DSRC Link as defined in the IEEE 1609 suite and IEEE P802.11p D11.0, March 2010 standards. The automotive grade electronic module is intended for installation in various vehicles types ranging from light duty vehicles, whose weight is less than 10,000 pounds; to heavy duty class 8 trucks. This device will be installed in a vehicle without requiring connection to proprietary in-vehicle systems. It must be capable of sending the Basic Safety Message (BSM) as defined in SAE J2735-200911, over a DSRC 5.9 GHz wireless communications link. The device should be capable of data storage, message processing, and transmitting BSM.

- HIA device interfaces and functions:
    - Interfaces
        - Vehicle Interface: The device should connect to the Vehicle's power source using a Delphi Micro HVT connector (see Appendix A, Figures 3.0 and 3.1 in Reference [1]).
        - Local Systems Interface (LSI): The device should provide at least one of the following (non-DSRC) communications interfaces/mechanisms; USB Port, Ethernet Port, Wi-Fi Port, Wi-MAX Port, or SD Card. More interfaces can be implemented at the device maker's discretion.
        - Local Systems Interface – Protocol Support: The device should implement one of the IPv4/IPv6 protocol suites for any Category A LSI interface type as listed in SRD-USDOTHIA-002-ReqINT003v001.
        - DSRC Radio Interface: The device should implement one (1) 5.9GHz DSRC radio as called out in IEEE 802.11p and IEEE 1609.
    - Operation, monitoring and control: operational states, operation configuration, system message log, device positioning and timing, device security
    - DSRC radio subsystem: FCC compliance, radio count, IEEE 802.11, IEEE 802.11p, IEEE 1609.2, IEEE 1609.3, IEEE 1609.4, radio performance, congestion control
    - Message processing: BSM

2.1.2 VAD (Vehicle Awareness Device)

In 2011, the USDOT replaced references to "Here I Am" with the term "Vehicle Awareness". The VAD [3] device has the same functional capabilities as the HIA device and only transmits a safety message (position, speed, etc.). Therefore, VAD is an automotive grade electronic module capable of sending a "Vehicle Awareness" message based on the Basic Safety Message defined in SAE J2735-200911. The message is to be transmitted over a DSRC Link as defined in the IEEE 1609 suite and IEEE 802.11p 2010 standards. The automotive grade electronic module is intended for installation in various vehicles types ranging from light duty vehicles, whose weight is less than 10,000 pounds, to heavy duty class 8 trucks. This device will be installed in a vehicle without requiring connection to proprietary in-vehicle systems. It must be capable of sending the Basic Safety Message as defined in SAE J2735-200911, over a DSRC 5.9 GHz wireless communications link. The device should be capable of data storage, message processing, and transmitting BSM.

- VAD interfaces and functions:
  - Interfaces
    - Vehicle Interface: The onboard equipment device should connect to the Vehicle's power source using a Delphi Micro HVT connector (see Appendix A, Figures 3.0 and 3.1 in Reference [1]).
    - Local Systems Interface (LSI): The onboard equipment device should provide at least two of the following (non-DSRC) communications interfaces/mechanisms; one from Category A (USB Port, Ethernet Port, Wi-Fi Port and Wi-MAX Port) and one from Category B (Removable storage (e.g. SD Card)). (Only two interfaces are needed. More interfaces can be implemented at the device maker's discretion)
    - DSRC Radio Interface: The onboard equipment device should implement one (1) 5.9GHz DSRC radio as called out in IEEE 802.11p and IEEE 1609. If external antennae are used, the onboard equipment device should connect to the antennae using a USCAR18 FAKRA SMB connector male type Z for 5.9GHz DSRC and male type C for GPS (see Appendix A [1], Figures 3.2 and 3.3).
  - Operation, monitoring and control: operational states, operation configuration, transmitted message log, device positioning and timing, device security
  - DSRC radio subsystem: FCC compliance, radio count, IEEE 802.11, IEEE 802.11p, IEEE 1609.2, IEEE 1609.3, IEEE 1609.4, radio performance, congestion control
  - Other communications: Local Systems Interface – Protocol Support (IPv4 and IPv6), Secure Non-DSRC IP Communications (Transport Layer Security (TLS) v1.2, Internet Protocol Security (IPSec) for IPv4, Internet Protocol Security (IPSec) for IPv6, Secure Shell, v2 (SSH-2), SSH File Transfer Protocol v6), Non-DSRC IP Firewall Rules, Secure Non-DSRC IP Communications Account Password Reset
  - WSMP message processing: SAE J2735 Basic Safety Message (BSM)

2.1.3 USDOT ASD (Aftermarket Safety Device)

ASD [4] is an aftermarket safety device for automotive use that will be installed in light vehicles, which will be used in the vehicle communication safety pilot that must be capable of both transmitting and receiving using dedicated short range communications (DSRC) radios, using the 5.9 Gigahertz (GHz) band approved for DSRC use by the Federal Communications Commission (FCC), and implement the appropriate Institute of Electrical and Electronics Engineers (IEEE) and Society of Automotive Engineers (SAE) standards (IEEE 802.11p, IEEE 1609 family, and SAE J2735). The aftermarket safety device is intended for installation in light vehicles (i.e., vehicles whose weight is less than 10,000 pounds). The device will need to be safely mounted within the vehicle in such a position that does not distract the driver nor increase the risk to both driver and passenger safety while at the same time meeting the placement requirements (i.e. stationary positioning). It must be capable of sending and receiving the Basic Safety Message as defined in SAE J2735-200911, over a DSRC 5.9 GHz wireless communications link. It will also need to account for the positional differences among the antenna, ASD itself, and the vehicle location (center) as described in the Basic Safety Message. The ASD should provide similar functionality to the safety systems in the integrated vehicles participating in the Safety Pilot, including "Vehicle Awareness" functionality and mature safety applications.

