Enabling Accelerated Installation of Aftermarket On-Board

Equipment for Connected Vehicles

FINAL PROJECT SUMMARY FOR MW121310A

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for
University of Virginia
Cooperative Transportation System Pooled Fund Study

Enabling Accelerated Installation of Aftermarket OBE –

Summary of the Project (UVA RFP#: MW121310A)

Introduction

The goal of this project was to evaluate the potential approaches for accelerating the introduction of aftermarket OBE devices to the vehicle fleet. Without a rapid deployment, the safety, mobility, and efficiency benefits of the USDOT Connected Vehicle Research Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the penetration expedient enough for maximum benefit. Therefore, aftermarket deployment is critical. The combination of aftermarket OBE devices and new vehicles equipped with 5.9 GHz DSRC or other communication technologies will more effectively produce benefits to the consumers. The four deliverables for the project are described below:

Task 1: A State of the Industry Report

The report analyzes and compares the current available communications technologies using literature reviews, related reports, and expert opinions as inputs for the analysis. In addition, the wireless technologies and applications commonly used by different modes of transportation including light passenger vehicles, transit vehicles, and heavy trucks are examined. Finally, the report compares various communication technologies in different application service scenarios to determine the key functions and requirements.

Task 2: Vendor/Market Readiness Report

The report summarizes industry's views of the current market readiness through interviews conducted with OEM, Tier 1, and Tier 2 experts. In addition, the availability of OBE hardware manufacturers to provide aftermarket dynamic configurable multi-band OBE product has been documented. Finally, the report captures consumer insight through focus groups on product attributes, unmet consumer needs, aftermarket OBE pricing, time to market for OBE applications, and where to distribute aftermarket OBE products.

Task 3: Procurement Guidance Document

The 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 content 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.

Task 4: Strategic Report Summarizing Recommended Actions

The report provides a summary of previous findings as well as any recent developments with regards to rapid introduction of aftermarket OBE devices to the vehicle fleet. An integration assessment for aftermarket OBE devices is discussed. In addition, an analysis of outside market forces that may affect driver adoption of connected vehicle technologies is shared. Finally, recommendations are provided for strategic approaches to foster the rapid introduction of aftermarket OBE devices and garner consumer interests to purchase these devices.

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Enabling Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles

TASK 1: STATE OF THE INDUSTRY REPORT

September 30, 2011

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Cooperative Transportation System Pooled Fund Study

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Executive Summary

This State of the Industry report is the first milestone in the University of Virginia's Enabling Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles Project. The report analyzes and compares the currently available communications technologies using literature reviews, related reports, and expert opinions as inputs for the analysis. In addition, the wireless technologies and applications commonly used by different modes of transportation including light passenger vehicles, transit vehicles, and heavy trucks are examined. Finally, the report compares various communication technologies in different application service scenarios to determine the key functions and requirements.

1 Introduction

1.1 Project Goals

The goal of this project is to accelerate the introduction of aftermarket OBE units to the vehicle fleet. Without a rapid deployment, the safety, mobility, and convenience benefits of the USDOT Connected Vehicle Research Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the 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 produce instantaneous benefits to the consumer. Furthermore, from the consumer perspective, only a system that provides immediate benefits will offer utility. Without utility, the USDOT Program systems and applications will not be accepted by consumers on its own merits.

In this industry report, various communications technologies under the current USDOT Connected Vehicle Research Program are examined including: 5.9 GHz DSRC, cellular 3G/4G/LTE/WiMAX, satellite, Wi-Fi, FM-RDS and Infrared. In addition, various vehicle types including light passenger vehicles, transit, and trucks, are considered.

1.2 Report Layout

In Chapter 2, the current wireless communications technologies are presented that includes 5.9 GHz DSRC, cellular 3G/4G/LTE/WiMAX, satellite, Wi-Fi, Bluetooth, FM-RDS and Infrared. The capabilities (e.g., latency, operating frequency, range, data rate and coverage) for each technology are briefly described in this chapter. In addition, the capabilities of the various wireless technologies are compared in a matrix analysis table. Furthermore, this chapter provides a comparison of the various wireless technologies for different applications (e.g., safety, efficiency and comfort/entertainment) in a matrix analysis table.

Chapter 3 describes the various communications technologies in different vehicles (e.g., light passenger vehicles, transit vehicle and heavy truck vehicles) applications requirement. Finally, a comprehensive overview of the progression of various pertinent technologies and applications are compared in an analysis table.

Chapter 4 discusses four safety application scenarios by using various wireless communications technologies including: Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW). For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services. This chapter also studies eight vehicular research projects (The USDOT Connected Vehicle Research Program, IVBSS, AASHTO Connected Vehicle, CAMP OTA Interoperability, INTERSAFE-2, CVIS, VICS and Smartway) by using various communication technologies. Finally, a summary of various communication technologies in safety/efficiency/entertainment application service scenarios is presented.

Chapter 5 provides conclusions based upon the literature review and expert judgment.

2 Wireless Communication Technologies

This section discusses the current one-way and two-way wireless communications technologies that are available or planned. The capabilities for each technology are briefly described in this section. In section 2.8, the capabilities of the various wireless technologies are compared in a matrix analysis table. In section 2.9, the various wireless technologies for different applications are compared in a matrix analysis table. Section 2.10 gives conclusions.

2.1 5.9 GHz DSRC

Strength: low latency, high mobility, free communication costs

Weakness: low bandwidth, limited coverage

Dedicated Short-Range Communication (DSRC) is 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). This will enable operations related to the improvement of traffic flow, highway safety, and other Intelligent Transport System (ITS) applications in a variety of application environments called WAVE/DSRC (Wireless Access in a Vehicular Environment). Furthermore, DSRC has the potential to provide low latency communications, which have been identified as a necessary capability to support the vehicle safety applications. In order to realize this potential, however, the correct technological choices must be made for the FCC (Federal Communications Commission) rules for this spectrum, and for the standards to be used in this band. The band plan being proposed in the United States for the 75 MHz of spectrum in the 5.9 GHz range has been under development for some time. Figure 2.1 shows the 5.9 GHz DSRC channel plan (one control channel and 6 service channels).

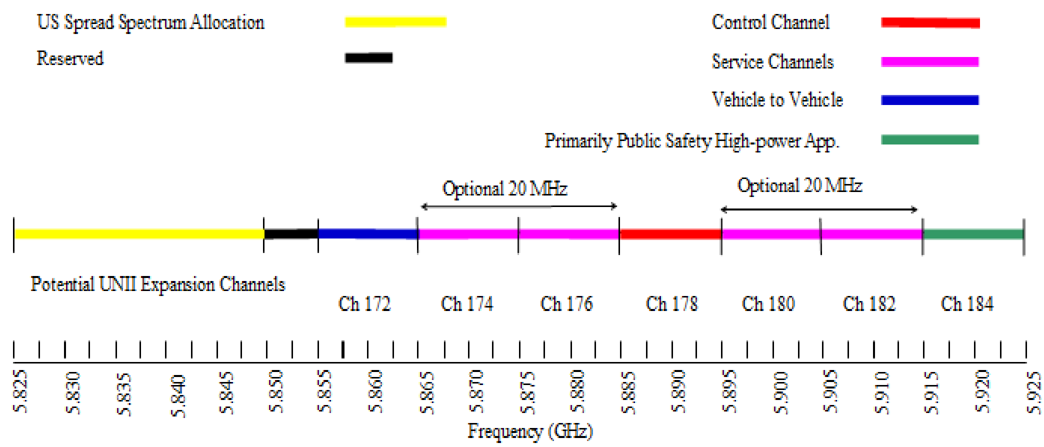

Figure 2.1 5.9 GHz DSRC Channel Plan [1]

2.2 Cellular 3G/4G/LTE/WiMAX

Strength: high bandwidth, wide coverage, high mobility

Weakness: high latency, requires communication costs

3G/4G/LTE/WiMAX generation mobile telecommunications 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 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.

2.3 Two-way satellite

Strength: wide coverage, provides navigation information for vehicles

Weakness: high latency, requires airtime costs

Satellites are used for a large number of purposes. Common types include military and civilian Earth observation satellites, communications satellites, navigation satellites, weather satellites, and research satellites. There are several application services using satellite technology such as satellite phone, satellite radio, satellite television and satellite navigation. Ubiquitous coverage over the continental US (as well as extended global coverage), provides a strong argument to consider two-way satellite services for wireless connectivity on vehicles. So far, however, the data services that are available and affordable have rather limited data capacity. Even with these data capacity limitations, there are a fairly wide range of telematics-type applications that could be supported using a short message data structure. For example, low bandwidth packet data services over satellite could be used to support vehicle telemetry applications, such as probe vehicle monitoring. Since the two-way satellite services are designed to operate as point-to-point communications channels, their mode of operation is not compatible with the vehicle safety applications. Another serious deficiency of these systems in relation to the vehicle safety applications communications requirements is the large inherent system latency. The expected airtime costs are yet another unresolved issue.

2.4 Wi-Fi

Strength: wide deployment, easy configurations, cost savings

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

The 802.11 series of standards were developed by the IEEE specifically to support wireless LANs. Both 802.11a and 802.11b (depending upon data rates required) could potentially support the inclusion of vehicles in 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 WiFi 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 (caused high packet loss rates), 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.

2.5 Bluetooth

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

Weakness: high latency, low speed, limited coverage

Bluetooth is 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 could be used for 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.

2.6 FM-RDS

Strength: high coverage, low cost

Weakness: high latency, low speed

FM-RDS (Radio Data System) is a one-way communications protocol standard for embedding small amounts of digital information in conventional FM radio broadcasts. This protocol is also used to send traffic data to PND (Personal Navigation Device) types of receivers. In 1992 the US National Radio Systems Committee issued the North American version of the RDS standard, called the Radio Broadcast Data System. The CENELEC (European Committee for Electrotechnical Standardization) standard was updated in 1992 with the addition of Traffic Message Channel and in 1998 with Open Data Applications and in 2000, RDS was published worldwide as IEC (International Electrotechnical Commission) standard 62106. As far as implementation is concerned, most car stereos will support at least AF (Alternative Frequencies), EON (Enhanced Other Network), REG (Regional), PS (Program Service) and TA/TP (Traffic Announcement, Traffic Program). There are a growing number of RDS implementations in portable and navigation devices thanks to lower-priced, small-footprint solutions.

2.7 Infrared

Strength: wide used for military and civilian purposes, low cost

Weakness: limited coverage

Infrared (IR) light is electromagnetic radiation with a wavelength longer than that of visible light, measured from the nominal edge of visible red light at 0.74 micrometers, and extending conventionally to 300 micrometres. These wavelengths correspond to a frequency range of approximately 1 to 400 THz, and include most of the thermal radiation emitted by objects near room temperature. Microscopically, IR light is typically emitted or absorbed by molecules when they change their rotational-vibrational movements. Infrared imaging is used extensively for military and civilian purposes. Military applications include target acquisition, surveillance, night vision, homing and tracking. Non-military uses include thermal efficiency analysis, remote temperature sensing, short-ranged wireless communication, spectroscopy, and weather forecasting. Infrared astronomy uses sensor-equipped telescopes to penetrate dusty regions of space, such as molecular clouds; detect objects such as planets, and to view highly red-shifted objects from the early days of the universe. In vehicular applications, Japan use infrared beacons and FM multiplex broadcasting in their VICS (Vehicle Information and Communication System) and Smartway systems. In their VICS system, infrared beacon can provide information about expressways and ordinary roads as far as 30 km ahead, and 1 km behind from the car. FM multiplex broadcasting can provide information about the prefectures you are in, neighboring area and regional borders.

2.8 Matrix Analysis by the Various Communication Technologies in Different Capabilities

In this section, the capabilities of the various wireless technologies are compared and summarized in Table 2.1.

Table 2.1 Comparison of Wireless Technologies in Different Capabilities

Technologies / Capabilities	5.9 GHz DSRC	Cellular 3G	Two-way Satellite	Wi-Fi	Bluetooth	FM-RDS	Infrared
Latency	200 micro sec [2]	1.5~3.5 sec [2]	60+ sec [2]	3~5 sec [2]	3~4 sec [2]	NA	NA
Operating frequency	5.9 GHz	Depending on its system	Depending on its type	2.4 GHz for 802.11b/ 5 GHz for 802.11a	2.4 GHz	87.5~108 MHz	1 to 400 THz

Range	1000 m [2]	~20-30 km	NA	1000 m [2]	10 m [2]	NA	0.74~300 micrometers
Data rate	Up to 27Mbps	Up to 240Kbps	Uplink: 60~1024Kbps Downlink: 256~2048kbps	802.11b: up to 11Mbps 802.11a: up to 54Mbps	Up to 1Mbps	1.1875 kbit/s	IrPHY: 2.4 kbit/s to 1 Gbit/s
Coverage	Nominal	High	High	Nominal	Low	High	Low
Two-way communication	O	O	O	O	O	X	X
Point-to-point/ Point-to-multipoint communication	O	O	O	O	O	O	O

2.9 Comparison of Wireless Technologies for Different Applications

Intelligent Transport Systems (ITS) are a promising solution to some problems (e.g., traffic accidents, congestion, environmental impacts and energy consumption) and active research is now taking place around the world to advance this technology. ITS is defined as using information and communication technology to form systems that address vehicles, roads and users as a triune entity in order to improve safety, transportation efficiency and comfort while protecting the environment, as shown in Fig. 2.2. ITS aims at establishing a sustainable mobility that balances comfort with safety, security and reduced environmental impacts. **There are three ITS major categories that are under research and implementation as listed below [3],**

- **Safety Applications: Safety applications are time-critical. They include assistance for safe driving (e.g. warning systems), airbags, impact and rollover sensors, adaptive cruise control, and distance control systems, etc.**
- **Efficiency Applications: Efficiency applications are intended for advances in navigation systems, establishment of electronic toll collection, optimization of traffic management and increasing efficiency in road management by building an integrated system of people, roads and vehicles utilizing advanced data communication technologies.**
- **Comfort/Entertainment Applications: Comfortable/Entertainment applications require a large bandwidth for the exchange of data within the car or with external devices. This domain is becoming very important due to the relevance of telematics in modern life: hands-free telephony, car navigation systems, CD, DVD, rear-seat entertainment, and remote diagnostics, etc.**

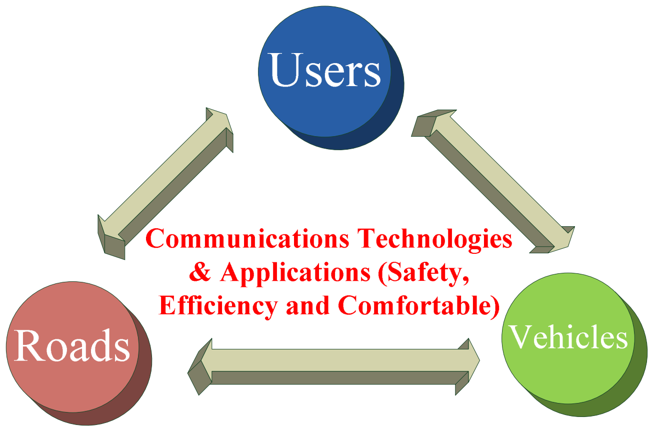

Figure 2.2 ITS Conceptual Model [4]

The various wireless technologies for different applications are explained as follows.

The 5.9GHz 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. The 5.9 GHz DSRC also support a wide range of roadside-to-vehicle and vehicle-to-vehicle communications, for which most of the efficiency applications (such as electronic toll collection) can be developed today (e.g., Kapsch has deployed 5.9 GHz DSRC for ETC).

Data communications over cellular 3G networks tend to be lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. The latency (at least several seconds) limitations will likely preclude the use of cellular communications for the majority of the time-critical vehicle safety applications. Internet connectivity via cellular 3G services can also support entertainment application (such as interactive online games).

Since the two-way satellite services are designed to operate as point-to-point communications channels, their mode of operation is not compatible with the vehicle safety applications. The two-way satellite communication is suitable for low bandwidth packet data services over satellite and could be used to support vehicle telemetry applications, such as probe vehicle monitoring.

The Wi-Fi systems could provide extensive data downloads to garaged vehicles, as well as allowing the vehicles to download non-time-critical information (such as video entertainment applications) to wider area networks.

Bluetooth is a low-power, low-cost, short-range (10m) wireless communication system. The coverage range and latency 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, for example, or entertainment-related communications between a vehicle and the owner’s home infrastructure.

The comparison of various wireless technologies for different applications is shown in Table 2.2. 5.9 GHz DSRC is very suitable for time-critical applications (e.g., assistance for safe driving). Wi-Fi or Bluetooth is suitable for in-vehicle applications (e.g., maps download for Wi-Fi communication and hands-free calling with mobile phones for Bluetooth communication). However, Cellular 3G or Satellite is very suitable for comfort applications (e.g., multimedia download for cellular communication and satellite television/satellite navigation for satellite communication).

Table 2.2 Comparison of Wireless Technologies for Different Applications

Technologies / Applications	5.9GHz DSRC	Cellular 3G	Two-way Satellite	Wi-Fi	Bluetooth
Safety	A	C	C	C	C
Efficiency	B	B	B	B	B
Comfortable/Entertainment	C	A	A	A	A

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

2.10 Summary

The vehicular application choice of which wireless technology 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 ranges up to 1 km are important. 5.9GHz DSRC is also suitable for non-safety applications (such as electronic toll collection or payment applications). 5.9 GHz DSRC will work for ETC, but the majority of ETC in US today uses 915 MHz DSRC. Bluetooth allows transfer speeds of up to 1 Mb/s, which is suitable for entertainment applications (e.g., music sharing), but the effective range is too short for DSRC applications. Primarily because of its low latency and reasonable range, 5.9 GHz DSRC has become the wireless technology of choice for safety applications

In 2005, the USDOT VSC (Vehicle Safety Communications) project developed a comprehensive list of communications-based vehicle safety and non-safety application scenarios [2]. More than 75 application scenarios were identified and analyzed resulting in 34 safety and 11 non-safety application scenario descriptions. Each safety application scenario was further defined to include an initial estimate of potential safety benefits, and eight high potential benefit safety application scenarios were selected for further study: traffic signal violation warning, curve 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]. Currently, the U.S. DOT's Connected Vehicles program is leading the activities on cooperative vehicular systems in the US [5].

In addition, with the rapid progress of semiconductor technology, mechanical components are gradually being replaced by electronics. Consumer demand for safety, comfort and energy efficiency is leading the auto electronics industry toward positive growth. Industry output is likely to reach US$155 billion in 2009 and increase to US$170 billion in 2010. As demand increases for safety, comfort and energy efficiency, the market for auto electronics such as security and telematics systems is expected to soar. It has been forecasted that the market share for auto security will increase from 13% to 16% between 2004 and 2009 [6].

3 Comparison of Various Communications Technologies and Applications in Different Type of Vehicles

Each type of vehicle has its own associated communication technologies and applications. Three types of vehicles are discussed including light passenger, transit, and heavy truck vehicles. This section will make comparisons of various communications technologies for different modes of transportation including light passenger, transit, and heavy truck vehicles.

3.1 Light Passenger Vehicles

Using technologies: 5.9 GHz DSRC, Satellite, Cellular, sensors

Applications: OnStar System, IVBSS

According to U.S. Department of Transportation's definition, a passenger vehicle means a car or truck, used for passengers, excluding buses and trains. Passenger vehicles are cars and light trucks up to 14,000 pounds Gross Vehicle Weight Rating (GVWR). Table 3.1 shows International Organization of Motor Vehicle Manufacturers statistics for two types (passenger/commercial) of vehicles. (http://oica.net/category/production-statistics)

Table 3.1 Production statistics for two types of vehicles in United States

Production Statistics	2006	2007	2008	2009	2010
Passenger Vehicle	4,366,220	3,929,368	3,776,641	2,195,588	2,731,105
Commercial Vehicle	6,897,766	6.856.461	4,916,900	3,535,809	5,030,338
Total (unit)	11,263,986	10,780729	8,693,541	5,731,397	7,761,443

3.1.1 OnStar System

The first application of light passenger vehicles was OnStar system [7], which is a subsidiary of General Motors that provides subscription-based communications, in-vehicle security, hands free calling, turn-by-turn navigation, and remote diagnostics systems throughout the United States, Canada and China. OnStar services are only available currently on vehicles manufactured by General Motors and Saab Automobile. The service is available for all vehicles that have the factory-installed OnStar hardware. A similar service is known as ChevyStar in Latin American markets. The service currently has more than five million customers. In addition, a new retail rear-view mirror with a built-in OnStar module, branded as OnStar FMV, became available to the public on July 24th, 2011. It provides some of the features an OEM system has, such as Automatic Crash Response, Stolen Vehicle Tracking, Turn-by-Turn Navigation, and Roadside Assistance.

The OnStar service relies on CDMA mobile phone voice and data communication, primarily via Verizon Wireless in the United States and Bell Mobility in Canada, as well as location information using GPS technology. Drivers and passengers can use its audio interface to contact OnStar representatives for emergency services, vehicle diagnostics and directions. OnStar equipped vehicles with an active subscription will also contact representatives based in Warren, Michigan; Charlotte, North Carolina; Makati, Philippines; and Oshawa, Ontario in the event of a collision in which the airbags are deployed. Newer models (on vehicles from approximately 2006 and later) will contact OnStar in any type of collision regardless of airbag deployment. This new service is called Advanced Automatic Crash Response (AACR) and is designed to assist emergency response efforts. When a driver presses the Red OnStar Emergency button or Blue OnStar button, current vehicle data and the user’s GPS location are immediately gathered. This information is then sent to OnStar. OnStar Emergency calls are routed to the OnStar Center with highest priority. Three centers exist to receive emergency calls: Warren, Michigan; Charlotte, North Carolina and Ontario, Canada, and all centers are open 24 hours a day.

All OnStar equipped vehicles have Stolen Vehicle Tracking, which can provide the police with the vehicle’s exact location, speed and direction of movement. Starting 2009, General Motors began equipping some new vehicles with Stolen Vehicle Slowdown. This feature allows OnStar to remotely slow down the stolen vehicle. The service is also expected to help reduce the risk of property damage, serious injuries or fatalities resulting from high-speed pursuits of stolen vehicles. Customers may opt out of that function. The first successful use of this service occurred in October 2009 when a stolen Chevrolet Tahoe was recovered and its suspected thief was apprehended. Also in 2009, General Motors began equipping some new vehicles with Remote Ignition Block, allowing OnStar to remotely deactivate the ignition so when the stolen vehicle is shut off, it cannot be restarted. All Stolen Vehicle Assistance services (Stolen Vehicle Tracking, Stolen Vehicle Slowdown and Remote Ignition Block) can be requested by the OnStar subscriber, but OnStar will not activate them until confirming with the police that the vehicle has been reported as stolen. OnStar subscribers may be eligible for anti-theft and low mileage insurance discounts. Since OnStar can help with the recovery of a stolen vehicle, some insurance companies recognize this and offer a discount. Also, with certain insurance companies (for example, GMAC Insurance) and with subscriber permission, OnStar will send the insurance company the vehicle's odometer reading every month. If the subscriber qualifies as a low-mileage driver, they may be eligible for an insurance discount.

Even if the vehicle is OnStar equipped, no OnStar services are available until the system is activated. Vehicle owners can choose between two plans:

- Safe & Sound: $18.95/mth ($24.95 in Canada), which includes Automatic Crash Response, Stolen Vehicle Assistance, Roadside Assistance, Remote Door Unlock, Remote Horn and Light Flashing, Red Button Emergency Services and OnStar Remote Vehicle Diagnostics
- Directions & Connections: $28.90/mth ($39.90 in Canada), includes all services in the Safe & Sound plan, plus turn-by-turn navigation

3.1.2 IVBSS

The second application of light passenger vehicles was IVBSS (Integrated Vehicle-Based Safety Systems), which includes Forward Collision Warning, Lane Change Merge, and Curve Speed Warning as safety sub-system for passenger car. The detailed description will discuss as follows:

- FCW Sub-system

Forward Collision Warning (FCW) system warns the driver when his/her vehicle is in danger of colliding with another vehicle that exists in its lane. The objective of this system is to warn the driver early enough so he/she can avoid the collision. FCW system design attempts to address different forward collision scenarios such as:

1) Host vehicle (vehicle equipped with the system) is moving in straight or curved road, and there is a slower/stopped/decelerating lead vehicle in the host vehicle current lane (straight or curved).
2) Host vehicle is moving in straight or curved road following a lead vehicle. The lead vehicle changes lane and new slower/stopped/decelerating lead vehicle appears in the host vehicle current lane (straight or curved).
3) Host vehicle is moving in straight or curved road following a lead vehicle. The host vehicle changes lane toward a new slower/stopped/decelerating lead vehicle.

In all of these scenarios the FCW is expected to warn the driver. The timing of the warning will depend on the design tradeoff that is needed to minimize the number of false alarms.

FCW system will not warn for vehicles that are not moving in the travel direction of the host vehicle. FCW system will not warn for vehicles that are moving or stopped outside the host vehicle lane.

- LCM Sub-system

The Lane Change Merge (LCM) sub-system addresses side collision scenarios involving intentional lane-change maneuvering of the host vehicle. Side looking radar is used to identify potential hazards in an adjacent zone extending from just in front of, to substantially rearward of the host vehicle. Vision is a stretch objective for LCM for the light vehicle IVBSS and will be used to augment the radar data. A warning is generated when a vehicle collision hazard exists in the adjacent zone, due to the lateral motion of the host vehicle. Supplemental information is provided via a mirror icon that is lit when a same-direction moving vehicle is detected in the blind-spot zone, or when a vehicle will be in the blind-spot zone.

Three basic functions comprise the LCM subsystem: to warn of side-collision hazards due to lane-change and merge situations; to inform of occupied blind-spot zone; and to calculate lateral available maneuvering room (AMR) for use by other subsystems. The detailed description was as follows. In addition, three side-looking radar sensors positioned on either side of the host vehicle provide obstacle data to the subsystem: rear-facing; rear side; and front side.

- To warn of side-collision hazards due to lane-change and merge situations:

  The data provided by the radar is used to create an understanding of obstacles in the adjacent proximity zone that extends from 0.5 to 3 meters laterally from the side of the host vehicle, and runs from approximately 3 meters forward of the front bumper of the host vehicle, to 18 meters rearward of the back bumper.

- To inform of occupied blind-spot zone:

  The blind-spot zone is a subset of the adjacent proximity zone that represents the area of the adjacent lane that is difficult for the driver to see, both directly by turning his/her head, and indirectly via the side mirror. The blind-spot zone extends from 0.5 to 3 meters laterally from the side of the host vehicle and runs from approximately the B pillar to 3 meters rearward of the back bumper of the host vehicle.

- To calculate lateral available maneuvering room (AMR) for use by other subsystems:

  The Available Maneuvering Room function delivers a pair of outputs that quantify the available lateral distance from the subject vehicle to detected objects in the adjacent path or the adjacent lane. The goal of this function is to optimize IVBSS warnings and improve on the performance that stand-alone IVBSS features can provide. The AMR function will enable IVBSS systems to respond to environment factors beyond the detection capabilities of any single system.

- CSW Sub-system

The CSW (Curve Speed Warning) sub-system warns the driver when the vehicle is traveling too fast for an upcoming curve. The objective of this system is to warn the driver early enough so he/she can avoid possible road departure at some point of the curve. In addition, CSW system design attempts to address curves that exist in:

1) Single road geometry.
2) Branching road geometry.

In all of these road scenarios, the CSW will warn the driver if he/she is driving at a speed more than the desired designed (by system) speed for this curve.

The Basic IVBSS CSW sub-system is a navigation-based system. CSW uses the navigation system to place the vehicle position on the map, and then, the CSW algorithm looks ahead on the map, extracts all possible driving path candidates, determines the intended driving path, performs a curvature calculation on the geometric data of this path, and finally performs a threat assessment based on the vehicle speed and road curvature ahead.

The light passenger vehicle IVBSS system will use a combination of GPS, digital maps, cameras, short-range radar and long-range radar.

Table3.2 is the IVBSS Sub-System Requirements in Passenger Vehicles Applications.

Table 3.2 IVBSS Sub-System Requirements in Passenger Vehicles Applications

IVBSS Sub system	Communication Type	Transmode	Min. frequency (Hz)	Latency (msec)	Max. Req'd comm. Range(m)
Cooperative Forward Collision Warning	Infra. To Vehicle (I2V) One Way Point to Multipoint	Periodic	~10	~100	~150
Lane Change Warning	Vehicle To Vehicle (V2V) One Way Point to Multipoint	Periodic	~10	~100	~150
Curve Speed Warning	Infra. To Vehicle(I2V) One Way Point to Multipoint	Periodic	~1	~1000	~200

3.2 Transit Vehicles

Using technologies: 5.9 GHz DSRC, Satellite (DGPS), Cellular, sensors (LIDAR)
Applications: BRT, Bus Station Tracking System

According to U.S. Department of Transportation's definition, a transit vehicle means a bus or light rail vehicle. According to 2006 data, there about 70,000 transit buses in the United States. There are also over 400,000 school buses. Transit buses account for about 2.2 billion vehicle miles per year, and according to the Federal Transit Administration (FTA) have a useful life of about 12 years. Transit vehicles are typically highly-customized with a variety of electronic equipment selected by transit operators to improve the monitoring of bus operations or better reporting of passenger usage data. All bus transit vehicles will fall under the same Connected Vehicle standards.

Transit vehicles represent a good target for early adoption of Connected Vehicle systems, as long as they can be shown to provide value to the operator. The cost of the equipment is relatively modest in comparison with other electronic systems typically deployed, so deployment of such equipment will generally depend on proving some level of operational benefits. There are two popular systems for transit vehicles.

3.2.1 BRT

Bus rapid transit (BRT) is a term applied to a variety of public transportation systems using buses to provide faster, more efficient service than an ordinary bus line. Often this is achieved by making improvements to existing infrastructure, vehicles and scheduling. The goal of these systems is to approach the service quality of rail transit while still enjoying the cost savings and flexibility of bus transit. The expression BRT is mainly used in North America; in Europe and Australia, it is often called a busway, while elsewhere, it may be called a quality bus.

The FTA has identified the concept of Bus Rapid Transit as a means to increase the efficiency of transit operations while maintaining transit's proven safety record. BRT also combines the quality of rail transit and the flexibility of buses. It can operate on exclusive transitways, HOV lanes, expressways, or ordinary streets. A BRT system combines intelligent transportation systems technology, priority for transit, cleaner and quieter vehicles, rapid and convenient fare collection, and integration with land use policy. Because of the limited right-of-way available to build new (and possibly dedicated) lanes for BRT operations, the FTA has identified lane assist as an emerging technology which will enable deployment of BRT systems. The premise behind lane assist technology is to increase the safety of BRT vehicles as they operate in the more unique environments, such as narrow lanes. Lane assist technology will allow BRT vehicles to operate at the desired higher operating speeds while maintaining the safety of the passengers, BRT vehicle and the motoring public.

In 2005, two Bus Rapid Transit technologies [8] are proposed from University of Minnesota. (1) Assisting Drivers Operating Buses on Road Shoulders; (2) A Virtual Mirror for Eliminating Vehicle Blind Zones

- Assisting Drivers Operating Buses on Road Shoulders

In bad weather, drivers have a difficult time determining the right boundary of the bus only shoulder, and are therefore reluctant to use the shoulder because they fear dropping a wheel off of the pavement, and getting a bus stuck in the soft dirt adjacent to the shoulder. This is further complicated in snow events and in winter in general, where snow removal operations have left some shoulders snow covered and the right edge of the shoulder even more obscure.

In order to solve the above problems, the driver assistive systems were developed. The driver assistive systems use DGPS and high accuracy geospatial databases as the core technologies upon which all system functionalities are built. (These core technologies can be augmented with other guidance methods in situations where DGPS service is either impractical or unavailable.) DGPS uses fixed GPS base stations and a means to use wireless broadcast capabilities to sent appropriate corrections to a roving GPS receiver in real time.

The driver assistive system also supports three modalities to provide lane assist feedback to the driver. Visual information is presented to the driver via a Head Up Display (HUD) and a Virtual Mirror Display. The visual information presented to the driver via the HUD includes simple system status information, lane boundary position information, and forward target information. To improve visibility on the sides of the bus, a LIDAR (LIght Detection and Ranging) based Virtual Mirror is used. The Virtual Mirror is comprised of three components: a sensor, a processor, and a graphical display.

- A Virtual Mirror for Eliminating Vehicle Blind Zones

While mirrors offer the driver greater visibility of the current surroundings, there are limitations to their use. Planar mirrors provide a relatively small field of view that creates blind zones, areas around the vehicle in which the driver cannot see when using the mirror. These blind zones create the need for the driver to check the mirrors often to determine if a vehicle has entered a blind zone or to turn their head to directly view these areas while driving, increasing the potential for accidents. Non-planar mirrors offer a larger field of view to the driver, but the image is smaller and often distorted, which can lead to the overestimation of distance even when the driver has experience using non-planar mirrors.

In order to solve the above problems, the Virtual Mirror technique was developed. This technique is for side collision warning and avoidance for transit applications. The virtual mirror technique can be “virtually” moved and re-oriented to view areas that would be impractical for a real mirror. If the driver wishes to eliminate the blind zone along the side of the vehicle, the virtual mirror could be “moved” so that it would be near the front corner of the car. The virtual mirror technique has been implemented using existing geospatial database tools and DGPS as a range sensing device; however, for practical applications, LIDAR or similar ranging sensors will have to be used. There are three basic types of LIDAR: DIfferential Absorption Lidar (DIAL), Doppler LIDAR, and range finders.

3.2.2 Bus Station Tracking System

The Bus Station Tracking System gives user the flexibility of enabling the in-bus terminal device to send real-time tracking data and receive it at the server. This system also emphasizes on tracking, monitoring the buses and their status on standard GIS maps such as proprietary map server or any map service providers like Goggle maps, Bing, Mapinfo etc. From table 3.1 [9], bus station tracking system take the bus to track the location, DSRC and GPS are main technologies, showing the bus station in what location, estimated time of arrival at the station, passenger car and the road to traffic congestion status of the case.

Table 3.3 Bus Station Tracking System

	Tradition Bus Stop System	Bus Station Tracking System
Transmission	GPRS	DSRC
Transmission Speed	Max 11Mbps	Max 25Mbps
Transmission Fee	Package	Free
Signal Scope	Long distance	Short Distance
Working Mode	Two Way	One Way /Two Way
On Time	Middle	High

3.3 Heavy Truck Vehicles

Using technologies: 5.9 GHz DSRC, Satellite, Cellular, sensors

Applications: IVBSS

According to U.S. Department of Transportation's definition, a Heavy Truck Vehicles means up to 26000 pounds Gross Vehicle Weight Rating (GVWR). There are approximately nine million medium and heavy vehicles on the road today (FHWA 2006), and each year about 260,000 new heavy vehicles are manufactured (the production rates for 2009 were substantially below normal levels due to economic factors). In general, the population of medium and heavy vehicles is expected to rise at a rate of about 2% per year. More than 700,000 of the heavy vehicles are private buses and motor coaches. The IVBSS system is developed for heavy truck vehicles.

3.3.1 IVBSS

The application of Heavy Truck Vehicles was IVBSS (Integrated Vehicle-Based Safety Systems), which includes Lane Departure Warning, Forward Collision Warning, and Lane Change Merge as safety sub-system for passenger car. The detailed description will discuss as follows:

- LDW Sub-system

The LDW (Lane Departure Warning) subsystem in IVBSS will be integrated into the vehicle and will share the same driver vehicle interface that the other subsystems use. In the IVBSS program, the LDW subsystem will be further integrated with the other subsystems to both improve the performance of the LDW functionality and to improve the performance of the functionality of the other.