- ASD interfaces and functions:
    - Interfaces
        - Local Systems Interface: The aftermarket safety device should provide at least one of the following mechanisms for the exchange of data to and from the device (USB Port, Ethernet Port, Wi-Fi Port, Wi-MAX Port, Bluetooth and Removable storage (SD Card))
        - Vehicle Power Connection: The aftermarket safety device should connect to the Vehicle's power source using a Delphi 064 Series connector.
        - Display: The aftermarket safety device should have a display for use as a human machine interface.
        - Speaker: The aftermarket safety device should have a speaker for use as a human machine interface.
    - DSRC Paired Radio Set: The aftermarket safety device should have two (2) 5.9GHz DSRC radios as called out in IEEE 802.11p and IEEE 1609
        - Optional Radio: The aftermarket safety device equipment should include one or more non-DSRC radios of the following types (3G Cellular and Wi-MAX).
    - Operations, management and control: operational states, operational configuration, system message log, device positioning, device security
    - DSRC radio subsystem: FCC compliance, DSRC radio count, IEEE 802.11, IEEE 802.11p, IEEE 1609.2, IEEE 1609.3, IEEE 1609.4, congestion control
    - Other communications: IP Based Connections (The aftermarket safety device should include one (1) IP based Ethernet connections for non-DSRC based communication links.)

- Message processing: DSRC Basic Safety Message, DSRC Collision Message, DSRC Map Data, DSRC Roadside Alert Message, DSRC SPaT (Signal Phase and Timing) Message, DSRC Traveler Information Message

In addition, USDOT's Safety Pilot Program have specified the selective types of ASD safety applications, including forward collision warning (FCW), emergency electronic braking light (EEBL), cooperative intersection collision avoidance system – violations (CICAS-V) and curve speed warning (CSW), based on vehicle-to-infrastructure and vehicle-to-vehicle communication via Dedicated Short-Range Communications (DSRC). Some of these applications have been implemented and demonstrated by automakers in Driver Clinics [1], for example. Each application's communication requirement is as follows:

- FCW communication requirements:
    - Using Communication Technologies: sensors, satellite, 3G/4G, Wi-Fi, 5.9 GHz DSRC (please see the State of the Industry Report)
    - Minimum frequency (update rate): ~ 10 Hz
    - Allowable latency: ~ 100 ms
    - Minimum data transmitted and/or received: position, heading, and velocity. Additional elements such as acceleration and yaw-rate would enhance the performance of FCW.
    - Maximum required range of communication: ~ 150 m
- EEBL communication requirements:
    - Using Communication Technologies: 5.9 GHz DSRC, satellite, 3G/4G, Wi-Fi (please see the State of the Industry Report)
    - Minimum frequency (update rate): ~10 Hz
    - Allowable latency: ~100 ms
    - Minimum data transmitted and/or received: position, heading, velocity, and deceleration
    - Maximum required range of communication: ~300 m
- CICAS-V communication requirements:
    - Using Communication Technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi (please see the State of the Industry Report)
    - Minimum frequency (update rate): ~ 10 Hz
    - Allowable latency ~ 100 ms
    - Minimum data transmitted and/or received: traffic signal status, timing, directionality, position of the traffic signal/stop sign stopping location, weather condition (if data is available)
    - Maximum required range of communication: ~ 250 m
- CSW communication requirements:

- Using Communication Technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi (please see the State of the Industry Report)
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Minimum data transmitted and/or received: curve location, curve speed limit, curvature, bank, road surface condition
- Maximum required range of communication: ~200 m

2.2 Japan Smartway OBE

Parallel to the Connected Vehicles Program (which evolves from earlier Vehicle Infrastructure Integration and IntelliDrive Programs) in the US, Japanese government agencies and industry have taken continuous initiatives over the last two decades to promote and implement Intelligent Transportation Systems (ITS). The latest and current program is called "Smartway" [5]. The Smartway program is built on the successful implementation of VICS (Vehicle Information and Communication System) [6] since the early 1990s and the high penetration of ETC (Electronic Toll Collection) transponders.

2.2.1 Published Standards

In conjunction with the Japan Smartway project, it is expected that more than 10 million units of onboard units will be shipped within 5 years [7]. These onboard units are provided by the OEMs and electronic industries in the form of an add-on device. While the functionalities of these units are not necessarily the same as intended for other programs around the globe, it is a respectable market force that can offer insights regarding the process of adopting aftermarket devices toward large-scale deployment.

The specifications of onboard units were developed in a manner of public and private cooperation. The national institute for land and infrastructure management (within the Ministry of Land, Infrastructure, Transport and Tourism) and 23 companies conducted joint research during the years of 2005-2007. Based on the outcome of this research, JEITA (Japan Electronics and Information Technology Industries Association) published standards [8] for the targeted onboard equipment. All private companies who wish to produce and provide these onboard units can ensure the interoperability with roadside units, ITS Spots, by following the published standards.

2.2.2 Brief Summary of Specifications of OBE for Japan Smartway

The JEITA standards referenced above contain detailed language on the functionality and construction of the onboard units. A brief summary is provided based on the review of the standards [9] for the DSRC section of the ITS OBE.

- OBE function and communication links
    - OBE includes VICS (FM, 2.4Gz, optical) communication
    - OBE includes navigation function

- 5.8 GHz DSRC also serves ETC
  - Communication protocols are based on ARIB STD-T75, STD-T88, ITS FORUM TC204
  - Communication link certification is based on SPF (Security Platform)
  - One-way and quasi-two way communication are allowed
- Standards provide or refer to other standards for the specifications of sub-systems or components, including:
  - Antenna
  - Receptor
  - Modulator
  - DSRC controller and processor
  - ETC processor
  - Basic application processor
  - Security platform
  - IC card reader interface
  - Human machine interface
  - Memory
- OBE construction:
  - Without sacrificing acceptance of IC card and user interface, the unit is to be made as small, compact, and light-weight as possible receptor
  - IC card reader should be robust in all temperature and vibration conditions
  - DSRC may be constructed as a separate body (Section 6.9)
  - Antenna installation on vehicle exterior should consider dust accumulation and water leakage
  - Antenna construction should be of small size, vibration resistant, and meet performance requirements
- Functions:
  - 5.8 GHZ communication with roadside unit for data exchange and payment transaction
  - Human Machine Interface: visual and auditory notification
  - Operation safeguard against malfunctioning, improper external communication or intrusion
  - Ability to switch between test mode and normal mode
  - Detection of roadside units and DSRC services offered by service providers are defined by Section 4.4.5 of STD-T75
  - Basic Application Processor (for applications offered by ITS Spots)

2.3 Similar Devices offered by Industry

This section provides descriptions of current DSRC and onboard devices that are relevant to the OBE within the context of this project.

2.3.1 Kapsch MCNU

The Multiband Configurable Networking Unit (MCNU) R1551 [10] is a wireless communication solution for transportation infrastructure. The MCNU is deployment ready and supports Vehicle Infrastructure Integration (VII) and industry common protocols for vehicle communications operating in the 5.9 GHz Dedicated Short Range Communications (DSRC) band.

- MCNU R1551 functions:
    - 5.9 GHz DSRC standard compliant: The MCNU R1551 communications are compliant with IEEE and SAE 5.9 GHz DSRC standards including IEEE 802.11p, 1609 standards and SAE J2735.
    - Licensed 4.9 GHz, Unlicensed 2.4 GHz and 5 GHz: The MCNU dual radio platform provides simultaneous communications in licensed and unlicensed frequency bands offering wireless broadband access to VII, Public Safety, Public Works and Public Access applications.
    - Secure Routing: The MCNU has two high-speed Ethernet ports to enable flexible routing between multiple wired and wireless IP subnets in the roadside network infrastructure. Built-in IPv4 and IPv6 firewall and VPN capabilities enable secure routing and tunneling through backhaul networks.
    - Deployment Ready: The MCNU is easy to deploy and installation ready. The MCNU management software provides a comprehensive SNMP-based network management solution for remote control of network configuration and performance monitoring.
    - Integrated GPS Positioning: The MCNU provides fast and accurate location information with its built-in WAAS enabled GPS receiver.
    - VII Application Interface: The MCNU open application interfaces allow a flexible and easy integration to the VII network services and transportation back office systems.
    - Web-based Configuration: The Web-based graphics interface allows for easy to use configuration of the MCNU platform.
    - WAVE Communications Test Software Suite: Built-in Communications Test helps to detect installation issues and provides information about wireless coverage, data transfer, and packet error rates.
- Kapsch MCNU R1551 applications: The MCNU supports transportation management, safety and security applications including support of Intelligent Transportation System (ITS) Vehicle Infrastructure Integration (VII) Initiative.
    - Electronic Toll Collection
    - E-Commerce

- Vehicle Safety/Crash Avoidance
- Emergency & Transit Vehicle Signal Preemption
- Traffic and Traveler Information
- Commercial Vehicle & Fleet Management
- Automotive OEM/Telematics

2.3.2 Savari MobiWAVE

MobiWAVE [11] is a wireless vehicular onboard unit, designed as a flexible open platform based on Linux for deploying Intelligent Transportation Systems (ITS) applications to improve mobility and safety on the roadways. The MobiWAVE on board unit is powered via the automotive cigarette lighter or a standard 110V connection. DSRC and Wi-Fi antennas are attached to the unit and do not require an external mount, as long as it is near the windshield. The magnetic mount GPS receiver can be attached to exterior of the vehicle for better reception.

- MobiWAVE functions:
  - Best-of-breed outdoor quality wireless radios: 600mw DSRC radio with transmit range over 50km (LOS) and -94dB receive sensitivity; 400mw Wi-Fi radio with transmit range over 50km (LOS) and -97dB receive sensitivity.
  - Variable channel widths: Support for 5MHz, 10MHz, 20MHz and 40MHz channel widths enables customizing throughput vs. range for applications.
  - GPS: Integrated SiRF Star III USB GPS enables location-based applications.
  - Integrated Bluetooth: Offers wide flexibility for in-vehicle devices. An ordinary cell-phone or PDA can be paired with MobiWAVE to be used as human interface. Cell-phone/PDA can also be used as a modem (via Bluetooth) to connect to 3G network.
  - Flexible backhaul options: Optional 3G modem enables continuous internet connectivity via 3G network. MobiWAVE seamlessly selects the best available uplink connectivity between DSRC, Wi-Fi and 3G at any given instance. Wi-Fi can be used in AP mode to share the 3G connectivity inside the vehicle.
  - Web-based management: Enables remote management and updates over the air (DSRC/Wi-Fi/3G) or through Ethernet.
  - Wireless software stack: IEEE 1609.3 and IEEE 1609.4 standards compliant WAVE protocol stack enables rapid development and deployment of ITS applications, providing interoperability with Kapsch TechnoCom MCNUs and Denso WSUs. IEEE 802.11 a/b/g/n standards compliant AP and Client mode software enables out-of-the-box interoperability with various commercial Wi-Fi APs and clients.
  - Security: Advanced wireless security features including WPA2, WPA, WEP, MAC Authentication and Radius Server based authentication plus IPSec and SSL for

application level security.
    - Easy-to-use, flexible SDK: Feature-rich libraries and header files for WAVE, IP, Web, GPS, Bluetooth, etc.
    - Touch-panel display: S200 model offers display and touch-panel functionality for touch-panel based HMI. Required software libraries are included in the SDK for easy development of touch panel interface.
- Savari MobiWAVE applications:
    - Electronic Payment: Toll collection, Open road tolling, Gas payment
    - Fleet/Mobile Device: Asset management/tracking
    - Mobile Router: In-Vehicle (bus, car, train) shared internet connectivity
    - Operations: Traffic congestion data collection, Weather data collection, Road surface conditions data collection
    - Enhanced Route Guidance and Navigation: Point of interest notification, Food discovery and payment, Map downloads and updates
    - Safety: Traffic signal violation warning, Curve over-speed warning, Emergency electronic brake lights, Pre-crash warning, Cooperative forward collision warning, Left turn assistant, Lane change warning and Stop sign movement assistance

2.3.3 Denso Wireless Safety Unit (WSU)

Denso's Wireless Safety Unit (WSU) [12] provides a hardware platform with an IEEE P802.11p radio interface plus the respective drivers, which perfectly integrates with OpenWAVE Engine. Originally, OpenWAVE Engine was initiated as ACUp (AKTIV Communication Unit - 802.11p) by BMW Group Research and Technology within the German research project AKTIV. The ongoing further development (named OpenWAVE Engine) aims at speeding up the European standardization activities. It is therefore intended to be provided to interested projects and partners as a highly efficient and easily extendible communication platform.