The core sensor of the LDW subsystem is the forward-looking camera. The image from the camera is processed and painted lane markers or other non-painted visual features that delineate the lane are detected. From this information, an assessment is made as to whether the host vehicle is within the lane boundaries or departing the lane boundaries. If the host vehicle appears to be unintentionally drifting out of the lane, a warning request is generated to focus the driver's attention on the roadway.

- FCW Sub-system

The FCW (Forward Collision Warning) capability will provide imminent and cautionary alerts to assist drivers in avoiding striking other vehicles from behind (rear-end collisions) or reducing the severity of a collision.

The primary sensors of the FCW subsystem are a pair of TRW AC20 radar units [12]. The AC20 radar unit has onboard processing hardware that will estimate target track data assigned to specific vehicles and objects. A set of evolving parameters is associated to each track that includes: track identification number, relative (radial) distance, relative rate (radial velocity), estimated relative (radial) acceleration, angular position, and track confidence level. The set of tracks will be managed according to the birth and death of vehicle tracks (i.e. entry and exit from the radar FOV). Each AC20 can track up to 8 vehicles simultaneously at a data rate of 40 ms.

- LCM Warning Sub-system

The LCM (Lane Change Merge) warning function advises or warns the driver of an impending crash with another vehicle occupying a proximity zone in the adjacent lane, on either side of the host vehicle, when changing lanes, turning, or passing a vehicle in front. The primary sensor information for the LCM subsystem is provided by four short-range side-looking radar sensors and a pair of rear-looking radar sensors. A pair of rear-looking cameras will also augment the LCM subsystem functionality.

The heavy vehicle IVBSS system will use a combination of Forward Radar, Rear-Looking Radar, Side-Looking Radar, Forward-Looking Camera, Rear-Facing Camera, Yaw Rate Sensor, Tri-axial Accelerometer and GPS Sensor.

3.4 Summary

Different type of vehicles should use several communication technologies in their application. For example, the light passenger vehicle should use a combination of GPS, digital maps, cameras (e.g., Forward-Looking camera), short-range sensor and long-range sensor (e.g., Forward Looking senor, Rear-looking sensor, Side-Looking sensor, Yaw Rate sensor and GPS sensor). The Transit vehicle should use GPS, cameras (e.g., Forward-Looking camera), short-range sensor in Bus Tracking system. The heavy vehicle should use Forward-Looking Camera and several types of sensors (e.g., Forward sensor, Rear-Looking sensor, Side-Looking sensor, GPS sensor and Yaw Rate sensor). Table 3.2 provides a summary of various communication technologies and applications in different type of vehicles.

Table 3.4 The comparison of technologies and applications in different type of vehicles

Type of vehicles	Technologies	Applications
Light Passenger Vehicles	5.9 GHz DSRC, Satellite, Cellular, sensors	OnStar System, IVBSS
Transit Vehicles	5.9 GHz DSRC, Satellite (DGPS), Cellular, sensors (LIDAR)	BRT, Bus Station Tracking System
Heavy Truck Vehicles	5.9 GHz DSRC, Satellite, Cellular, sensors	IVBSS

The communication requirements for communications-based vehicle safety applications are considering the type of communications, transmission mode, update rate, allowable latency, maximum required range of communication, these descriptions are summarized as following:

Type of Communications: consider (1) source - destination of the transmission (infrastructure-to-vehicle, vehicle-to-infrastructure, vehicle-to-vehicle communica -tions), (2) direction of the transmission (one-way, or two-way), (3) source-reception of the communication (point-to-point or point–to-multipoint).

Transmission Mode: Describe whether the transmission is triggered by an event (event-driven) or (sent automatically at regular intervals (periodic).

Update Rate: Define the minimum at which a transmission should be repeated (e.g., 1Hz).

Allowable Latency: Define maximum duration of time allowable between when information is available for transmission and when it is received (e.g., 100msec).

Maximum Required Range of Communication: Defines the communication distance between two units that is required to effectively support a particular application (e.g., 100m).

The general, the 100 millisecond latency requirement and the broadcast nature of the communications determines the required technology. In addition, the data packets to support most vehicle to vehicle communications are determined to be less than 100 bytes.

In general the **light passenger vehicle** industry is also exceedingly cost conscious. Each vehicle platform is based on a production cost budget, and any extra cost either increases the price or reduces the profitability of the vehicle. As a result, vehicle manufacturers weigh the cost of every part against the need for that part, or the estimated value to be perceived by a prospective buyer. Vehicle executives are highly wary of adding cost without proof that the added value provided by that cost will pay off. The result of this situation is that it is challenging to add new equipment to a vehicle. Typically the demand for the equipment must be obvious in the marketplace before such equipment will be embedded in the design. Many examples of this exist in the history of the motor vehicle. The first car radios appeared in about 1928, eight years after they were available for home use. In 1962 Philips invented the compact audio cassette medium for audio storage, introducing it in Europe in August 1963, and then in the United States in November 1964. However, it was not until about 1974 that cassette players were available for cars, and sometime after that before the cassette player was standard equipment.

As a result, deploying Connected Vehicle related equipment in vehicles requires that the system provides clear value to the vehicle user (such that a vehicle manufacturer can be sure that the added feature will provide value to the customer commensurate with the cost of the equipment). This value must be realizable by customers in a time frame that is relevant to their ownership of the vehicles (that is, they must realize its value while they own the car, and preferably when they are considering their vehicle purchase). These considerations are generally in conflict with the dynamics of the market. The time required to achieve sufficient penetration in the fleet, such that some benefits (value) are obvious to the owner, is longer than that which would motivate the installation (and cost) of the equipment.

Transit vehicles are typically highly customized with a variety of electronic equipment selected by transit operators to improve the monitoring of bus operations or better reporting of passenger usage data.

Heavy trucks generally use multiplex networks for gauges and other electronics, and generally they are configured to support a variety of aftermarket installed electronic equipment. The typical large truck also includes physical provisions for such equipment. As a result, it is much easier to add equipment to a truck, either as original equipment or as aftermarket equipment than it is to add such equipment to a passenger vehicle.

While comprising less than four percent of the overall vehicle population, the heavy vehicle industry is highly aware of the benefits and costs of technology, consequently they are much more proactive in making changes. The industry tends to support retrofit configuration much more easily than the passenger vehicle market, so it is a strong candidate for supporting early adoption of Connected Vehicle systems. Commercial vehicle operators have also demonstrated a willingness to participate in government-sponsored technology initiatives where it this will enhance their efficiency or productivity. Today, for example, about 400,000 trucks use PrePass and NORPASS tags for electronic pre-clearance at weight stations and ports-of-entry.

4 Comparison of Various Communications Technologies in Different Application Service Scenarios

This section discusses a variety of application scenarios by using various wireless communications technologies. Four safety applications, Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW) are described from section 4.1 to section 4.4. For efficiency applications, VICS and Smartway cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. The more detailed will be described from section 4.5 to section 4.6. For comfort/entertainment applications, Visteon's Connected Car application will present in section 4.7. In section 4.8, a Vehicle Group Communication System (VGCS) was developed on the basis of ITRI's experience in the deployment of IEEE 1609/802.11(p) On-Board Units (OBUs). In section 4.9, we discuss eight related research projects (including US, Europe and Japan) by using various communication technologies. In section 4.10, the various communications technologies for different application scenarios are compared in a matrix analysis table.

4.1 Forward Collision Warning (FCW)

Using technologies: sensors, satellite, 3G/4G, Wi-Fi, 5.9 GHz DSRC

The Forward Collision Warning (FCW) application is designed to aid the driver in avoiding or mitigating collisions with the rear end of vehicles in the forward path of travel through driver notification or warning of the impending collision. The application does not attempt to control the host vehicle in order to avoid an impending collision. This FCW application uses information communicated from neighboring vehicles via V2V (Vehicle to Vehicle) 5.9 GHz DSRC. The host vehicle receives BSM (Basic Safety Message) from other vehicles. Using information from BSM regarding other vehicles' position, velocity, heading, yaw rate, and acceleration along with its own position, dynamics and roadway information (map data), the host vehicle determines whether a rear-end collision with the lead vehicle is likely. In addition, the host vehicle transmits position, velocity, acceleration, heading, and yaw rate to other vehicles.

Figure 4.1 is a demonstration of a Forward Collision Warning application scenario. The host vehicle is assumed to have a cooperative Forward Collision Warning system that implies, among other things, that the host vehicle is able to transmit and receive standardized 5.9 GHz DSRC messages designed for V2V safety applications. However it is assumed that not all target vehicles will be equipped with 5.9 GHz DSRC on-board units. In the figure three targets are shown corresponding to three vehicles. Target 2 is shown to have a 5.9 GHz DSRC on-board unit and transmits standardized 5.9 GHz DSRC messages designed for V2V safety applications periodically, while targets 1 and 3 do not have 5.9 GHz DSRC on-board units. The communication range for the 5.9 GHz DSRC message sets should be chosen to take into account the requirements of a Forward Collision Warning system. The Forward Collision Warning system in the host vehicle will process all the targets and classify them as in-path or out-of-path targets. The system will then select the closest-in-path target and process the target's dynamics information and provide a warning to the driver if the threat assessment algorithm indicates a threat.

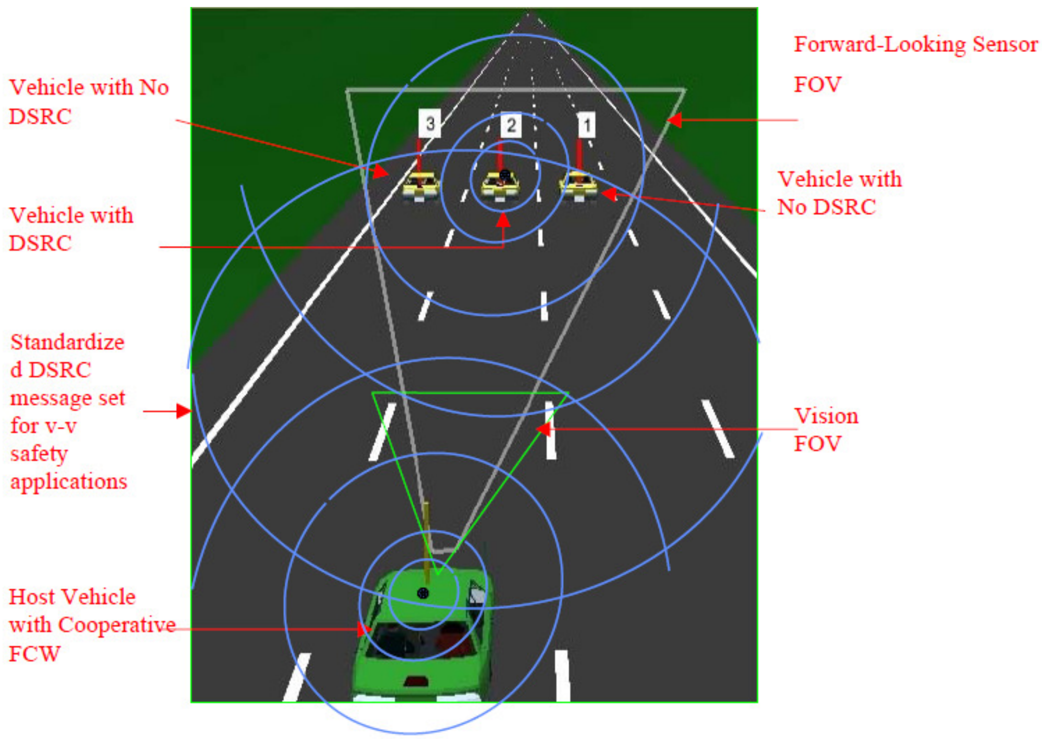

Figure 4.1 Forward Collision Warning scenario [2]

A Forward Collision Warning system will typically use a **forward-looking sensor** [12] mounted at the front of the host vehicle that detects targets (other vehicles or objects) ahead of the host vehicle and in its field of view. An accurate prediction of the forward lane geometry ahead of the host vehicle (up to 200 meters) is necessary in order to properly classify the targets as in-path or out-of-path, and thereby identify potential threats of rear-end collision. For FCW, incorrect classification of in-path and out-of-path targets leads to false alarms and missed detections in the system, which may limit deployment and user acceptance. To predict the forward road geometry ahead of the host vehicle, the system may also use a **GPS** receiver for vehicle position measurement, a map database, a vision system that detects lane markers, a **vehicle speed sensor** [12], and a **yaw-rate sensor** [12]. However, each of these approaches has limitations. Yaw-rate sensors do not possess the capability to determine the forward road geometry up to 150 m since the prediction is based on extrapolation of curvature of the road at the current host vehicle position. The limitations of using yaw-rate to determine forward road geometry are easily demonstrated as a host vehicle travels on a straight section of road into a curve. Lane markings tracker based on a vision system can also be used to provide a forward road geometry estimate but they have been unable to do so at distances required by FCW.

Table 4.1 summarizes various communication technologies for FCW application. The **forward-looking sensor** [12] mounted in front of the vehicles to estimate range, range rate, acceleration, and azimuth of multiple objects ahead of the host vehicle at a maximum detection range of at least 200 m and an azimuth field of view of 16 degrees. The unit should provide dedicated on-board processing capabilities for multiple target identification, tracking and scenario identification. The **yaw-rate sensor** [12] should provide the yaw angle and rate relative to the longitudinal travel of the host vehicle. The **GPS sensor** [12] should be utilized to determine the position of the host vehicle. Positional information will be used in conjunction with a dynamically created digital map (map download through **3G/4G/Wi-Fi** technologies) to provide information related to false alarms, roadside objects, and roadway geometry. The FCW application uses information communicated from neighboring vehicles via V2V **5.9 GHz DSRC**. It is expected that the **5.9 GHz DSRC** equipped vehicles would periodically broadcast the standard message set to neighboring vehicles within a certain desired range. Current automotive radars used in FCW systems are capable of track updates at an update rate of 100 ms and have a range of coverage 150 m. Hence, the update rate for V2V communication is expected to be at least 100 ms, and the communication range is expected to be at least 150 m.

Table 4.1 FCW application by using various communication technologies

Communication technologies	Function description
Sensors	● Forward-looking sensor ● Vehicle speed sensor ● Yaw-rate sensor ● GPS sensor
Satellite	Combine a GPS receiver for vehicle position measurement
3G/4G/Wi-Fi	Download digital map
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication (use the On-Board Unit of 5.9 GHz DSRC to share that information with other vehicles)

4.2 Emergency Electronic Brake Lights (EEBL)

Using technologies: 5.9 GHz DSRC, satellite, 3G/4G, Wi-Fi

When a vehicle brakes hard, the Emergency Electronic Brake Light (EEBL) application conveys this information to surrounding vehicles. The EEBL application enables a host vehicle to broadcast a self-generated emergency brake event to other vehicles following behind. Upon receiving such event information, the following vehicle (with a safety device capable of detecting a braking event) determines the relevance of the event and provides a warning to the driver if appropriate. This application would only function during interactions between vehicles with safety systems that will transmit or detect a braking event. This application will help the driver of following vehicles by giving an early notification of lead vehicle braking hard even when the driver's visibility is limited (e.g. a large truck blocks the driver's view, heavy fog, rain). This information could be integrated into an adaptive cruise control system.

Figure 4.2 demonstrates an Emergency Electronic Brake Lights scenario on a 3-lane highway. In the figure, vehicle E brakes hard and broadcasts the message. Vehicles with 5.9 GHz DSRC radio unit will listen to the message sent by vehicle E and check to evaluate if the message is relevant (e.g., for vehicle C, a "hard brake" message from D might not be relevant). If the "hard brake" message is relevant to the application host vehicle, the driver is warned (e.g., driver of vehicle B and C).

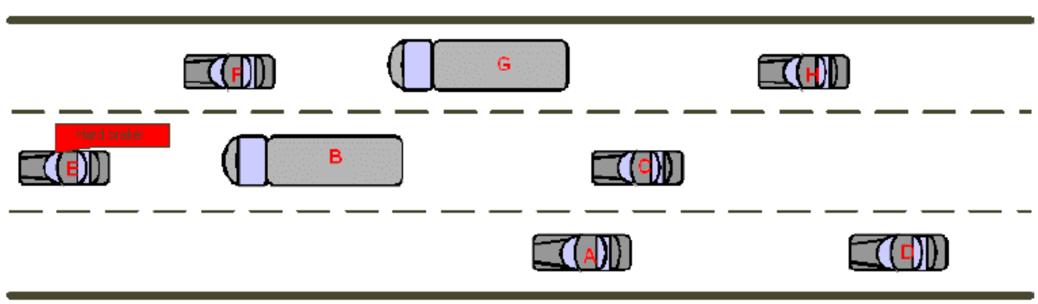

Figure 4.2 Emergency Electronic Brake Lights scenario [2]

Table 4.2 summarizes various communication technologies for EEBL application. For this application scenario, it is assumed that the vehicle in an emergency braking situation would be equipped with a **5.9 GHz DSRC** unit. It is also assumed that the message from the vehicle would be sent to the following vehicles, including the ones that are behind a much larger vehicle (e.g., a big truck). The message sender needs to have an algorithm to decide if an "emergency braking" message delivery is necessary (e.g., deceleration greater than 0.6g). If a vehicle determines that it is braking hard then it could use the On-Board Unit of 5.9 GHz DSRC to share that information with others. In order to determine if an "emergency braking" message is relevant to the listening vehicle, the listening vehicle needs to know the relative location from which the message originated (e.g., front, rear, left, right). This can be done based on its **GPS** information and the **GPS** information of the braking vehicle. A map database (map download through **3G/4G/Wi-Fi** technologies) would help to provide information such as which lane the vehicle is traveling. In addition, the road curvature can be taken into account when an application host vehicle evaluates "emergency braking message" to see if a warning to the driver is necessary.