- Denso WSU functions:
    - Single board computer and 5.9 GHz DSRC radio
    - Supports IEEE 802.11p, IEEE 1609.2, IEEE 1609.3, IEEE 1609.4
    - Single automotive connector: power, ignition sense, RS-232 (GPS/PPS/serial data), CAN, Ethernet, USB, GPIO
    - Dual RF FAKRA connectors for antenna diversity
    - WSU 1.0 software base (Linux 2.6.11 OS)
    - Hosts application and framework modules
    - Provides an API for additional applications
    - Start-up on ignition, graceful shutdown
- Denso WSU applications:
    - Forward Collision Warning

- Lane Change Assist
  - Intersection Movement Assist
  - Electronic Emergency Brake Light (EEBL)
  - Curve Over-speed Warning (speed distribution, or min curve speed methods)
  - In-vehicle signage applications (speed limit, construction zone, or other)

2.3.4 ITRI WAVE/DSRC Communication Unit (IWCU)

ITRI WAVE/DSRC Communication Unit (IWCU) [13] is an integrated wireless communication system designed for deploying Intelligent Transportation Systems (ITS) applications and improving traffic safety on the roadways. IWCU 4.0 OBU is a WAVE/DSRC communication equipment mounted in a vehicle. It supports automotive grade operating temperature range from -40° C to +85° C. The IWCU is compliant with IEEE 802.11p and IEEE 1609, known as the WAVE/DSRC standards and also ETSI Europe ITS standards. With these capabilities, it can support many different types of communication including intra-vehicle, vehicle-to-vehicle (V2V), vehicle-to-roadside (V2R). The IWCU also provides software development kit (SDK). Using the SDK tools, many ITS applications can be developed easily on this flexible open platform. The IWCU satisfies all things the next-generation ITS communication needs.

- IWCU functions:
  - Support IEEE 802.11p & IEEE 1609 compliant WAVE/DSRC protocol stack
  - Support ETSI TC ITS CAM, DENM, BTP, GN6, GN, ITS-G5A compliant protocol stack
  - Support SAE J2735 Basic Safety Messages (BSM)
  - Provide SDK tools and documentation
  - Support automotive grade operating temperature range from $-40^{\circ}C$ to $85^{\circ}C$
- IWCU applications:
  - Cooperative safety applications (road construction warning, car accident warning)
  - Electronic Emergency Brake Light (EEBL)
  - Electronic Toll Collection (ETC)
  - Vehicle Group Communication Application
  - RSU Management System

2.3.5 NEXCOM VTC 6200

NEXCOM's [14] popular VTC Series range has been extended with the launch of VTC 6200, a dedicated computing solution for in-vehicle surveillance applications. The VTC 6200 utilizes the powerful video processing capability of the Intel® Atom™ D510 processer which can support Dual Core technology. With additional Video Capture Module, VTC 6200 is another solution for in-vehicle surveillance applications.

- NEXCOM VTC 6200 functions:
  - Internal wireless communication (3.5G, GSM/GPRS, WLAN, Bluetooth)

- Smarter ignition power on/off, delay-time and low voltage protection
- PCI104, MiniPCIe socket, and proprietary PCIe module expansion
- 8~60V wide range DC power input
- Dual VGA output (clone mode)
- Rugged fanless design to meet IP65 and MIL standard
- Flexible chassis design for PCI-104 and HDD can be used at the same time
- Support 2 x isolated RS-232 ports (COM1, COM2)
- Isolated GPIO

- NEXCOM VTC 6200 applications:
    - Support video surveillance or mobile VDR applications within vehicles such as trains, buses, boats and trams

3 OBE System Definition and Requirements

In this section, we offer a description of essential requirements for onboard equipment. We start by discussing how OBE system requirements are tied into the considerations of target users, vehicle platforms, and operating scenarios.

3.1 Target Users and Vehicle Platforms

In order to properly define the requirements for OBU, the intended operating environment and target users should be thoroughly considered. This is critical because the functionality and application requirements are dictated by users' needs, and the success of implementation is fully dependent on users' experience. The factors most relevant to users and vehicle platforms that should be taken into account in defining the requirements of OBE's are discussed below.

3.1.1 Operating Conditions

The performance of the OBE, and in turn the specifications, are strongly dependent on the following operational parameters:

- Geographical regions and operating environment

  This type of operating parameters affects the ability of the onboard unit to accurately and successfully update its position or transmit data when it is required.
    - For example, in urban canyon settings, the GPS system may not perform adequately to provide accurate or timely position data that are required for OBE to perform the embedded applications properly. If this is a concern, then the specifications of OBE must contain descriptions of countermeasures when the unit is operating under such degraded conditions.
    - As another example, if OBE utilizes a wireless communication link that has the risk of not performing adequately, then the malfunctioning mode or degraded mode must be addressed. These conditions may include, for example, DSRC not in

line-of-sight, out of range, or cellular connectivity not present in rural or mountainous areas.
  - As a further example, weather conditions (snowy, rainy, windy, temperature range, etc.) may pose particular threats for equipment installations and operations.

- Roadway types

  OBE-equipped vehicles are likely required to operate on freeways, arterials, local streets, and near or at intersections. Potential risks of operations may include the following exemplar scenarios:
  - If there is an application that utilizes traffic conditions, data on arterials are subject to greater local variations at signal-controlled intersections and traffic information may not be as widely available as for freeway segments.
  - There are a number of intersection related applications that can be enabled by V2V or V2I communication, such as signal priority for transit vehicles and red-light-running warnings for all vehicles. For this type of applications, the OBE needs to communicate in a timely manner with roadside equipment (RSE) or the traffic signal controller to obtain the signal phase and timing (SPaT) information, which may only be available at selective locations.

3.1.2 Vehicle Platforms and Users

The performance of OBE, and thus their specifications accordingly, are heavily dependent on the following operational parameters:

- Vehicle platforms

  The consideration of vehicle fleets heavily influences the targeted applications and equipment requirements.
  - For specialized fleets of heavy vehicles, as documented in the earlier Vendor/Market Readiness Report, a focus group of professional drivers indicated preferences for safety-oriented applications because of the heavy workloads associated with operating commercial vehicles for long hours.
  - For transit buses, for example, the time saving features of providing signal-priority at intersections may be of much greater interests.
  - For police fleets, the connectivity with back office database for online download of driver and vehicle information while being kept informed of the whereabouts and of other officers in duties may be of high priorities.
  - For general public, receiving various types of Telematics services such as traveler information, vehicle diagnostics and maintenance, traffic conditions, or parking will be relatively important to users.

- Equipment Compatibility

  Associated with vehicle platforms, the specifications of OBU may vary. For example,

  - The regular passenger cars today may have a built-in navigation system or the user may have opted to have a portable navigation device. In this case, if the OBE has a human-machine interface that will issue visual or auditory signal when the applications are in effect. A mechanism should be provided to accommodate one or the other to avoid repetition or interference. Similar countermeasures should be put in place for onboard audio systems, when auditory signals are provided by the ASD.
  - Some commercial vehicles may be installed with aftermarket collision-avoidance systems that include a suite of sensors and a human-machine interface. Others may also have existing wireless backhaul connectivity for fleet management purposes. These onboard devices or systems may supplement or interfere with the functional operations of ASD.
  - Electro-magnetic interference is a typical issue that should be sufficiently addressed when additional radio or communication links are brought into a vehicle.
  - Power supply or antenna installation understandably will vary with specifications or constraints that are particular to different vehicles.
- User Groups

  Even for the same vehicle platform, the OBU requirements must be tailored for the targeted user groups to ensure positive user feedback and maximal utilization. The considerations of user groups may include the following factors:
  - User demographics, such as age, gender, driving experience, and their prior exposure to in-vehicle electronic technologies will affect their perceptions of the usefulness and functional performance of OBU and associated applications.
  - Professional drivers, such as commercial vehicle and transit drivers are different from general public users as they focus on performing the driving responsibilities for others and carrying out their assigned duties. Their preferred functionality or services may tend to be more focused on specific operating conditions rather than the diversity in user demands from a large group of general users.

3.2 Component and Sub-System Overview

A typical OBE will include the sub-systems and components highlighted below.

3.2.1 CPU - Current commercial product capacity: 400 MHz ~ 1.6 GHz

The Central Processing Unit (CPU) is the portion of an OBE system that carries out the instructions of a system program, to perform the basic secure, arithmetical, logical, and input/output operations of the system. The CPU plays a role somewhat analogous to the brain in the OBE.

3.2.2 Memory - Current commercial product capacity: 64 MB ~ 2 GB

In OBE, memory is the ability of an organism to store, retain, and recall information and experiences. In addition, memory can be used for reliability and robustness to the environmental conditions expected in the vehicle environment.

3.2.3 Storage - Current commercial product capacity: 64 MB ~ 4 GB

In OBE, storage refers to computer components and recording media that retain digital data. In addition, storage refers to storage devices and their media not directly accessible by the CPU, (secondary or tertiary storage), typically hard disk drives, optical disc drives, and other devices slower than RAM but not volatile (retaining contents when powered down) [15]. Some other examples of secondary storage technologies are: flash memory (e.g. USB flash drives or keys), floppy disks, magnetic tape, paper tape, punched cards, standalone RAM disks, and Iomega Zip drives.

3.2.4 Communication interfaces

OBE system may provide and support multiple communication interfaces (e.g., DSRC radio, 3G/3.5G, Wi-Fi, Bluetooth and 10/100 Mbps Ethernet) for V2V or V2I applications. The detailed contents will be described in Section 3.3.

3.2.5 CAN bus interface

Controller Area Network (CAN) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. CAN is a message-based protocol, designed specifically for automotive applications but now also used in other areas such as industrial automation and medical equipment. CAN is one of five protocols used in the OBD-II vehicle diagnostics standard. The OBD-II standard has been mandatory for all cars and light trucks sold in the United States since 1996, and the EOBD standard has been mandatory for all petrol vehicles sold in the European Union since 2001 and all diesel vehicles since 2004.

3.2.6 GPS - Current commercial product capacity: Accuracy: 5m RMS (Root-Mean-Squared) with WAAS (Wide Area Augmentation System) ~ 10m RMS without WAAS

In general, OBE system uses a combination of internal and external GPS (Global Positioning System) receivers. Therefore, the OBE GPS module should provide a suite of positioning services to the other onboard services and applications based on the output of the external (primary), or internal (secondary) GPS receiver. The internal GPS receiver is used primarily to provide an accurate time base for the DSRC Radio; however, it also is available for use as a back-up source of positioning information. The external GPS receiver is used to track the position of the vehicle between GPS position reports by keeping track of distance and heading changes, and extrapolating a position fix from the last known fix.

A GPS module will be utilized to determine the position of the host vehicle. Positional information will be used in conjunction with a dynamically created digital map to provide information related to false alarms, roadside objects, and roadway geometry. Therefore, the GPS module should provide the following features:

- Access to the latest GPS position

- Position listeners for both the GPS position (received every second) and the extrapolated position (calculated every 100 ms)
- Polygon listeners – A polygon is represented as the list of points that define its edges. All polygons must be simple in the mathematical sense: two edges must never intersect
- Circle listeners – A circle is represented as a center location and a radius.

3.3 Dynamically Configurable Multi-Band Wireless Communication

With the advance of wireless communication, multi-band OBEs have become highly desirable. For an OBE, there are four popular wireless communication interfaces, such as DSRC, 3G/3.5G, Wi-Fi and Bluetooth. The characteristics of these communication links have been fully discussed in the earlier State of the Industry Report. Some detailed features of the communication links are further described in this section.

- Dynamic interface switching

The OBEs need to switch multi-band wireless communication interfaces dynamically, depending on its application requirements. The timing of switching the interface depends on multiple factors – transmission range, data rate, reliability, power consumption, scalability, and others.

- From the point of view of transmission range, if the distance between the sender and receiver exceeds the DSRC transmission range (around 500m~1000m), data can be transmitted and switched smoothly through 3G/3.5G interface.
- For inter-vehicle communications, the drivers can set a default communication interface (such as DSRC for safety purpose). If the drivers want to access Internet backbone, the OBE can switch to Wi-Fi interface dynamically.

- DSRC interface

Strength: low latency, high mobility, free communication costs

Weakness: low bandwidth, limited coverage

- In Dedicated Short-Range Communication (DSRC) interface, it uses a short to medium range communication technology operating in the 5.9 GHz range. It was established for services involving vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications. The Standards Committee E17.51 endorses a variation of the IEEE 802.11a MAC for the DSRC link. DSRC supports vehicle speeds up to 120mph, nominal transmission range of 300m (up to 1000m), and default data rate of 6Mbps (up to 27Mbps). The 5.9 GHz DSRC latency is three orders of magnitude lower than other existing wireless technologies. It appears to uniquely meet the basic communications requirements for most of the vehicle safety applications. This will enable operations related to the improvement of traffic flow, highway safety, and other ITS applications in a variety of application environments called WAVE/DSRC.