Table 4.2 EEBL application by using various communication technologies

Communication technologies	Function description
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication (use the On-Board Unit of 5.9 GHz DSRC to share that information with other vehicles)
Satellite	Get GPS position information
3G/4G/Wi-Fi	Download digital map

4.3 Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)

Using technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi

The Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) [13][14] safety application is designed to assist drivers in avoiding crashes in the intersection by warning the driver of an impending violation of a traffic signal or a stop sign. Cooperative means that the system involves both infrastructure and in-vehicle elements working together. A CICAS-V equipped vehicle approaching a CICAS-V equipped intersection receives messages about the intersection geometry, GPS differential corrections, and status of the traffic signal. The driver is issued a warning if the equipment in the vehicle determines that, given current operating conditions, the driver is predicted to violate the signal in a manner which is likely to result in the vehicle entering the intersection. This application requires the device to receive Signal Phase and Timing (SPaT) messages transmitted by the roadside equipment (RSE) at CICAS-V equipped intersections.

The basic concept of CICAS-V is illustrated at a high level in figure 4.3 for a signalized intersection. In the figure, a CICAS-V equipped vehicle approaching a CICAS-V equipped intersection receives messages about the intersection geometry and status of the traffic signal. The driver is issued a warning if the equipment in the vehicle determines that, given current operating conditions, the driver is predicted to violate the signal in a manner which is likely to result in the vehicle entering the intersection. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of traffic control device violations will decrease, and result in a decrease in the number and severity of crashes at controlled intersections.

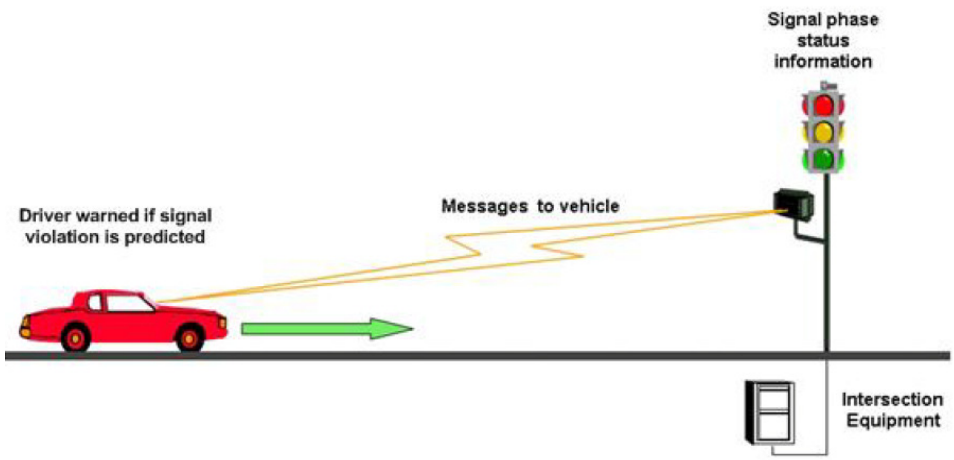

Figure 4.3 Cooperative Intersection Collision Avoidance System – Violations scenario [13]

Table 4.3 summarizes various communication technologies for CICAS-V application. In this application, each vehicle contained a computing platform, **5.9 GHz DSRC** radio (using the existing WAVE radio), **DGPS** (Differential GPS) system, and other hardware software components that were integrated with the vehicle bus to obtain **vehicle-sensor** data. The computing platform performed the data processing, warning algorithms, DVI (Digital Visual Interface), and other software functions required by the application. The equipped vehicles were used for the evaluation of the elements of the concepts of operation (e.g., map broadcast, message set, and timing) and the functional evaluation of the in-vehicle and the intersection application. The CICAS-V system requires an intersection map (map download through **3G/4G/Wi-Fi** technologies) of sufficient accuracy to enable matching the vehicle to the road or even to the lane in intersections with dedicated turn lanes.

The application design is dependent on the availability of RSE at CICAS-V signalized intersections that have a local GPS base station receiver. The GPS base station receiver is configured to compute correction factors for the **GPS Satellite** signals that are needed to make the position result from GPS position estimation algorithms match the base station's known fixed location. In addition to the 5.9 GHz DSRC and GPS antennas, the RSE is also connected to a **Wi-Fi** antenna that allows local software updates and system maintenance.

Table 4.3 CICAS-V application by using various communication technologies

Communication technologies	Function description
Sensor	GPS sensor
Satellite	DGPS (obtain GPS position information)

5.9 GHz DSRC	V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	● Download digital map ● V2R (Vehicle to Roadside) communication
Wi-Fi for RSE	Local software updates and system maintenance

4.4 Curve Speed Warning (CSW)

Using technologies: sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi

Curve Speed Warning (CSW) aids the driver in negotiating curves at appropriate speeds. This safety application will use information communicated from roadside beacons located ahead of approaching curves. The communicated information from roadside beacons would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the roadside equipment.

Figure 4.4 demonstrates a Curve Speed Warning (CSW) scenario on a mountain road. The vehicle enters the communication range of a roadside beacon. The beacon continuously transmits curve geometry for the upcoming series of turns. In addition to standard curve parameters, broadcast messages note the minimal shoulder due to a cliff at the hairpin and, if equipped with surface condition sensors, the presence and location of ice on the road. Given sensor and beacon constraints, additional beacons may provide supplemental coverage at various points along the road. The vehicle computes a safe curve speed based on broadcast message content, which contains the posted speed limit, current road geometry, shoulder characteristics, weather conditions, and, if equipped, road surface conditions, as well as the vehicle's inherent handling characteristics and any applicable vehicle sensor data. The CSW application must be provided to the driver early enough to allow a controlled deceleration and safe negotiation of the curve.

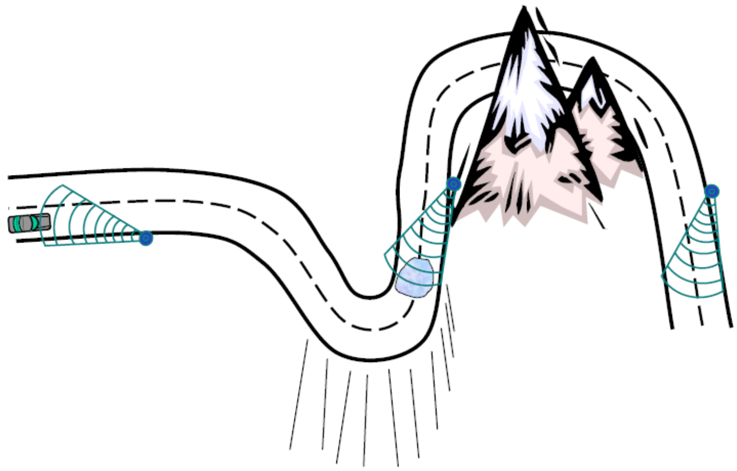

Figure 4.4 Curve Speed Warning scenario [2]

Table 4.4 summarizes various communication technologies for CSW application. The in-vehicle system combines information from the roadside beacon (through **5.9 GHz DSRC/3G/4G/Wi-Fi** communication) with vehicle parameters and on-board **sensor** data to determine if the driver should be warned to reduce speed in order to safely negotiate the curve. In this application, a warning could be derived using a digital map database (map download through **3G/4G/Wi-Fi** communication), **GPS** position (through **satellite** communication), vehicle speed, on-board **sensor** information, and vehicle handling characteristics, such as maximum allowable lateral acceleration and stability control parameters. The curve speed warning becomes much more reliable and accurate when up-to-date curve layout and actual road surface conditions are communicated from a roadside beacon to the approaching vehicle. The roadside beacon will provide road geometry parameters, which especially benefits vehicles that do not have onboard digital maps, current map updates, or GPS positioning. Changes to the curve’s geometry may be available via the beacon (possibly updated by a road maintenance crew or by digital map updates), which may be derived from probe vehicle reports. If properly equipped, an enhanced beacon may provide local **sensor** data to determine the actual road surface condition.

Table 4.4 CSW application by using various communication technologies

Communication technologies	Function description
Sensors for roadside	● Weather condition sensors (e.g., rain, heavy fog) ● Surface condition sensors (e.g., the presence and location of ice on the road) ● GPS sensor
Sensor for vehicle	GPS sensor
Satellite	Get GPS position

5.9 GHz DSRC	V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	● Download digital map ● V2R (Vehicle to Roadside) communication

4.5 VICS Applications

Using technologies: sensors, satellite, Radio wave, Infrared, FM

VICS (Vehicle Information and Communication System, since 1990)[15] is an innovative information and communication system, enables user to receive real-time road traffic information about congestion and regulation. This information is edited and processed by Vehicle Information and Communication System Center, and shown on the navigation screen by text or graphical form.

The VICS Center provides VICS information 24 hours a day, 365 days a year to the entire country using the three types of media shown below. There are two types of "Beacon", one is "Radio wave beacon" on expressways, and the other is "Infrared beacon" on major ordinary roads. "FM multiplex broadcasting" provides wide area information, and "Beacons" send necessary and detailed information about nearest road condition based on the position where the car is moving.

(1) Radio wave beacon

These beacons are installed mainly on expressways as shown in figure 4.5, providing road traffic information in a range of approximately 200km ahead of the car.

- Radio wave beacon can provide information about expressways, a by-path near interchanges, and neighboring ordinary roads, in a range of about 200 km ahead from the car.
- This information tells you the condition of traffic congestion, link-travel-time on expressway, regulations, SA/PA information, interruption, interval-travel-time between interchanges, etc.
- The navigation equipment can receive radio from your running direction within 70 meter radius from each beacon.

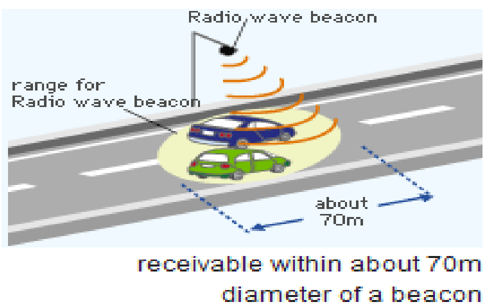

Figure 4.5 Radio wave beacon scenario

(2) Infrared beacon

These beacons are installed on main ordinary roads as shown in figure 4.6, providing road traffic information as far as 30km ahead of, and 1km behind the car.

- Infrared beacon can provide information about expressways and ordinary roads as far as 30 km ahead, and 1 km behind from the car.
- This information tells you the condition on traffic congestion link-travel-time, regulations, parking lot information, interval-travel-time, etc.
- The navigation equipment can receive signal from running direction within 3.5 m from each beacon.

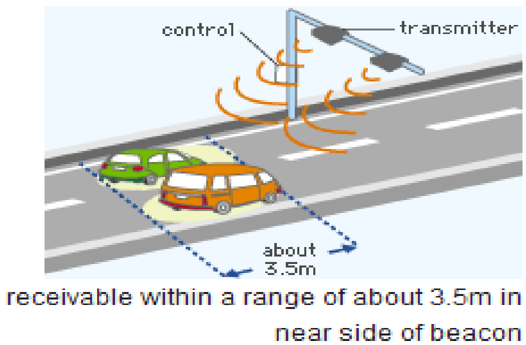

Figure 4.6 Infrared beacon scenario

(3) FM multiplex broadcasting

In figure 4.7, FM multiplex broadcasting provides road traffic information in the relevant prefecture and its surroundings from the local NHK FM broadcasting stations.

- FM multiplex broadcasting can provide information about the prefectures you are in, neighboring area and regional borders.
- Multiplexed with audio broadcasting from NHK FM stations, the information is sent in the same frequency band.
- The information is transmitted twice five minute to ensure reception, with the data of 50,000 characters per 2.5 minutes.

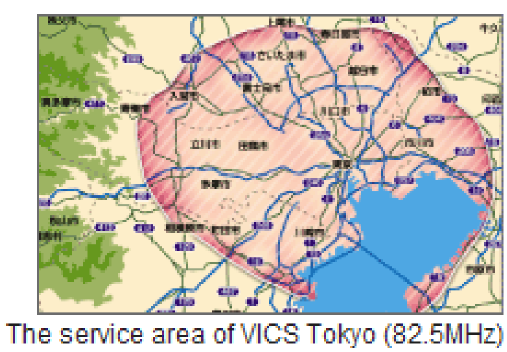

Figure 4.7 FM multiplex broadcasting scenario

VICS provides three kinds of displays in real time depending on the type of car navigation unit:

(1) Map Display (Level 3): This map display overlays VICS information about traffic congestion, etc. onto car navigation system maps. Drivers can see road and traffic information on their current location that allows them to avoid congestion and select the shortest route to their destination.

(2) Simple Graphic Display (Level 2): VICS information is displayed in simple graphic form on the monitor of the car navigation unit. The main feature of this type of display is that information is shown in simple, graphic patterns or text.

(3) Text Display (Level 1): VICS information is displayed in text form on the monitor of the car navigation unit. Information is provided clearly and briefly using short phrases.

The information received will vary according to the car location and the capabilities of the car navigation unit. Table 4.5 summarizes various communication technologies for VICS application.

Table 4.5 VICS application by using various communication technologies

Communication technologies	Function description
Radio wave, Infrared, FM	Transmits processed information to car navigation units.
Sensor for vehicle	GPS sensor
Satellite	Get GPS position

4.6 Smartway Applications

Using technologies: sensors, satellite, 5.8 GHz DSRC, Bluetooth, 3G/4G, Wi-Fi

A Smartway [16] cooperative vehicle-highway system platform facilitates the deployment of services from a core service, such as ETC, to services in conjunction with car navigation systems such as VICS (Vehicle Information and Communication System), one of the Smartway cooperative vehicle-highway system services. A Smartway platform also enables the smooth deployment of a variety of services, including services to support safe-driving such as AHS (Advanced cruise-assist Highway Systems), payment services for parking, etc., along with private sector services. The Smartway cooperative vehicle-highway system platform makes possible a variety of services and can be implemented smoothly, efficiently, and at a low overall cost.

Figure 4.8 shows the concept of the Smartway applications. The cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. Specifically, a variety of services are provided using a platform that consists of elements such as DSRC, ITS onboard units, digital maps, and roadside sensors, with the vehicle, driver, other vehicles, road managers, and service providers serving as the constituent elements of ITS. The private sector is expected to provide diverse services through the open Smartway platforms.

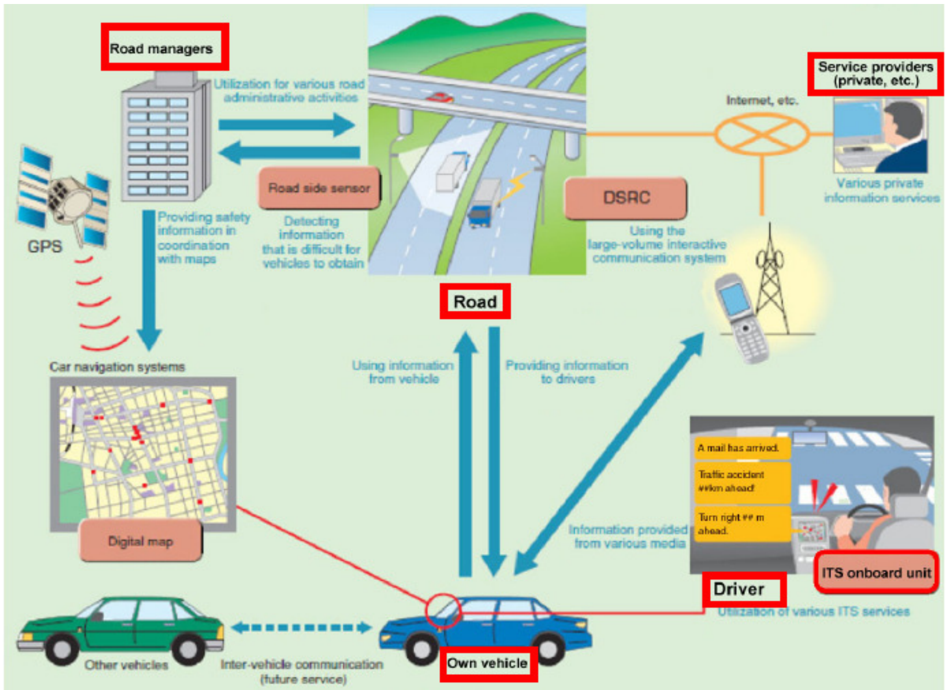

Figure 4.8 Various component elements and applications involved in ITS [16]

Figure 4.9 illustrates the deployment of services on the Smartway cooperative vehicle-highway system platform. A platform can be used to implement a wide variety of applications, including information supply applications, support for safe driving, road management, parking facilities, and disaster prevention measures. Table 4.5 summarizes various communication technologies for Smartway application.