- 3G/3.5G interface

Strength: high bandwidth, wide coverage, high mobility

Weakness: high latency, requires communication costs

- In 3G/3.5G interface, it refers to the set of standards for mobile phones and mobile telecommunication services fulfilling the International Mobile Telecommunications-2000 (IMT-2000) specifications by the International Telecommunication Union. Application services include wide-area wireless voice telephone, mobile Internet access, video calls and mobile TV, all in a mobile environment. To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200 Kbit/s. The "always on" packet data capabilities of the 3G cellular technologies will virtually eliminate the call set-up delays of data connections over current cellular systems. However, end-to-end latency is likely to remain in the range of at least several seconds, due to the server processing required in the mobile location registers, and the multiple packet forwarding necessary to deliver data to/from dynamically changing cellular sites. As well, data communications over these networks tend to be of a lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. These latency limitations will likely preclude the use of cellular communications for the majority of the vehicle safety applications.

- Wi-Fi interface

Strength: wide deployment, easy configurations, cost savings

Weakness: limited coverage, high latency, high mobility cause high packet loss rate

- In Wi-Fi interface, it follows the IEEE 802.11 series specification to support wireless LANs. Both 802.11a and 802.11b (depending upon data rates required) could potentially support the inclusion of vehicles within the range of wireless home LANs. Such home systems could provide extensive data downloads to garaged vehicles, as well as allowing the vehicles to download non-time-critical information to wider area networks. At the present time, 802.11b systems are rapidly being deployed for home, office and public area LANs. These developments offer the opportunity for 802.11b-equipped vehicles to upload and download data through these wireless LANs while the vehicles are within range of the "hot spots". In addition, when a car connects via a Wi-Fi AP, it can potentially transfer data at the same rates as static clients connected to the same network. However, as cars move at high speed rate, their connectivity is both fleeting (resulting in high packet loss rates and usually lasting only a few seconds at urban speeds), and intermittent, with gaps from dozens of seconds up to several minutes before the next time they obtain connectivity.

- Bluetooth interface

Strength: low power (consumes less battery), low cost

Weakness: high latency, low speed, limited coverage

  - In Bluetooth interface, it uses a proprietary open wireless technology standard for exchanging data over short distances (using short wavelength radio transmissions in the ISM band from 2400-2480 MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security. Bluetooth may serve as a vehicle-to/from-infrastructure communications channel for stationary vehicles in close proximity to the desired communications point. Although the operational parameters of Bluetooth in terms of range and latency preclude its ability to support most of the identified vehicle safety applications, it may still be used to enhance safety related tasks, for example, updating navigational databases while the vehicle is parked in the garage. The range limitations that prevent the use of Bluetooth to support vehicle safety applications, however, would not prevent it from supporting commercial applications like electronic payments at fast food drive-thrus, or entertainment-related communications between a vehicle and the owner's home infrastructure. In addition, Bluetooth allows transfer speeds of up to 1 Mb/s.

- Summary

The vehicular application choice of which wireless communication interface to use will always involve making trade-offs among multiple factors – cost, coverage range, data rate, reliability, power consumption, technology life, scalability, and others. For example, 5.9GHz DSRC (suitable for time-critical safety vehicular applications) is meant to be a complement to cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones are important. Short-range wireless protocol such as 5.9GHz DSRC is suitable for efficiency applications such as payment applications. 5.9 GHz DSRC will also work for electronic toll collection (ETC) even though the majority of ETC in US today uses 915 MHz DSRC. In addition, Bluetooth allows transfer speeds of up to 1 Mb/s, which is suitable for entertainment applications (e.g., music sharing), despite its short range. Cellular communication is widely available therefore making it an ideal technology for implementing telematics services, where the latencies caused by network delays are tolerable. The comparison of various wireless communication interfaces for different applications is shown in Table 3.1.

Table 3.1 Comparison of Wireless Communication Interfaces for Different Applications

Interfaces / Applications	DSRC	3G/3.5G	Wi-Fi	Bluetooth
Safety	A	C	C	C
Efficiency	B	B	B	B
Comfort/ Entertainment	C	A	A	A

A: Very suitable; B: Suitable; C: Inappropriate

3.4 OBE Functionality and Wireless Technologies

As discussed in the State of the Industry Report the functionality and wireless communication links are deeply associated with one another. The particular selection of communication sub-systems will be determined by the desired functionality of the OBE system. Safety features often require different functionality than convenience features, which can drive the use of different wireless technologies. The wireless technologies evaluated are DSRC 5.9 GHz, Satellite, 3G/4G, Wi-Fi, and Bluetooth.

Signal range, latency period, and connectivity are all important considerations in terms of functionality. Each wireless technology's strengths and weaknesses have been discussed above. As a brief recap, DSRC 5.9 GHz is best suited for most time critical safety features, which require short latency periods. 3G/4G is well equipped for convenience functions and many non-time critical safety features. Wi-Fi is appropriate for convenience features that do not necessitate constant connection. Users can access Wi-Fi connection in home garages or at public access points, where they are able to download and/or upload useful information (e.g. up-to-date maps). Bluetooth can be utilized in various short-range convenience features for wireless information transfer between device (e.g. cell phone) and vehicle.

The appropriate combination of these technologies to achieve determined user needs and wants is dependent on whether the functionality of the system is more safety or convenience oriented. Some OBEs such as those in the USDOTs Safety Model Pilot program are geared toward safety, while others, such as telematics devices, are largely meant to provide convenience features to the user.

4 OBE Procurement Requirements

4.1 Preliminary Steps before Generating Procurement Document

Prior to developing the contents of a procurement document for OBE, some preliminary preparations will be beneficial to adequately define the requirements of the OBE as well as to ensure a successful outcome from the procurement process. Certain factors for considerations are discussed below.

4.1.1 Deployment Background

As discussed in Section 3.1, the OBE needs to be tailored to the geographical regions, operating environment, target users, user needs, and vehicle platforms. It is essential that such background information be sufficiently gathered and documented before the functionality and sub-systems of an OBE can be properly specified.

4.1.2 Purpose of Testing and Deployment

The expected outcome of procuring and installing OBE on test vehicles is dependent on the usage of the procured OBE. For example, the goals and objectives will be drastically different for field operational tests and commercial deployment. In field operational tests, the intent will be focused on extensive data collection for later analysis to verify the validity of operational concepts and the robustness and reliability of embedded applications. On the other hand, in commercial deployment, the goals will be more oriented toward positive user experience and effective business cases. In field operational tests, data collection capabilities of OBE and accompanying systems will be far more critical than other considerations. For commercial deployment, on the other hand, the sophistication of human interface and packaging finish will carry more weights.