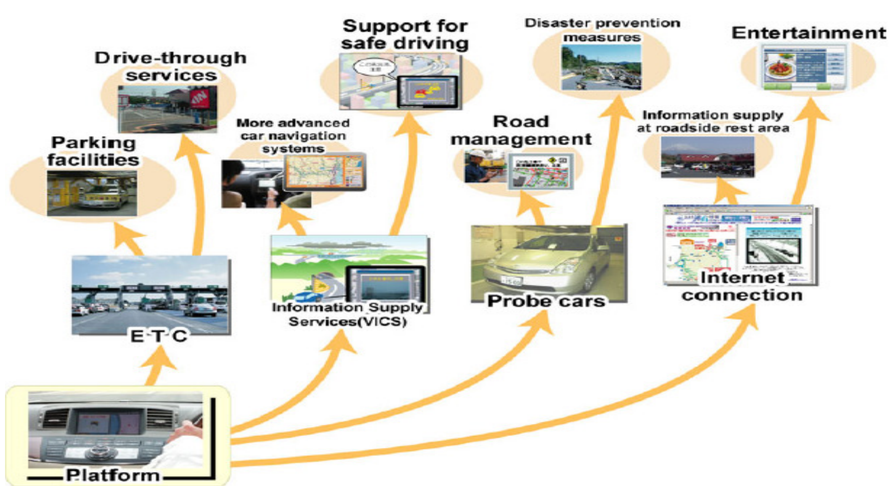

Figure 4.9 Evolution of Smartway applications [16]

Table 4.6 Smartway application by using various communication technologies

Communication technologies	Function description
Sensors for roadside	• Weather condition sensors (e.g., rain, heavy fog) • Surface condition sensors (e.g., the presence and location of ice on the road) • GPS sensor
Sensor for vehicle	GPS sensor
Satellite	Get GPS position
5.8 GHz DSRC	• V2V (Vehicle to Vehicle) communication • V2R (Vehicle to Roadside) communication
3G/4G/Wi-Fi	• Download digital map • V2R (Vehicle to Roadside) communication

4.7 Connected Car Application

Using technologies: 5.9 GHz DSRC, sensors, 3G/4G, Bluetooth, satellite, WiFi

"Connected Car" application is being considered for roadside inspections, freight tracking, road-condition notifications, parking management and enforcing rules on drivers' working hours. The core enabler of "Connected Car" application is providing effective data communications between vehicles and other sources and users of transportation and related data. The desire to deliver this capability in a focused and consistent manner was the primary driver behind the specification and development of 5.9 GHz DSRC. The communications networks, protocols, security, and messaging formats continue to be fundamental items of discussion and development for "Connected Car" research, development, testing, and demonstration.

The "Connected Car" is Visteon's Internet-connected platform for next generation infotainment services for the automotive market. The car is simply another mobile device, and the ability to fully integrate disparate features, functions and content is a critical aspect of providing a user experience that is optimized for the car. Using a combination of GPS and Wi-Fi, cars can communicate their location data to a central office, but it also enables them to communicate with each other. Visteon's "Connected Car" concept is an ideal platform for showcasing the power of providing seamless access to media while in the car. The prototype vehicle will be able to get online via a variety of methods, and considering that an estimated 62.3 million global consumers will have Internet access in their vehicles by 2016 (compared to just 970,000 at the end of 2009).

Figure 4.10 shows the basic ideas for using various wireless technologies in V2V/V2I communication. In the figure, all current popular communication technologies are used, including sensors, 5.9 GHz DSRC, satellite, WiFi, 3G/4G/WiMAX and Bluetooth.

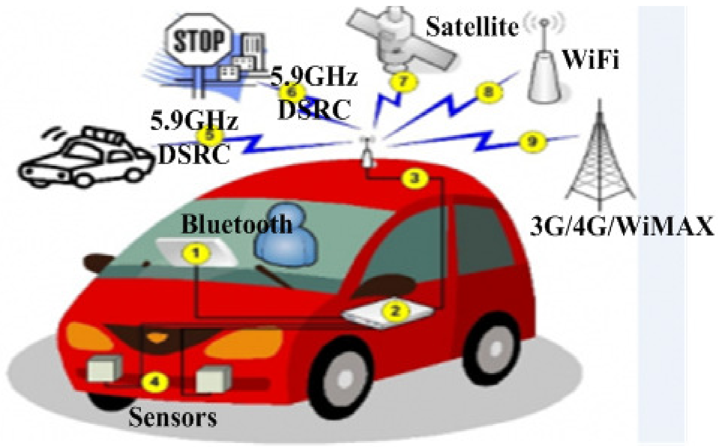

Figure 4.10 Basic concept of the Connected Car system

Table 4.7 summarizes various communication technologies for Connected Car application. In this application, **5.9 GHz DSRC** could be used, for example, to warn nearby cars of sudden braking or an airbag deployment, thereby alerting cars out of visual range and preventing or limiting accidents. It could be used to set up ad hoc networks to pass data between cars in order to, for example, signal icy spots on the road (many cars can detect ice through **sensors** as part of their skid-control systems) or co-ordinate "platoons"—groups of vehicles travelling closely together under automatic control. Other proposed uses include signaling the approach of emergency vehicles and ensuring that traffic lights give priority to buses and emergency vehicles. Besides using the 5.9 GHz DSRC technology, letting users listen to their favorite radio stations through a **3G/4G** or **Bluetooth** connection. The "Connected Car" application is also preparing a whole new in-car infotainment experience based around the Internet. Visteon clearly has put flexibility center stage by designing an open architecture automotive-grade in-vehicle infotainment (IVI) development platform that is capable of connecting to the outside world through various methods, including the use of embedded phones, tethered mobile devices or USB connectivity cards. Much more advanced GPS/video system would be in the car if it had access to the web (through **satellite, WiFi** or **3G/4G** communication).

Table 4.7 Connected Car application by using various communication technologies

Communication technologies	Function description
5.9 GHz DSRC	● V2V (Vehicle to Vehicle) communication ● V2R (Vehicle to Roadside) communication
Sensors	● GPS sensor ● Weather condition sensors (e.g., ice, rain, heavy fog)

Satellite	Combine a GPS receiver for vehicle position measurement
Bluetooth	In-vehicle infotainment (radio, music connection)
3G/4G/Wi-Fi	● In-vehicle infotainment (radio, web access) ● V2R (Vehicle to Roadside) communication

4.8 Vehicle Group Communication Application

Using technologies: sensor, satellite, 5.9 GHz DSRC

Over the comfort/entertainment applications in vehicle networks, group communications are expected to enhance the experience and amusement of driving. Since 2009, ITRI design and implement a Vehicle Group Communication System (VGCS) [17][18] over real-life IEEE 1609/802.11(p) On-Board Units (OBUs). VGCS can track the group members' current locations and broadcast voice/data over a vehicle group, enhancing drivers' and riders' experiences when they cruise together. Using VGCS each group member can broadcast his/her voice to other group members. The communications among group members are logically full-duplex. That is, one can speak and listen at the same time. With this function, a group member can quickly report its own status and observed road/traffic condition to the group leader and other group members, when encountering accidents or raising special needs (e.g., refueling). This way, the group leader can change the movements of the vehicle group to fast respond with the changes of road/traffic conditions and group members' needs (e.g., change the destination/route of the vehicle group or temporarily gather all group members in a certain place). VGCS also provides an integrated GUI interface to show and track the locations of all vehicle group members. Each group member periodically broadcasts its own location information using the 802.11(p) radio. Using this interface, the leader of the vehicle group can track the locations of all his group members, helping him make decision on the movements of the whole vehicle group. Table 4.6 summarizes various communication technologies for VGCS application.

Table 4.8 VGCS application by using various communication technologies

Communication technologies	Function description
Sensor for vehicle	GPS sensor
Satellite	Get GPS position
5.9 GHz DSRC	V2V (Vehicle to Vehicle) communication

4.9 Related Research Projects by Using Various Communication Technologies

4.7.1 The USDOT Connected Vehicle Research Program

The implementation dilemmas associated with the original VII (Vehicle-Infrastructure-Integration) approach and the new technologies emerging in the market indicated that it was time to adapt the research program based on new information. But, significantly, the original vision remained the same; it was only the USDOT Connected Vehicle Research Program [19] approach to achieving the vision that needed to be revised to take advantage of new opportunities.

Results of a recent high-level NHTSA analysis of the potential of V2V and/or V2I to address crash types indicate that V2V has the potential to address a large proportion of crashes involving unimpaired drivers. Specifically, up to 82 percent of all crashes by unimpaired drivers could potentially be addressed by V2V technology. If V2V were in place, another 16 percent of crashes could potentially be address by V2I technology. In imminent crash situations, V2V is uniquely capable of addressing forward collisions and lane change/merge collisions. At very high market penetration levels V2V can also address intersection collisions. V2I has the potential to address road departure and intersections crashes at lower market penetration levels. The actual effectiveness of V2V and V2I in addressing these crash types still remains to be tested.

While the potential of V2V technology was recognized in the VII Program, benefits would be delivered only when a sufficient number of equipped vehicles were on roadways to interact. Early in the VII program, it was difficult to envision a feasible way out of this dilemma. But now, a plethora of consumer electronics devices are available in vehicles. The exponential growth of the use of these devices by travelers may open up a new avenue to accelerate DSRC into the vehicle fleet.

The concept is to embed DSRC communications in aftermarket devices, such as navigation systems, so that they emit a simple “Here I Am” message. The “Here I Am” message would be a subset of the full V2V message. Portable navigation systems are prevalent, and many smaller consumer devices also have navigation applications. “Here I Am” messages are continually emitted when these devices are turned on, and do not require any driver interface. Safety could be significantly increased by notifying other vehicles of the location of a vehicle that contains a “Hear I Am” device.

Aftermarket devices have access to power, communication (typically cell) and location via GPS. This basic data, plus a little more, constitutes the “Here I Am” message. The V2V message includes all of this information, plus more robust data that is available directly from vehicle systems. The differences in message content will determine the type of applications that can be supported. “Here I Am” messages will probably have limitations in their capabilities; they will likely not have access to data from internal vehicle electronic systems. On the other hand, there is much that could potentially be accomplished with these simple messages. In addition, the presence of “Here I Am”- equipped devices would provide increased early benefit to fully equipped V2V vehicles, which could sense the location of an emitting device. The V2V research program includes testing and validation of aftermarket DSRC devices and their potential benefit for owners of both vehicles and devices. If the research shows that these devices are effective, the market penetration dilemma may be diminished. If not, then other options need to be pursued. DSRC ASDs (Aftermarket Safety Devices) developed and produced under this solicitation will undergo evaluation and testing by US DOT as described in this solicitation. Those ASDs deemed qualified will be eligible for placement on a Qualified Products List (QPL) for use in the upcoming planned Safety Pilot model deployment. US DOT anticipates that the Government, or designated Contractor, may purchase 300 to 500 ASD units from the various suppliers (e.g., ITRI) on the ASD QPL for use in the model deployment. US DOT anticipates that these purchased units will then be tested and installed in the candidate vehicles, subsequently referred to as aftermarket-equipped vehicles.

4.7.2 IVBSS

The IVBSS (Integrated Vehicle-Based Safety Systems) [20] program is a five-year cooperative research agreement to combine several crash warning subsystems-including forward collision, lane departure, lane change, and curve speed warning--into a single, integrated concept to enhance the safety of both passenger vehicles and heavy trucks.

During the first two years of the IVBSS program (2006-2007), the industry team designed, built, and conducted tests to verify the prototype systems on the passenger cars and heavy trucks. The prototype vehicles underwent a series of closed-course track tests aimed at ensuring that the integrated system met the performance requirements and was safe for use by unescorted volunteer drivers during the field operational test, which was planned for Phase II. Approval to proceed with Phase II was granted on April 8, 2008.

In Phase II (June 2008-October 2010), a fleet of 16 passenger cars and 10 heavy trucks were constructed and prepared for the field test. Ten (10) IVBSS-equipped International ProStar 8600-series trucks owned by Conway Freight, Inc. of Ann Arbor, Michigan were used. The heavy truck field test began in February 2009 and was completed on December 15, 2009. The trucks were driven by 20 volunteer drawn from the pool of Conway's regular pick-up and delivery and line haul drivers and operated over a ten month period, amassing 16,500 hours of driving. Approximately 650,000 miles of driving data was collected with 140,000 miles of baseline data and 510,000 miles with the integrated system enabled.

The light vehicle field test began in April 2009 and was completed on May 1, 2010. Sixteen 2006-07 Honda Accord LX sedans were outfitted with the IVBSS sensor suite and used by 108 volunteer drivers recruited in Southeastern Michigan. Field test participants used the vehicle for a 40-day period. During the first 12-days, the integrated system was disabled, allowing collection of baseline driving data. The integrated warning system became operational at the end of the 12th day, allowing collection of 28 days of driving data per volunteer. Light vehicle drivers were debriefed following completion of their use of the test vehicle and were invited to participate in focus groups along with other drivers. Approximately 220,000 miles of driving data was collected during the field test, with 74,000 miles of baseline driving data and 146,000 miles with the integrated system enabled.

Visteon is responsible for IVBSS system design, development and integration of: FCW with brake pulse; Lane Change Warning (LCW) with BSD; LDW (Lateral Drift Warning); CSW (Curve Speed Warning); radar to radar and radar to vision fusion; driver behavior model and arbitration; HMI (Human Machine Interface) for the multi-feature system; and the fabrication of 6 development vehicles and a 16-vehicle FOT (Field Operational Test) fleet. The FOT involves exposing a fleet of 16 IVBSS-equipped Honda Accord cars to 12 months of naturalistic driving. Laypersons with a valid driver's license were recruited to drive passenger cars equipped with the integrated system and data collection hardware installed on-board. The 108 test participants are lay drivers from southeastern Michigan who drove these cars as their personal vehicles for several weeks. The cars were instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics data. Subjective data on driver acceptance was collected using a post-drive survey, driver debriefing and a series of focus groups.

4.7.3 AASHTO Connected Vehicle

In 2009, AASHTO (American Association of State Highway and Transportation Officials) [21] prepared its Connected Vehicle Strategic Plan. Among the specific actions identified in the plan was the need to perform an analysis of the potential approaches for deploying the infrastructure components of Connected Vehicle systems by state and local transportation agencies. The plan also called for the identification of AASHTO's role in all aspects of Connected Vehicle infrastructure deployment.

This plan approaches Connected Vehicle infrastructure deployment as a set of likely sequential scenarios. It recognizes that technologies and events will continue to impact agency operations even without intentional decisions on the part of those agencies. The focus is on articulating the needs of the agencies and anticipating the context in which agencies will make specific deployment decisions.

The scenarios describe the progressive deployment of Connected Vehicle systems out to a twenty-year horizon. They start with an assessment of the current state, touching on key drivers and activities. Each step in time corresponds to a new deployment goal—a particular emphasis for that phase of development. Anticipated external events and policy decisions are also identified, and the most likely arc of technology developments is projected from the current state.

As a general guiding principle, the scenarios assume that public agencies will be motivated to deploy the field infrastructure for Connected Vehicle systems to achieve near-term benefits from applications that enhance mobility, provide localized safety improvements, or enhance the operational performance of the agency in some manner. Public agencies will deploy DSRC field infrastructure in recognition of its long-term value in Connected Vehicle active safety applications, but will leverage that investment to support a variety of applications in the near-term.

NHTSA (National Highway Traffic Safety Administration) plans to make two decisions relating to DSRC deployment. The first will be for light vehicles in 2013, and the second will be for heavy vehicles in 2014. NHTSA is not calling this a regulatory decision, but rather an "Agency" decision, and has committed to analyzing research results between now and then to determine whether or not subsequent action is merited. Subsequent action could include a rulemaking to require V2V safety equipment in vehicles. However, action could take many forms, with rulemaking being only one option.

For the purposes of IVBSS project, the scenarios assume that NHTSA will, in some fashion, decide to move forward with a requirement to mandate factory-installed DSRC equipment on-board both light and heavy vehicles. Assuming this happens, prior experience would suggest that on-board equipment (OBE) will first appear in newly-manufactured light vehicles for the 2020 model year, rolling out in 2019.

This timing assumption has a major influence on the deployment approach presented in the scenarios. While it can be said that the benefits to drivers of OBE-equipped passenger cars and heavy vehicles will increase as the deployment of RSEs increases, it is also true that there are no benefits to the deployers of RSEs if there are no OBE-equipped vehicles with which to communicate. Therefore, in order to encourage near-term deployment of DSRC roadside infrastructure, the state and local agencies must pursue approaches that do not rely on the presence of a growing population of factory-equipped passenger vehicles before the end of the current decade.

4.7.4 CAMP OTA Interoperability

A team formed by Visteon, PATH, and ITRI is currently participating in this CAMP-OTA (Over-the-air) interoperability study. The project, Interoperability Issues of V2V Based Safety System Project (V2V-Interoperability), is led by CAMP (Crash Avoidance Metrics Partnership, an automaker consortium) and is sponsored by US Department of Transportation (USDOT). The V2V-Interoperability Project addresses part of the NHTSA V2V Safety Application Research Plan. It is a follow-up to the recently completed Vehicle Safety Communications (VSC, 2003-05) and Vehicle Safety Communications – Applications (VSC-A, 2007-09) projects that specifically addresses interoperability challenges that are critical to the deployment and effectiveness of V2V safety systems. The goal of this project is to ensure that all V2V safety applications work across any, and all, equipped vehicles, regardless of make, model, or qualified retrofit equipment.

The V2V Interoperability system that will be developed as part of the project will serve as a test bed by which many technical issues that are currently roadblocks to deployment will be addressed. Issues that directly impact interoperability include message sets, communication standards, congestion control, data authentication, security, and privacy. Test bed and system requirements will be developed and will focus on facilitating the resolution of technical issues only. Any policy related issues or recommendations that arise from researching technical issues will be conveyed to the appropriate participants who are involved in resolving these issues. Resolutions to technical issues will be verified against current standards and anomalies or gaps, if present, will be identified, addressed and brought back to the appropriate standards bodies.

4.7.5 INTERSAFE-2

The INTERSAFE-2 project [22], which is funded by EC under the 7th Framework Program (June ’08 – May ’11), aims to develop and demonstrate a Cooperative Intersection Safety System (CISS) that is able to significantly reduce injury and fatal accidents at intersections.

Today, most so called “black spots” have been eliminated from the road networks. However, intersections can still be regarded as black spots. Depending on the region and country, from 30 to 60% of all injury accidents and up to one third of the fatalities occur at intersections. This is due mainly to the fact that accident scenarios at intersections are among the most complex ones, since different categories of road user interact in these limited areas with crossing trajectories.

The novel CISS combines warning and intervention functions demonstrated on three vehicles: two passenger cars and one heavy goods vehicle. Furthermore, a simulator is used for additional R&D. These functions are based on novel cooperative scenario interpretation and risk assessment algorithms.