4.1.3 Operation Scenarios and OBE Performance Specifications

Some in-depth descriptions for operation scenarios beyond the background factors will need to be more explicitly described for procurements. For example, imagine that a V2V safety application is to be implemented on an OBE. If users are driving such equipped vehicles in real world environment among a large number of unequipped vehicles, the drivers will have to adapt and become accustomed to somewhat infrequent activation of the V2V safety application and rely on his/her diligence to operate safely when the application is not functional due to being surrounded by unequipped vehicles. Even though users can be informed in advance about these situations when application may or may not function, user experience and expectation unavoidably will be meaningfully affected by the sometimes-on or sometimes-off situations under similar driving conditions.

To address these situations, the technical requirements of OBE in various operating conditions will have to be defined properly for normal, unexpected, degraded, and malfunctioning scenarios. Accordingly, the performance requirements of OBE and associated applications will have to be adequately described within the procurement document to provide a clear set of criteria to evaluate and certify qualified products. Irrespective of application types, performance specifications for technical sub-components as well as execution of applications in various operating scenarios should be laid out thoroughly so that vendors can pre-test and validate the reliability of their products.

4.1.4 Survey of Target Users and Assessment of User Needs

Following the discussions in Section 3.1 about vehicle platforms and user groups, we will reiterate that there are preferences and concerns associated with different "targeted customers" of OBE. A deep understanding of users' needs will allow better alignment of overall project objectives and final outcome of OBE usage and deployment in the field.

4.1.5 Market Status and Vendor Readiness

The use of wireless communication for vehicle based applications is a relatively dynamic market and the potential vendors are likely to update their offerings in a rapid pace. While in earlier reports the research team has documented the current market status, it will be advantageous to communicate with known vendors or conduct an updated search to learn about the latest developments in the field. Relevant and somewhat critical to the procurement of OBE is the price range and cost basis in the prevalent market place. Via preliminary discussions with multiple potential vendors, the availability of OBE in a targeted cost range will allow a better definition of components and capabilities that can be successfully procured.

4.2 Outline of an OBE procurement document

This section will walk through a high-level outline of a procurement document for a standard OBE module. The intent is to provide government agencies a guideline that can be used when developing an OBE procurement document specific to their requirements. The outline is split up into six sections with each section containing factors relevant to a Request for Proposal (RFP).

4.2.1 Procurement Schedule

To begin the RFP document it is important to state the planned procurement schedule for the project. The schedule should be clear with regards to key milestones and specific dates associated to the milestones. Below are typical milestones that should be part of an OBE procurement document.

- RFP Issue Date – Document issue date to potential suppliers.
- Submission of Written Questions – Milestone when suppliers must submit all questions relevant to the issued RFP.
- Written Question Response – Planned date when responses to all questions will be sent out to all potential suppliers.
- Proposal Due Date – Milestone when all potential suppliers must submit their response to the RFP.
- Selection of Preferred Supplier(s) – Date when preferred suppliers will be awarded the contract.
- Project Start – Official start date of the project.

4.2.2 Project Scope and Requirements

In this section the project scope and requirements applicable to an OBE module will be reviewed. It is critical to clearly document the scope and requirements specific to the OBE module in order to minimize or eliminate any confusion during the response of the RFP. The following areas will assist in clearly defining the project.

- Module Delivery Schedule - This schedule will define each phase of the project where modules are expected to be delivered to the customer. The type of module should be specified for each phase (i.e. non-functional samples for packaging study) so the supplier can plan appropriately. Also, the quantity of modules and date they must be received should be specified for each build phase.
- Certification Testing – It is important to specify what certification testing will be performed. The number samples that will be certified. When and where certification testing will be conducted and a single point of contact for certification testing. If the vendor offers some pre-existing certification, details about the testing must be provided. Having a pre-existing certification may or may not exclude a vendor's device from certification testing.
- Engineering Support – This section will provide detailed information to suppliers with regards to what type of engineering support will be expected during the entire program. The engineering support should be specified as on-site or on-call support and should correlate to the build phases identified in the module delivery schedule.
- Program Schedule – In the RFP there should be an overall program schedule, which contains all of the project phases and milestones required for the program. This overall schedule will assist the suppliers in the planning and execution of the program.
- Requirements – The requirements section should state what specifications the devices must meet. It is important to include all specifications as attachments to the RFP when issued to potential suppliers. If there are specific requirements not stated in a specification it should be included in this section of the RFP.

4.2.3 RFP Requirements

The main purpose of the section is to document what specific requirements must be met or followed with regards to submission of responses to the RFP. The requirements below are a guide and should not be considered all-inclusive since RFP requirements will vary from customer to customer.

- A comprehensive solution to achieve the objectives provided
- A statement acknowledging the supplier's understanding of the scope of RFP
- The supplier must provide a unit price based on the device deliverables
- The supplier must warrant its products/services to the requirements and objectives in the RFP
- The supplier must provide delivery schedule for the fully functional devices and identify potential bottlenecks.
- Prices quoted will be firm for a minimum of a specified time period
- The supplier is expected to complete documents provided

- Products and services are to be quoted F.O.B.

4.2.4 Submission Directions

The submission directions should focus on the supplier's intent to respond to the RFP. The content in this section should answer questions regarding the formal submission process. There should be a single point of contact identified to answer any questions regarding the submission of the RFP document. Also, the customer should document their rights and any restrictions associated with the RFP process.

4.2.5 Evaluation Criteria

In this section it is important to define what criteria the RFP's will be assessed on. Below are typical aspects to consider in the evaluation process. Each agency should review their procedures and processes to develop the appropriate criteria for their respective project.

- Ability to meet the functional requirements of this RFP.
- Willingness to comply with the proposed agreement.
- Commitment and experience in successfully performing similar agreements.
- Adherence to industry standards.
- Compliance to the proposed delivery schedule.
- Lead times and their impacts on delivery schedules.
- Overall product quality including the results of product testing.
- Price, price protection and total cost of ownership.
- A viable manufacturing plan
- Value added proposals.

4.2.6 RFP Submission Format

Guidelines for the submission format of the RFP should be specified to assist the suppliers during the submission process as well as for agencies during their review of the proposals. The format should conform to an agency's guidelines. Below is general format as a reference.

- Title Page
- Table of Contents
- Executive Summary
- Scope of Proposed Solution
- Company Background and Customer List
- Client References
- Exceptions to the Agency's Terms and Conditions
- Response to Equipment Specifications
- Cost Proposal
- Comprehensive List of Assumptions
- Project Staffing/Resumes

4.3 Functional blocks of an OBE "module"

As discussed in Section 3.2, an OBE module should include several components, such as CPU, memory, storage, communication interfaces, CAN bus interface, GPS, etc. This section describes guidelines to define requirements for each of the OBE module.