The cooperative sensor data fusion is based on:

- state-of-the-art and advanced on-board sensors for object recognition and relative localization,
- a standard navigation map and information supplied over a communication link from
- other road users via V2V if the other vehicle is so equipped
- infrastructure sensors and traffic lights via V2I if the infrastructure is so quipped to observe the complex intersection environment.

As a result, the deployment of the INTERSAFE-2 system could provide a positive safety impact of 80% with respect to injuries and fatal accidents at intersections. Thus a total safety benefit of up to 40% of all injury accidents and up to 20% of all fatalities in Europe is possible.

The utilization of V2X communication for CISS at a small number of equipped intersections would boost the overall market penetration of communication in vehicles, since the benefit for those who buy first could be experienced at every equipped intersection.

4.7.6 CVIS

CVIS (Cooperative Vehicle-Infrastructure Systems) [23] is a major new European research and development project aiming to design, develop and test the technologies needed to allow cars to communicate with each other and with the nearby roadside infrastructure.

Based on such real-time road and traffic information, many novel applications can be produced. The consequence will be increased road safety and efficiency, and reduced environmental impact.

The project's ambition is to begin a revolution in mobility for travelers and goods, completely re-engineering how drivers, their vehicles, the goods they carry and the transport infrastructure interact.

With CVIS, drivers will influence the traffic control system directly, and get guidance to the quickest route to their destination. Information shown on road signs will be available wirelessly and be shown on a display in the vehicle. Such displays can also warn drivers of approaching emergency vehicles, allowing emergency personnel to reach accidents faster with less danger for themselves and for cars along their path. In the same way, hazardous goods shipments can be tracked at all times and have priority along a pre-selected safe route.

Other key innovations include high-precision positioning and local dynamic maps, a secure and open application framework for access to online services and a system for gathering and integrating monitoring data from moving vehicles and from roadside detectors and sensors.

All this, however, can only happen if there is full interoperability in the communication between different makes of vehicle and between vehicles and different types of roadside systems. CVIS will therefore develop a mobile router using a wide range of communication media, including mobile cellular and wireless local area networks, short-range microwave (DSRC) or infra-red, to link vehicles continuously with roadside equipment and servers. The project will apply and validate the ISO "CALM (Communications Access for Land Mobiles)" standards for continuous mobile communication, and will provide input to standards development in European and global standardization bodies.

To validate the project's results, all CVIS technologies and applications will be tested at one or more test sites in six European countries: France, Germany, Italy, Netherlands/Belgium, Sweden and the UK.

However, technology is not the only stumbling block on the road to a reality where every car, every traffic light, every road sign and every kilometer of roadway is equipped with CVIS-like technology. A number of non-technical obstacles will also have to be overcome. The CVIS project is therefore creating a toolkit to address key "deployment enablers" such as user acceptance, data privacy and security, system openness and interoperability, risk and liability, public policy needs, cost/benefit and business models, and roll-out plans for implementation.

CVIS Project Key Results

Within the main blocks of Core Technologies, Cooperative Applications, Test Sites and Deployment Enablers, the CVIS project will produce the following key results:

- a multi-channel terminal capable of maintaining a continuous Internet connection over a wide range of carriers, including cellular, mobile Wi-Fi networks, infra-red or short-range microwave channels, ensuring full interoperability in the communication between different makes of vehicle and of traffic management systems;
- an open architecture connecting in-vehicle and traffic management systems and telematics services at the roadside, that can be easily updated and scaled up to allow implementation for various client and back-end server technologies;

- techniques for enhanced vehicle positioning and the creation of local dynamic maps, using satellite positioning, radio triangulation and the latest methods for location referencing;
- extended protocols for vehicle, road and environment monitoring to allow vehicles to share and verify their data with other vehicles or infrastructure nearby, and with a roadside service centre;
- application design and core software development for:
    - cooperative urban network management, cooperative area destination-based control, cooperative acceleration/deceleration and dynamic bus lanes;
    - enhanced driver awareness and cooperative traveler assistance on inter-urban highways;
    - commercial vehicle parking and loading zones booking and management, monitoring and guidance of hazardous goods and vehicle access control to sensitive areas.
- deployment enabling toolkit in the form of models, guidelines and recommendations in the areas of openness and interoperability; safe, secure and fault-tolerant design; utility, usability and user acceptance; costs, benefits and business models; risks and liability; cooperative systems as policy tool; and deployment road-maps.

4.7.7 VICS

In Japan, the VICS (Vehicle Information and Communication System) [15] system aims at improving convenience for drivers by offering following three advantages. First, VICS makes it possible to cut costs by shortening the time required for transportation. Second, VICS improves road safety by providing accurate information. Third, VICS helps to protect the environment by streamlining traffic. The objective of the VICS system is to create a higher standard of living, and contribute to social and economic development by offering these advantages. Eliminating traffic congestion, reducing traffic accidents, and improving road environment are challenges faced by every nation in the modern world. VICS addresses these concerns by enabling drivers to select the shortest, most convenient routes available and ensuring that traffic is dispersed appropriately. VICS is being utilized successfully as a system for improving road safety and traffic flow, making roads more driver-friendly.

4.7.8 Smartway

Smartway [16], Japan's cooperative vehicle-highway systems, consists of roads, vehicles, communication and processing systems. The concept of the Smartway, cooperative vehicle-highway system platform was developed on the basis of Japan's experience in the deployment of ITS. Specifically, a variety of services are provided using a platform that consists of elements such as DSRC, ITS onboard units, digital maps, and roadside sensors, with the vehicle, driver, other vehicles, road managers, and service providers serving as the constituent elements of ITS. The private sector is expected to provide diverse services through the open Smartway platforms. A Smartway cooperative vehicle-highway system platform facilitates the deployment of services from a core service, such as ETC, to services in conjunction with car navigation systems such as VICS, one of the Smartway cooperative vehicle-highway system services. A Smartway platform also enables the smooth deployment of a variety of services, including services to support safe driving such as AHS, payment services for parking, etc., along with private sector services. The Smartway cooperative vehicle-highway system platform makes possible a variety of services and can be implemented smoothly, efficiently, and at a low overall cost. Various means of communications, such as mobile phone, DSRC, FM multiplex broadcasting etc., are available for connecting road and vehicle. It is important to consider the characteristics of each communication technology when selecting the most suitable communication means.

4.10 Matrix Analysis by the Various Communication Technology in Different Application Service Scenarios

Communications technologies are also changing—and driving change—faster than any other area of technology. The transportation community's needs and opportunities are not unique among private or public industries. The communications products and services on the market are serving an immense range of applications. The diversity of needs has engendered a corresponding diversity of communication solutions, some of which might be applicable to the particular needs of a transportation systems opportunity. **This section provides a summary of communication technologies that have potential for addressing some part of safety, efficiency or comfortable applications.**

In section 2.7, the various wireless technologies for different applications (Safety, Efficiency and Comfort/Entertainment) are compared in a matrix analysis table. In this chapter, Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations

(CICAS-V) and Curve Speed Warning (CSW) safety application scenarios are described. For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services.

Table 4.7 provides a summary of various communication technologies in different application service scenarios. FCW, EEBL and Vehicle Group Communication applications require vehicle-to-vehicle communications, while CICAS-V, CSW, VICS, Connected Car and Smartway applications require infrastructure to vehicle communications.

Table 4.9 Different application scenarios by using various communication technologies

Applications / Technologies	5.9 GHz DSRC	Sensors	Satellite	Bluetooth	3G/4G/ WiMAX	Wi-Fi	Radio	Infrared
Forward Collision Warning (FCW)	○	○	○		○	○		
Emergency Electronic Brake Lights (EEBL)	○		○		○	○		
Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)	○	○	○		○	○		
Curve Speed Warning (CSW)	○	○	○		○	○		
VICS	○ (5.8 GHz)	○	○	○	○	○	○	○
Smartway	○ (5.8 GHz)	○	○		○	○	○	○
Connected Car	○	○	○	○	○	○		
Vehicle Group Communication System	○	○	○		○			

5 Conclusions

A number of comments and remarks can be drawn from this industry report. At the highest level of abstraction, the main conclusion is that 5.9 GHz DSRC is potentially an important enabler of a large number of vehicle safety applications, and other communication technologies offer significant potential application (e.g., efficiency or comfort/entertainment) benefits in the longer term.

- **Comments and Remarks for Wireless Communications Technologies**

The current wireless communications technologies are presented that includes 5.9 GHz DSRC, cellular 3G/4G, satellite, Wi-Fi, Bluetooth, FM-RDS and Infrared. 5.9 GHz DSRC is uniquely suited to mobile vehicular applications needing high bandwidth and low latency in short range communications (on the order of a few hundred meters). Each communication technology has different strengths and weaknesses as shown in Table 5.1.

Table 5.1 Strengths and weaknesses for various communication technologies

Technologies	Strength	Weakness
5.9 GHz DSRC	low latency, high mobility, free communication costs	low bandwidth, limited coverage
Cellular 3G/4G/LTE/WiMAX	high bandwidth, wide coverage, high mobility	high latency, requires communication costs
Satellite	wide coverage, provides navigation information for vehicles	high latency, requires airtime costs
Wi-Fi	wide deployment, easy configurations, cost savings	limited coverage, high latency, high mobility cause high packet loss rate
Bluetooth	low power (consumes less battery), low cost	high latency, low speed, limited coverage
FM-RDS	high coverage, low cost	high latency, low speed
Infrared	wide used for military and civilian purposes, low cost	short coverage

3G/4G cellular communication services are available from a host of providers in the U.S. The technologies underlying those services vary among providers, but all provide similar voice and data services through phone handsets and cellular data modems. Cellular network services are not generally appropriate, however, for real-time localized data exchange. Network latencies and the potential for dropped connections make cellular services inappropriate for real-time V2V and I2V safety applications. Satellite is very suitable for comfortable applications (e.g., satellite television/satellite navigation). Wi-Fi is not specifically designed for vehicular applications, but has been used effectively to communicate between vehicles and fixed stations, such as parking lots and maintenance yards. Wi-Fi connections from vehicles to roadside collectors have been used in probe data collection applications in Michigan. Bluetooth allows transfer speeds of up to 1 Mb/s, which is suitable for in-vehicle entertainment applications (e.g., hands-free calling with mobile phones).

Compared to other wireless communications technologies, however, 5.9 GHz DSRC is still early in its development and application life cycle. Proof-of-concept demonstrations have been deployed in Michigan and California, but there are to date no widespread deployments. Some private demonstrations by a 5.9 GHz DSRC system vendor of tolling applications have been provided to certain agencies. U.S.DOT is currently developing a Safety Pilot Program for a large demonstration of V2V and I2V safety applications in 2011-2013.

- **Comments and Remarks for Different Type of Vehicles**

Different type of vehicles (e.g., light vehicle, transit vehicle and heavy vehicle) should use several communication technologies in their application. Table 3.2 provides a summary of various communication technologies and applications in different type of vehicles. Basic requirements are required that message packet size is small, approximately 200 to 500 bytes, not including the security overhead, which is approximately 200 bytes.

Maximum required range of communications is short, about 50 to 300 meters. Most applications are one-way, point to multipoint broadcasting messages, also have allowable latency of 100 milliseconds. Pre-crash warning has special requirements in two way, point to point messages, and an allowable latency of 20 milliseconds.

- **Comments and Remarks for Different Type of Applications**

Four popular safety applications (Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), Cooperative Intersection Collision Avoidance System – Violations (CICAS-V) and Curve Speed Warning (CSW)) that are potentially enabled by 5.9 GHz DSRC have been identified just within the scope of this report. Having such a range of potentially enabled safety applications means that the installed cost of 5.9 GHz DSRC (and other required) hardware in vehicles may be able to be balanced by the benefits of the multiple applications, thus substantially reducing the effective cost-per-application. For efficiency applications, VICS and Smartway applications are developed for ETC or payment services. For comfort/entertainment applications, Connected Car and Vehicle Group Communication System (VGCS) application are developed for voice or music sharing services. Chapter 4 also reviews eight research projects (The USDOT Connected Vehicle Research Program, IVBSS, AASHTO Connected Vehicle, CAMP OTA

Interoperability, INTERSAFE-2 and CVIS, VICS and Smartway) by using various communication technologies. Table 5.2 shows that each application uses several types of communication technologies.

Table 5.2 Safety applications by using different communication technologies

Applications	Using Communication Technologies
Forward Collision Warning (FCW)	sensors, satellite, 3G/4G, Wi-Fi, 5.9 GHz DSRC
Emergency Electronic Brake Lights (EEBL)	5.9 GHz DSRC, satellite, 3G/4G, Wi-Fi
Cooperative Intersection Collision Avoidance System – Violations (CICAS-V)	sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi
Curve Speed Warning (CSW)	sensors, satellite, 5.9 GHz DSRC, 3G/4G, Wi-Fi
VICS	sensors, satellite, Radio wave, Infrared, FM
Smartway	sensors, satellite, 5.8 GHz DSRC, Bluetooth, 3G/4G, Wi-Fi
Connected Car	5.9 GHz DSRC, sensors, 3G/4G, Bluetooth, satellite, WiFi
Vehicle Group Communication System	sensor, satellite, 5.9 GHz DSRC

Furthermore, communications infrastructure presents a variety of challenges, especially since technology is changing so rapidly. Depending on the application, different communications media will be either desirable or necessary. Fiber optic cable, in which many states have invested heavily, and radio systems including 800 MHz were frequently mentioned as either needing expansion or requiring new infrastructure to support backhaul. It was noted that where signalized intersections will be equipped with 5.9 GHz DSRC RSEs for safety applications, technical issues remain, such as line-of-sight, and interference. Any of these could potentially impact a safety system's ability to function properly.

Commercial cellular services have been used in a variety of commercial telematics deployments. The California SafeTrip-21 Connected Traveler Field Test Bed Mobile Millennium project used standard 3G Nokia phones as probe data sources. Cellular connections have been used for backhaul from RSEs in the VII California Test Bed and as one option in the VII POC Test Bed in Michigan. OnStar has used a dedicated on-board cellular connection for many years, and Ford is using a Bluetooth connection to a driver's cell phone handset for its SYNC connection. In addition, although WiMAX has been deployed in the U.S. by Clearwire as a 4G commercial cellular service, it can operate in unlicensed spectrum and can be deployed as a private network. It was used for backhaul purposes as part of the VII POC in the Michigan demonstration test environment.

In recent years, sensors play an important role in safety applications (e.g., FCW, CICAS-V and CSW). Especially, the light vehicle should use a combination of GPS, digital maps, cameras (e.g., Forward-Looking camera), short-range sensor and long-range sensor (e.g., Forward Looking senor, Rear-looking sensor, Side-Looking sensor, Yaw Rate sensor and GPS sensor). The heavy vehicle should use Forward-Looking Camera and several types of sensors (e.g., Forward sensor, Rear-Looking sensor, Side-Looking sensor, GPS sensor and Yaw Rate sensor).

In the future, some safety applications will be broadly useful across the industry, but may not have a large enough market to directly incentivize commercial development. Alternatively, significant investment for research and development relative to the size of the market may create a barrier to entry for any but the largest developers. Interoperability requirements and over-specification of features can constrain innovation and further reduce competitive commercial incentives. In these cases, it may make sense to directly fund development of applications that benefit the industry as a whole. Agency coalitions and pooled funds have successfully used this development model for ITS applications and demonstrated its effectiveness under similar constraints.

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Enabling Accelerated Installation of Aftermarket On-Board

Equipment for Connected Vehicles

TASK 2: VENDOR/MARKET READINESS REPORT

December 9, 2011

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Cooperative Transportation System Pooled Fund Study

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Executive Summary

This Vendor/Market Readiness report is the second milestone in the University of Virginia's Enabling Accelerated Installation of Aftermarket On-Board Equipment (OBE) for Connected Vehicles Project, conducted under the umbrella of Cooperative Transportation System Pooled Fund Study. The report summarizes industry's views of the current market readiness through interviews conducted with OEM, Tier 1, and Tier 2 experts. In addition, the availability of OBE hardware manufacturers to provide aftermarket dynamic configurable multi-band OBE product has been documented. Finally, the report captures consumer insight through focus groups on product attributes, unmet consumer needs, aftermarket OBE pricing, time to market for OBE applications, and where to distribute aftermarket OBE products.

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 Vehicle Research Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the 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 Program systems and applications will not be accepted by consumers on its own merits.

In this vendor/market readiness report, the thoughts of the industry are communicated, along with the current availability of devices and the ability for industry to manufacture OBE equipment. In addition, consumer opinions with regards to product features and price points are documented.

1.2 Report Layout

In Chapter 2 the opinion of industry is broken into three sections: OEMs, Tier 1 suppliers, and Tier 2 suppliers. Each of the sections will provide insight on the challenges, opportunities, technologies, features, and product readiness of aftermarket OBE as expressed by industry experts. A summary of the key findings from all three groups will conclude the chapter.

Chapter 3 provides an analysis of onboard equipment beginning with background information with regards to the aftermarket industry, followed by an overview of components related to aftermarket products. Next, the availability of key technologies required for aftermarket products will be discussed. An assessment of potential aftermarket OBE products will be reviewed. Finally, a summary of the readiness of aftermarket OBE hardware will complete the chapter.

Chapter 4 will provide perspectives from surveyed consumers based on focus group studies with regards to product attributes, unmet customer needs, OBE hardware pricing, thoughts on when product features would come to market, and where consumers would prefer to purchase, as well as service OBE hardware.

Chapter 5 provides conclusions based upon the interviews conducted, the OBE hardware analysis, focus group events, and expert judgment.