- CPU requirements
    - For security applications, the OBE should choose more powerful CPU (e.g., 1.6 GHz) due to high computing needs.
    - For general purpose applications that do not need high computing power (e.g., electronic payment), the OBE can choose slower CPU (e.g., 400 MHz) to execute program instructions.
- Memory requirements
    - For GIS (Geographic Information System) and digital map applications, the OBE should support large memory (e.g., 512 MB) to store and operate the geographically referenced data.
- Storage requirements
    - The OBE should support large storage space (e.g., 4 GB) for the logging of transmitted 802.11 frames in log files (Enables comparison of transmitted and received packets during post-test analysis).
- Communication interfaces requirements
    - DSRC radio interface:
        - For time-critical, short-range (500m~1000m) and safety applications, the OBE should support 5.9GHz DSRC (Dedicated Short Range Communications) radio as called out in IEEE 802.11p and IEEE 1609.
    - Ethernet interface:
        - For wired communication applications (e.g., Internet access), the OBE should support Ethernet interface (e.g., 10/100 Mbps).
    - 3G/3.5G interface:
        - For non-time-critical, large-file transfer (e.g., CD, DVD, movies) and long-distance applications, the OBE should support 3G/3.5G interface.
        - For future generations of products, Long Term Evolution/4G will become available.
    - Wi-Fi interface:
        - For non-time-critical and AP mode applications (e.g., hot-spot), the OBE should support Wi-Fi interface.
    - Bluetooth interface:
        - For low-power, short-range (10m) and entertainment applications (e.g., music sharing, hands-free telephony), the OBE should support Bluetooth interface.
- CAN bus interface requirements

    - The CAN bus can be used in vehicles to connect engine control unit and transmission, or (on a different bus) to connect the door locks, climate control, seat control, etc. For safety (e.g., emergency electronic braking light (EEBL)) applications, the OBE should get braking signal through CAN bus interface.
- GPS requirements
    - For time-critical and safety application, the OBE should support fast and accurate location information with its built-in WAAS (Wide Area Augmentation System) enabled GPS receiver. (Accuracy: 5m RMS (Root-Mean-Squared) with WAAS ~ 10m RMS without WAAS)
    - The OBE should, for any OBE using a GPS receiver as part of its positioning service, be configurable (default to ON) to use WAAS corrections. (To increase the accuracy of positioning information.)
    - The OBE should maintain a system clock based on timing information from the GPS receiver. (To increase the accuracy of timing information.)

4.4 Notable Related Activities in Other Regions and Sectors

Similarly inspired by the leapfrogging advancements of computing and communication technologies, many regions and sectors around the world are pursuing the developments of cooperative vehicles and roadways aggressively. European commission spearheaded multiple-year projects on the co-operative systems under several stages of the Research Framework Programs [16] (e.g. SESAR project, Marco Polo project, etc.). To facilitate harmonized and efficient utilization of low latency communication, in 2008 the Commission adopted a decision to reserve the 5.9 GHz band for safety related ITS applications [17]. The core services include optimized speed and route recommendations, alerts and warnings on speed limits, weather, road works, traffic jams, and accidents, dynamic bus lane allocation, access control, optimized delivery logistics, truck rest area parking information and reservation, etc. The industrial participants established the car-2-car association [18], promoting a common industry-wide approach. The opportunities exist to convert existing market devices into OBE modules to achieve desired functionalities. An example of this is the Japan ITS OBE, which evolved from a VICS/ETC product to include additional ITS applications. Existing hardware and wireless capabilities have the potential to transform into next generation ITS products. The key to this transformation is the development of OBE hardware that is forward compatible and can evolve through software updates.

Aside from the coordinated efforts by government bodies globally to explore and promote the use of wireless communication to enhance safety and mobility, various commercial sectors have made considerable progress in the last two decades to advance the realization of connected vehicles. This has been particularly noticeable in the field of Telematics in conjunction with onboard infotainment systems. For example, since the introduction of

OnStar® [19] in the 1990s, a number of car manufacturers [20-23] and their affiliated service providers now offer safety, security, navigation, remote diagnostics, and personal services with a combinational use of wireless communication, GPS, and onboard sensing and control capabilities. The frontier of such applications are advancing at an increasing pace as various manufacturers continue to offer features and state-of-the-art personalized mobile experience in vehicles [24, 25]. For example, applications originally created for mobile devices can now be linked seamlessly and become part of the in-vehicle infotainment systems [26, 27]. With the explosive growth in onboard connectivity, mobile applications are now becoming an integral part of the vehicle environment, and are vigorously pursued by many technology providers [28, 29]. The availability of these applications and services and their associated onboard units should be compared and considered in the procurement of an OBE module.

5 Conclusions

This guidance report has summarized several important areas surrounding the procurement of OBE modules, from the review of current projects, the OBE definition/requirements, and the OBE procurement requirements. Each of the areas mentioned contain relevant information agencies can use to assist in the development of OBE procurement documents for their respective ITS projects. The key take-a-ways for each area are listed below.

With regards to the literature review both the Safety Pilot Model Deployment and Japan Smartway OBE projects are important research initiatives agencies can reference when developing their specific OBE programs. Also, there are several devices throughout the industry developed by Kapsch, Savari, Denso, ITRI, NEXCOM, and others that can be the evaluated during the development of an RFP proposal. The research projects and industry devices provide a solid foundation for any type of OBE module development or deployment being plan by agencies over the next few years.

The OBE definition and requirements section provides an in-depth review of what is required in a typical OBE module (e.g., CPU, memory, storage, communication interfaces and GPS). The relationship of the OBE system requirements to target users, vehicle platforms, and operating scenarios is clearly expressed. In addition, the OBE system needs to switch multi-band wireless communication interfaces (e.g., DSRC, 3G/3.5G, Wi-Fi and Bluetooth) dynamically, depending on its application requirements. This detailed review is a beneficial guide that can be referenced during the development of a particular OBE module for an agency project.

The flow of the OBE procurement requirements section is set up to guide the development of an OBE RFP document. It is important to begin with the proper definition of the desired OBE module. Once the project is defined the outline of the OBE procurement document can be developed. Supporting documentation such as a the functional blocks of an OBE module and reference to other noteworthy activities related to OBE development have been provided to assist in the completion of the OBE RFP.

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