2 Interviews

The research team identified a broad list of industrial experts to interview and solicit inputs from several different sectors of the automobile and technology industries. Among those that provided documented feedback, the group of experts included five OEMs, eight Tier 1 Suppliers, and ten Tier 2 Suppliers. This chapter will share their opinions on challenges, opportunities, technology, features, and product availability for the aftermarket onboard equipment market. Section 2.1 will focus on insight from automotive manufacturers. In section 2.2 Tier 1 suppliers' feedback will be discussed. Section 2.3 will provide reactions from Tier 2 suppliers. Section 2.4 will summarize key insights from all three groups.

2.1 OEMs (Automotive Manufacturers)

Automotive manufacturers have committed considerable resources in research and development related to vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies to date. They are steadfast in developing next generation vehicle technologies to improve safety and security while enhancing efficiency, convenience, and comfort. All of the OEMs interviewed embrace the development and deployment of intelligent transportation systems and were keen to share their thoughts on challenges, opportunities, technology, features, and product availability. In the next few paragraphs we will discuss each area in greater detail.

Challenges will exist with any new product or system introduced into the market, and V2V/V2I systems are no exception. OEMs conveyed four main areas of concern with regards to the acceleration of aftermarket OBE into the market. The first challenge is the deployment of the infrastructure to support OBE hardware. The second concern is the stability and reliability of communication coverage over the majority of United States roads. The third concern revolves around security and the ability for V2V/V2I systems to authenticate users instantaneously 100% of the time. The final challenge is related to a viable business model where OEMs can offer a product that delivers required features and functions to the consumer profitably. It is expected that collaboration and compromise among key stakeholders will identify viable solutions that can be implemented.

With regards to opportunities that the OEMs identified, there are three key areas to assist in the acceleration of OBE deployment. The main consensus to accelerate deployment is a government mandate that will establish basic principles required for V2V and V2I systems and allow industry to work together on developing the appropriate products for the market. Another opportunity is the development of industry standards to help with reliability or interoperability issues. Well defined standards assist in the product development phase and reduce the time to deliver a product to market. The third area with potential is incentives from the insurance industry for the purchase and installation of OBE hardware. The customer receives the short term benefit by subsidizing the cost of the OBE hardware and everyone benefits from the long term gains associated with the reduction in accidents, elimination of fatalities, less congestion, and a low carbon society.

In regards to wireless communication technology associated with V2V and V2I products the OEMs are aligned with the type of communication technologies that are suitable for given applications. For safety applications, 5.9 GHz DSRC is currently the appropriate technology. For efficiency and comfort applications, 3G/4G/LTE are the technology of preference. Wi-Fi could be used for some comfort applications with the understanding that connection to Wi-Fi is limited to certain scenarios and not viable during typical driving modes. Both two-way satellite and Bluetooth wireless communication are not practical technologies for the primary communication of V2V and V2I systems.

During the discussion of aftermarket OBE features the OEMs provided insight on a tiered approach to deploying features and functions. Initial systems should focus on safety applications that are passive and provide the driver relevant information or warnings of upcoming events. Efficiency and comfort applications can be introduced at the same time based on consumer interest and acceptance. The subsequent generation of products should continue to advance the safety features from passive to a more active role to warn drivers of upcoming events. Furthermore, as the industry takes action on consumer feedback from products and applications in the field, the number of efficiency and comfort applications available to the consumer will increase greatly.

In looking at the ability to manufacture and deliver aftermarket OBE to the market the majority of OEMs envision a three to four year product delivery plan. This assumption takes for granted that the major challenges discussed earlier in this report have been addressed and all stakeholders are in agreement on practical solutions. In general, the OEMs believe the supply base has feasible product delivery plans to support the OBE market and there is no design or manufacturing limitations at this time.

2.2 Tier 1 Suppliers

Similar to OEMs, the Tier 1 Suppliers are investing significant time and resources in developing technologies related to V2V and V2I systems. They have aligned goals with the OEMs to deliver advanced safety and security systems. In addition to safety and security, they plan to improve or add efficiency and comfort features as well. Through the interviews the Tier 1 Suppliers provided input on challenges, opportunities, technology, product features, and product availability. Even though most of the feedback from the interviews aligned with the OEMs opinion, there are some additional insights we will discuss in the following paragraphs.

The four main concerns of the Tier 1 suppliers matched with that of the OEMs - infrastructure deployment, communication coverage, security, and business case. In addition, there were two more concerns frequently discussed with the group. The first item is bandwidth limitations of the wireless communication system in cases where too many users in a particular area overload the network. In current cellular networks this scenario can happen and some percentage of the users lose cellular service. Loss of service may be tolerable for cellular consumers since their usage is typically not safety critical, but for V2V and V2I systems a loss of communication would be unacceptable. The second concern mentioned is driver distraction for the consumer with new V2V and V2I systems. It is imperative that government and industry collaborate on the user experience related to V2V and V2I systems in order to minimize the possibility of driver distraction when consumers interact with these safety systems. Fortunately, projects like the Safety Pilot/Model Deployment program will provide a collaborative environment for all stakeholders to observe, document, and address the major challenges identified.

The insight from Tier 1 Suppliers with regards to opportunities echoed the opinion of the OEMs. A government mandate, industry standards, and insurance industry incentives are great initiatives to accelerate an aftermarket deployment. The key to success is for each initiative to deliver resolution to some degree during the aftermarket deployment phase. Another opportunity discussed by the Tier 1 Suppliers involves the experience of the consumer. Products that satisfy customer expectations such as ease of use, performance, and perceived value will be successful in the market. It would be easy to say that industry is the only stakeholder responsible for addressing the experience of the consumer, and in most markets this is true, but for the V2V and V2I market where safety is so critical all stakeholders have a responsibility to contribute to an acceptable consumer experience.

In evaluating wireless communication technology the majority of the Tier 1 Suppliers are in agreement that 5.9 GHz DSRC is the primary communication technology for safety applications. There is also consensus with efficiency and comfort applications using 3G/4G/LTE communication. A few responses indicated the potential of future LTE networks to support some of the safety applications planned for DSRC, but not completely replace DSRC as the primary communication technology. Additional research would be required to understand the complete role of the LTE network and what applications LTE is suitable for. Tier 1 Suppliers agree with OEMs that Wi-Fi would be appropriate for comfort features, but view it as impractical for V2V systems during typical driving modes. Two-way satellite and Bluetooth wireless communications are also viewed by the group as unlikely technologies for primary communication in V2V and V2I systems.

With regards to aftermarket OBE features, the Tier 1 Suppliers envision safety, efficiency, and comfort applications all being available to the consumer. They all agree that safety features should be standard, with efficiency and comfort features being optional. The thought behind standard and optional features is based on the assumption that the majority of consumers will be more interested in efficiency and comfort than safety. This should drive demand in purchasing optional features, which in turn should provide an additional source of revenue beyond the purchase of the base hardware.

Tier 1 Suppliers have accounted for the ability to manufacture and deliver aftermarket OBE in their product delivery plan. The majority of the Tier 1 Suppliers refrained from sharing their production timing for V2V and V2I systems mainly due to proprietary information. Some were willing to provide their opinions, which correlated with the observation from OEMs for a three to four year product delivery plan. Tier 1 Suppliers are confident that the supply base can achieve their product delivery plan.

2.3 Tier 2 Suppliers

In support of the OEMs and Tier 1 Suppliers, the Tier 2 Suppliers are devoting considerable time and resources to developing new components or enhancing existing components to advance the development of V2V and V2I systems. They are in a unique position to leverage technologies and products designed for adjacent industries to accelerate the product development process for the automotive industry. During the interview process the Tier 2 Suppliers provided similar feedback on challenges, opportunities, technology, OBE features, and product availability. The insight received is comparable to the other two group interviews with a few new points to be examined.

Beginning with challenges, the Tier 2 Suppliers were completely aligned with the Tier 1 Suppliers concerns of infrastructure deployment, communication coverage, security, business case, bandwidth limitations, and driver distraction. Of the six areas mentioned, the Tier 2 Suppliers view infrastructure deployment, communication coverage, and the lack of business case as top concerns for V2V and V2I systems. This group identified liability as an additional concern. Due to the nature of the safety systems being discussed, a few of the Tier 2 Suppliers viewed liability as an area where government and industry need to work in partnership. They believe collaboration between industry and government is vital when developing potential solutions for all of the challenges.

The opportunities shared by the Tier 2 Suppliers were again completely in line with the views of Tier 1 Suppliers. This alignment once again demonstrates how well the industry works together to achieve common goals and initiatives. They are certain that the best opportunities to accelerate deployment lie in the area of a government mandate, release of industry standards, participation by the insurance industry, and a successful consumer experience. The Tier 2 Suppliers believe additional initiatives will surface as plans are developed and executed for the main opportunities identified.

In reviewing wireless communication technology with this group there is no difference in opinions of the OEMs or Tier 1 Suppliers. The use of 5.9 GHz DSRC for safety applications and 3G/4G/LTE for efficiency and comfort applications show the most promise for accelerated deployment. Several of the suppliers added that as the capability of the LTE network evolves over time safety features could leverage these advancements. Tier 2 Suppliers provided the same insights as the other two groups with regards to Wi-Fi, two-way satellite, and Bluetooth.

The Tier 2 Suppliers believe aftermarket OBE safety features should be the primary focus with regards to delivering applications to the market. The reason for this is that the efficiency and comfort applications have been part of the mobile device market since the introduction of the smartphone and implementation of these type of features into OBE hardware will require much less time than safety features. Due to the different development times, they are convinced that efficiency and comfort features are ready and will continue to evolve for deployment, while safety features are being implemented and offered.

With regards to the ability to manufacture and deliver aftermarket OBE the Tier 2 Suppliers are the most confident in having components ready for OEMs and Tier 1 Suppliers. The majority of suppliers believe one to two year product delivery plans are attainable for the components they plan to develop for the market. This confidence is derived from their ability to leverage technology and components developed for other industries, which reduces development and deployment times.

2.4 Summary of Interviews

In looking at all three groups as a whole there is admirable alignment among each of them with regards to the five topics we discussed. In terms of industry's view of accelerating deployment of aftermarket OBE hardware there is consensus on challenges, opportunities, technology, OBE features, and product availability. Having consensus is the first step to building a solid development plan. It is important for government and all other stakeholders to come to the same level of consensus with industry in order to achieve the goal of accelerating the deployment of OBE into the market and realizing the benefits of Connected Vehicles. From the view point of industry they are committed and appear to be willing to work with all stakeholders to achieve the goal.

3 OBE Hardware Analysis

3.1 Background

To discuss the OBE hardware availability, we suggest starting with a broader perspective. Aftermarket can come in many forms and levels of capabilities, which will be tailored to the preference of customers and visions of marketers that are built on viable business cases. For example,

- Value-added subscription services to provide real-time traffic information are being offered via portable navigation devices (PND).
- Applications can be purchased and downloaded onto cellular phones to execute various convenience and entertainment services.
- Nokia's Terminal Mode[i] approach is to enable users to run smart phone applications with built-in vehicle interface and to facilitate creations of new services and applications with the same platform on the phones or in the cars.
- USDOT's Safety Pilot Program is in the process of developing and implementing selective types of aftermarket devices that can perform safety functions, such as curve speed warning (CSW) and emergency electronic braking light (EEBL), based on vehicle-to-infrastructure and vehicle-to-vehicle communication via Dedicated Short-Range Communications (DSRC).

3.2 Aftermarket Components

To help assess the availability of on-board aftermarket devices, it is helpful to dissect into the envisioned functionality and components of an aftermarket device. Essentially, an aftermarket on-board equipment (OBE) or device (OBD) includes the following components:

- Wireless Communication links
  This is central to the operational concepts of connected vehicles, in which wireless communication links enable the exchange of data and empower the applications for safety, mobility, environment, comfort, convenience, etc.
- Interface
  The most common manner of interfacing with the drivers/users are provided via visual and auditory messages, but haptic or other means to offer sensory inputs to users may also be considered.
- Application/Processing
  Depending on the system architecture, a varying degree of processing power is needed and it resides within the OBE/OBD.
- Data Storage
  Depending on the system architecture, a varying degree of data storage capability will reside within the OBE.

3.3 Availability of Key Technology Components

A general review is provided below to assess the availability of technical components that are required to construct aftermarket devices:

- Communication links
  The wireless communication links that have been discussed or deployed for Connected Vehicles usage includes Bluetooth, Wi-Fi, DSRC, Cellular, Radio, and Satellite, and Infrared.. Almost all of these technological elements are very mature and in mass production, except for DSRC. With ongoing evaluation and validation activities conducted by industry and government DSRC technology will be fine tuned and ready for initial deployment. Government regulation may help to speed up its process for maturity and mass production.
- Sensor
  A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. For example, a Forward Collision Warning system will typically use a forward-looking sensor mounted at the front of the host vehicle that detects targets (other vehicles or objects) ahead of the host vehicle and in its field of view. There has been tremendous progress in this area, and the market is generally ready to offer sensors to be coupled with aftermarket devices if needed.
- Global Navigation Satellite System
  Providing highly accurate positioning information by means of Global Navigation Satellite System (e.g. GPS) is important for ITS applications, especially crucial for time-critical active safety applications. Achieving lane-level precision may be necessary for lane change warning or intersection collision warning.
- Interface
  In recent years, automakers have implemented and offered a number of in-vehicle features, including comfort and convenience applications such as Telematics Services offered by OnStar[ii], Ford Sync[iii] and similar systems. In addition, safety systems are increasingly available to provide lane-departure warning and prevention, pedestrian alerts, blind spot warning, frontal collision warning and braking assist. It suffices to say that the state-of-the-art in-vehicle interface, as provided by OEMs today, will have the capabilities to handle the required driver interaction in aftermarket devices if they can be adopted appropriately for the functionality served by aftermarket devices. The caveat is that aftermarket devices may not be fully integrated, with vehicle-based Control Area Network (CAN) data bus for example, and may only provide limited forms of interactions. While NHTSA have taken steps to offer guidelines in interface design after considering various issues including driver distraction, the effectiveness

of a safe and effective driver interface via portable and aftermarket devices remains an open question and is to be evaluated on a case-by-case basis.

- Processing/Data Storage
  Given the advancements in computing, there is little doubt that the electronics industry is well positioned to provide the needed functionalities and capabilities to be implemented on aftermarket devices.
- Application
  The acceptability and usefulness of applications have to be evaluated on a case-by-case basis, given the potential diversity of aftermarket devices. With an increasing number of in-vehicle Telematics systems being offered by OEMs and industrial participants and the dynamic adaptive capabilities of the computing and software industries, any deficiency in this landscape will be quickly overcome. The robustness and feasibility of safety-oriented applications, such as DSRC-based V2V and V2I functions, are still in the process of being verified in field tests conducted by the automakers and government agencies around the globe. The current USDOT Safety Pilot Model Deployment[iv], for example, is a major effort in this aspect.

3.4 Current Status and Evolutionary Choices of Aftermarket OBE

In this section, we contemplate and assess the potential adoption of various devices as aftermarket OBE, from their current forms. First, the necessary additions to several portable or brought-in devices that are required for these devices to become an effective OBE capable of realizing full safety, mobility, and environment benefits are considered. For example, in the current USDOT Safety Pilot activities, a couple of vendors have proposed to integrate safety functions into cell phones. In another example, Japan Smartway[v] project is adopting an approach that builds upon Electronic Toll Collection (ETC) and VICS[vi] to offer an OBE that expands to safety and other applications.

The table below provides an overview of some currently available devices and their potential to become the envisioned aftermarket devices.

Table 3.1 Overview of available devices

Types of Devices	Current Functionality and Capabilities	Additional Features Needed
Portable Navigation Devices	• Map/GPS/Navigation • Optional Traffic Information (via FM-RDS)	• Computing power to host additional applications • Additional interface with drivers if needed; It needs to be cognizant of driver distraction issues

		• Additional communication links (such as DSRC, 3G/4G, Wi-Fi) • Interface with vehicle CAN bus and other sensors if needed
Advanced Cell Phones	• Map/GPS/Navigation • All kinds of comfort, convenience, entertainment functions • 3G/4G connection	• Additional communication links (such as DSRC) • Additional interface with drivers if needed; It needs to be cognizant of driver distraction issues • Interface with vehicle platforms if needed (such as Nokia's Terminal Mode) • Interface with vehicle CAN bus and other sensors if needed
Evolving or Non Traditional Connected Devices (e.g. Tablets)	• Map/GPS/Navigation • All kinds of comfort, convenience, entertainment functions • 3G/4G connection • Most have convenient interfaces already	• Additional communication links (such as DSRC); It needs to be cognizant of driver distraction issues • Interface with vehicle platforms if needed (such as Nokia's Terminal Mode) • Interface with vehicle CAN bus and other sensors if needed
OBU from DSRC Vendors	• Data protocols conforming to SAE J2735 and IEEE 802.11p, 1609 standards	• Additional communication links (besides DSRC) • Computing power (if needed) to host additional applications • Interface with drivers • Interface with vehicle CAN bus and other sensors if needed

Based on the industry feedback, the two most viable communication technologies relevant to the aftermarket safety devices are DSRC and cellular 3G/4G. Based on their performance characteristics, these two technologies might be used individually or in conjunction to deliver safety and mobility functionalities. Devices that currently have cellular connectivity could be converted into OBE with required modification to the interface and addition of relevant application software. But the problem with current cellular connection is coverage, assured quality of services and latency. The latency will improve with the deployment of 4G systems but other factors make it practical only for applications like soft safety, probes, remote diagnostic etc. DSRC is much better suited for hard safety applications, which demands a latency of less than one tenth of a second. As an example, there is already an implementation of DSRC integration with a cell phone by OKI[vii], Japan. These DSRC devices, which can be integrated with cell phones, could act as excellent portable OBEs.

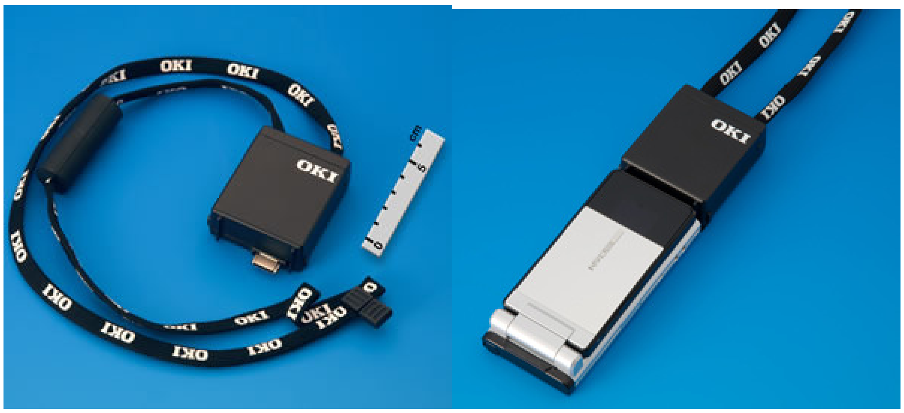

Figure 3.1 DSRC attachment for mobile phone by OKI, Japan

3.5 Summary of OBE Hardware Readiness

In summary, when considering the market readiness of hardware components needed for aftermarket devices, we can be fairly certain that the associated industries are already equipped or in a position to gear up for the demands. Certain sectors of the market are already progressing rapidly to utilize wireless communication to offer consumers convenience and mobility applications. Many industrial players are still waiting for the eventual validation of DSRC technologies or the like to assure that potential safety benefits can be realized and more importantly government agencies are ready to proceed with a mandate on safety regulations.

4 Consumer Research

In order to gain consumer expectations with regards to aftermarket OBE hardware two focus group interview (FGI) events were conducted to discuss product attributes, unmet customer needs, OBE hardware pricing, thoughts on when product features would come to market, and where consumers would prefer to purchase as well as service OBE hardware.

4.1 Focus Group Background

The focus group events were split into two sessions. One session focused on commercial vehicle drivers and the other session focused on ordinary passenger drivers. Drivers from both sessions were required to have some experience with in-vehicle electronics or brought-in consumer electronics that help in their daily commute. All of the participants had more than ten years of driving experience. Participant feedback from each session implies that communication technologies can assist or improve the consumer's driving experience.

4.2 Product Attributes

A recent white paper from U.S.DOT [viii] describes the premise of the original approach to the Vehicle Infrastructure Integration (VII) initiative that provides the basis for the earliest discussion of deployment strategy. The white paper explains that Vehicle to Vehicle (V2V) communications could provide the greatest safety gains. It would take time to equip all cars, trucks, and buses to achieve these benefits and could potentially result in approximately $44 billion in safety benefits. Below are sixteen applications that would be available on V2V and V2I systems:

1. Emergency Braking Warning
2. Traffic Signal Violation Warning
3. Stop Sign Violation Warning
4. Curve Speed Warning
5. In Vehicle Signage: Local Notifications
6. In Vehicle Signage : Regional Road Redirection
7. Traffic Information: Real Time Traveler Information
8. Electronic Payments: Toll Roads
9. Electronic Payments: Gasoline Purchase
10. Electronic Payments: Parking Fee
11. Roadway Condition: Weather
12. Roadway Condition: Road Maintenance
13. Traffic Management: Corridor Management
14. Traffic Management: Ramp Metering
15. Traffic Management: Signal Timing Optimization
16. Traffic management: Big Events

Each of the focus group participates were provided the list of sixteen applications. They were asked to select and prioritize the applications based on their perceived importance and interest levels. Participates were also asked to select the top ten applications they would like to have in an aftermarket OBE product. Tables 4.1 and 4.2 provide a summary of responses from each focus group.

In Table 4.1, the commercial vehicle drivers highly preferred to have collision warning systems to keep them safe while driving and provide timely assistance with functions such as emergency braking, road maintenance, traffic signal violation, curve speed and redirection warning. The drivers believe traffic management functions such as corridor management, signal timing optimization, and ramp metering should be the responsibility of public sectors. Their expectation is that it is preferable for the public sector to offer high quality, real time, traveler information, which can be accessed from connected vehicles.

Table 4.1 Importance and Interest from Commercial Vehicle Drivers

Applications	Commercial Drivers
Emergency Braking Warning	1
Roadway Condition: Road Maintenance	2
Traffic Signal Violation Warning	3
Roadway Condition: Weather	4
Curve Speed Warning	5
In Vehicle Signage : Regional Road Redirection	6
Traffic Management: Corridor Management	7
Traffic Management: Signal Timing Optimization	8
Traffic Management: Ramp Metering	9
Electronic Payments: Toll Roads	10
Traffic Information: Real Time Traveler Information	11
Electronic Payments: Parking Fee	12
Stop Sign Violation Warning	13
Traffic management: Big Events	14
In Vehicle Signage: Local Notifications	15
Electronic Payments: Gasoline Purchase	16

In Table 4.2, the passenger vehicle drivers prefer the real-time traffic information items for their route selection dynamically. Roadway condition weather, road maintenance, real-time traveler information, big events, and signal timing optimization are top features selected by passenger vehicle drivers.

Table 4.2 Importance and Interest from Ordinary Vehicle Drivers

Items	Ordinary Drivers
Roadway Condition: Weather	1
Roadway Condition: Road Maintenance	2
Emergency Braking Warning	3
Traffic Information: Real Time Traveler Information	4
Curve Speed Warning	5
Traffic management: Big Events	6
Traffic Management: Signal Timing Optimization	7
Traffic Management: Corridor Management	8
Stop Sign Violation Warning	9
In Vehicle Signage : Regional Road Redirection	10
Electronic Payments: Toll Roads	11
Traffic Signal Violation Warning	12
In Vehicle Signage: Local Notifications	13
Traffic Management: Ramp Metering	14
Electronic Payments: Gasoline Purchase	15
Electronic Payments: Parking Fee	16

4.3 Consumer Unmet Needs

The focus group participants were asked to identify any product features or attributes beyond the sixteen applications with regards to V2V and V2I safety features for aftermarket OBE products. The participants provided several features including potential V2V/V2I applications and non-V2V/V2I applications. The reason for documenting the non-V2V/V2I applications is to point out that consumers are interested in safety applications even if the applications are associated with Advanced Driver Assistance Systems (ADAS) products and are not necessarily offered through the V2V/V2I framework. According to the list of consumers' unmet needs, the safety-related features are their top priority. Below is a list of the most popular responses:

Potential V2V/V2I applications:

- Obstacles identification: An onboard safety system that detects objects such as vehicles or pedestrians around the vehicle, and properly warns the driver.
- Dynamic navigation system: A system that provides navigation suggestions based on real-time traffic information.

Non- V2V/V2I applications (ADAS features):

- 360 degree around view: A camera monitoring system that renders a bird's-eye view of the exterior of the vehicle on a driver's display.
- Back end camera system: A system that provides views of vehicle rear-end to alert drivers of obstacles.

- Driver drowsiness detection: An onboard system that monitors the driver status and detects driver's drowsiness.
- Forward collision warning detection system: A system equipped with radar or lidar to detect and track targets in front of the vehicle and provides hazard warnings.
- Blindspot detection system: A system equipped with short-range sensors to detect other vehicles located in the driver's blind spot that alerts the driver of their presence.

4.4 Feedback on OBE Pricing

According to focus group respondents there is a wide variation in what features or attributes would be the three most popular applications. They did seem to be aligned with an average price for an aftermarket OBE product of $200. There were a couple of respondents that believed the OBE product price should be below $100. With regards to the maximum price the response from the participants was $500 for an aftermarket OBE product.

4.5 Timing to Market of Features

The participants were asked to provide their opinions on when applications would be available to consumers in the market. They believe that emergency braking warning, curve speed warning, traffic information, real time traveler information, and weather information could be available in the market in one or two years. The rest of the applications would come to market in three years or beyond. The responses have been documented in Table 1.4.

Table 4.3 Participants Opinion on Time to Market for OBE Applications

Application	Time to Market
Emergency Braking Warning	1-2 years
Curve Speed Warning	1-2 years
Traffic Information: Real Time Traveler Information	1-2 years
Roadway Condition: Weather	1-2 years
In Vehicle Signage : Regional Road Redirection	3-5 years
Roadway Condition: Road Maintenance	3-5 years
Traffic Management: Corridor Management	3-5 years
Traffic Signal Violation Warning	3-5 years
Stop Sign Violation Warning	3-5 years
In Vehicle Signage: Local Notifications	3-5 years
Traffic Management: Ramp Metering	3-5 years
Traffic Management: Signal Timing Optimization	3-5 years
Traffic management: Big Events	3-5 years
Electronic Payments: Toll Roads	5+ years
Electronic Payments: Gasoline Purchase	5+ years
Electronic Payments: Parking Fee	5+ years

4.6 Where to purchase Aftermarket OBE Hardware

In both focus group session participants were asked where they would prefer to purchase and return for service their aftermarket OBE hardware. The commercial vehicle customers listed auto repair shops as the most popular location for purchase and service. The next most popular location identified was major retail stores followed by automotive electronics specialty stores.

For passenger customers both major retail stores and OEM dealerships were equally favored for purchase and service of aftermarket OBE products. Participants commented that either selection would be suitable but they stressed that reputable and reliable service would be the deciding factor for where to purchase the product.

4.7 Summary of Consumer Research

According to the consumer surveys, commercial vehicle drivers tend to care about the safety-related functions, and passenger vehicle drivers prefer real-time traffic information functions to assist their route decision while driving. No specific price range was identified but $500 seems to be limit. The accident warning and driver information applications will be available sooner than traffic management ones. Commercial vehicle drivers would prefer to purchase their aftermarket OBE hardware in auto repair shops, while passenger vehicle drivers prefer retail store and OEM dealerships as their purchase locations.

5 Conclusions

A number of observations can be summarized from this Vendor/Market Readiness report. The main conclusions are:

1) Industry and consumers perceive that current or future aftermarket devices have the potential to deliver V2V and V2I applications.
2) The industry is well aligned to develop and deliver aftermarket dynamic configurable multi-band OBE products within a three to four year product delivery plan.
3) Industry experts have identified challenges and opportunities in accelerating the deployment of the aftermarket OBE market. In the following paragraphs each of the main conclusions will be discussed.

Manufacturers of current or future aftermarket products such as portable navigation devices, advanced cell phones, connected devices, and DSRC OBUs all have great potential to enhance their product capability by implementing V2V/V2I applications. The general view of the industry is that the technical and manufacturing capabilities are certainly present to accelerate the deployment of aftermarket OBE to the market. The remaining road blocks or challenges are more business or institutional related issues. Consumer research shows a high level of interest in safety features and willingness to accept aftermarket products with V2V/V2I features. The main concerns from consumers are cost and ease of use.

Insight from industry reveals OEMs and Suppliers are all aligned with a three to four year product delivery plan. The plan assumes collaboration between all major stakeholders to address key challenges prior to execution of the product delivery plan. Consumers would like to see some aftermarket OBE products in the market in one or two years with safety features like emergency braking warning, curve speed warning, real time traffic information, and roadway weather condition. They believe the time to market for all other applications would be three years or beyond. Feedback on pricing from consumers revealed an average price point of $200 with a maximum of $500 for an aftermarket OBE product. Consumers were comfortable with purchasing aftermarket OBE product at existing distribution channels of the aftermarket industry.

The main challenges identified by industry are infrastructure deployment, communication coverage, security, business case, bandwidth limitations, driver distraction, and product liability. Each of the challenges mentioned demands that all stakeholders work together collaboratively to identify solutions and take responsibility in implementing the necessary actions. A government mandate, industry standards, and insurance industry incentives are initiatives that are identified by industry, and they should be part of the solutions that accelerate the deployment of aftermarket OBE product.

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Enabling Accelerated Installation of Aftermarket Onboard Equipment for Connected Vehicles

TASK 3: PROCUREMENT GUIDANCE DOCUMENT

February 15, 2012

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University of Virginia
Cooperative Transportation System Pooled Fund Study

Table of Contents

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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Enabling Accelerated Installation of Aftermarket On-Board

Equipment for Connected Vehicles

TASK 4: STRATEGIC REPORT SUMMARIZING RECOMMENDED ACTIONS

April 27, 2012

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Cooperative Transportation System Pooled Fund Study

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Executive Summary

This Strategic Report Summarizing Recommended Actions is the fourth and final milestone in the University of Virginia's Enabling Accelerated Installation of Aftermarket On-Board Equipment (OBE) for Connected Vehicles Project, conducted under the umbrella of Cooperative Transportation System Pooled Fund Study. The report will capture a summary of previous findings as well as any recent developments with regards to rapid introduction of aftermarket OBE devices to the vehicle fleet. An integration assessment for aftermarket OBE devices will be discussed. In addition, an analysis of outside market forces that may affect driver adoption of connected vehicle technologies will be shared. Finally, recommendations will be provided for strategic approaches to foster the rapid introduction of aftermarket OBE devices and garner consumer interests to purchase these devices.

With regards to the integration of OBE devices into the vehicle it is important to understand the interface to the vehicle as well as the communication technologies. The key aspects regarding the interface of the device are the power supply connection, integration of the vehicle communication network, and the human-machine-interaction. As for the integration of different wireless communication technologies it will depend on the applications and features specified for the OBE device. Wireless technologies such as cellular, DSRC, Wi-Fi, and Bluetooth in combination, or in some cases alone, are capable of supporting a wide variety of OBE devices. For reference both the USDOT Safety Pilot Model Deployment and Japan Smartway program are important projects in the advancement of OBE products for consumers. Furthermore, industry devices from Kapsch, Savari, Denso, ITRI, and NEXCOM are examples of dynamically configurable multi-band wireless hardware that could be developed as OBE devices with the appropriate software development customized for specific applications.

When looking at outside market forces that may influence consumers adoption of OBE devices there is great potential to integrate V2V and V2I features in current Aftermarket products like telematics modules, smartphone applications, and PND's. With regards to technological influence products that can combine safety features with convenience and comfort features can provide a viable value proposition to consumers. The political opportunity to influence consumers will reside with a government mandate. The insurance industry can be a key catalyst with regards to adoption with incentives associated with OBE products.

There are challenges and opportunities that have a significant impact on the deployment of aftermarket OBE devices. The main challenges are viable business cases, infrastructure deployment, security, scalability, driver distraction, and product liability. The main

opportunities are a government mandate, standards, and insurance incentives. Each of the identified challenges can be resolved by the leadership of the primary party and with commitment and collaboration by all stakeholders involved.

1 Introduction

1.1 Project Goals

The goal of this project is to evaluate the potential approaches for accelerating the introduction of aftermarket OBE devices to the vehicle fleet. Without a rapid deployment, the safety, mobility, and efficiency benefits of the USDOT Connected Vehicle Research Program will not be realized. It is widely recognized that deployment on new vehicles alone will not provide the penetration expedient enough for maximum benefit. Therefore, aftermarket deployment is critical. The combination of aftermarket OBE devices and new vehicles 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 Program systems and applications will not be accepted by consumers on its own merits.

1.2 Report Layout

In Chapter 2 the integration assessment of OBE devices is discussed in three areas: important aspects of OBE interfaces to the vehicle, dynamic configurability of multi-band wireless communication, and current OBE devices in the market.

Chapter 3 provides an analysis of market forces that may affect consumer adoption of aftermarket OBE devices. The chapter begins with the identification of outside market forces that could influence consumer purchasing behavior. Next, a model analysis is presented to identify pro’s and con’s associated with Social, Technology, Environment, and Policy (STEP) factors with regards to the OBE market. Finally, a mixed analysis is utilized to provide insights in product, price, promotion, and place (4P) in relation to consumer, competitor, company, and community (4C) for the aftermarket OBE market.

Chapter 4 will offer recommendations on strategic approaches to foster the rapid introduction of aftermarket OBE devices. In addition, recommendations to garner consumer interest to purchase aftermarket OBE devices will be discussed.

Chapter 5 provides summary remarks based upon the previous reports and this current report as a conclusion to this project.

2 Integration Assessment for OBE devices

This section provides an overview of requirements and issues related to the interface, attributes, and communication technology of aftermarket OBE devices, to establish the foundation for discussions in later sections.

2.1 Important aspects of OBE interface to the vehicle

In this section, we offer a description of important aspects with regards to interface to the vehicle, and discuss how the power supply, vehicle communication network, and HMI are connected to the vehicle.

- Power supply

The vehicle should provide 12V (for light passenger vehicle) or 24V (for heavy truck vehicle) DC power input to the OBE device. In general, the OBE device's power consumption is typically specified at a relatively low level.[1] In addition, the OBE is equipped with a standard type of power connectors.[2]

- Vehicle communication network

Most modern vehicles are equipped with an in-vehicle communication network. A vehicle network is a specialized internal communications network that interconnects components inside a vehicle (e.g. automobile, bus, and train). Special requirements for vehicle control such as assurance of message delivery, assured non-conflicting messages, assured time of delivery as well as low cost, EMF noise resilience, redundant routing, and other characteristics mandate the use of less common networking protocols. Protocols include Controller Area Network (CAN), Local Interconnect Network (LIN), and others. 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. Although there are no hard requirements in general for interfacing to in-vehicle communication network, it is extremely advantageous to have the network interface to leverage the data elements within the vehicle communication network into OBE functionalities. For safety applications, such as emergency electronic braking light

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[1] For example, based on USDOT procurement specifications of HIA [1] the power consumption should be less than 16 W, and according to the Maximum Operating Current requirement, the HIA device should operate at a maximum of 1 amp in the Halt, Run, and Start modes.

[2] For example, in related USDOT procurement, it is required that OBE should provide one of three types of power input connector/interface listed below. DC-JACK connector (Worldwide industrial standard [2]) is a basic power input interface for the OBE device. Delphi connector is mandatory power input for USDOT projects (such as USDOT VAD and ASD projects [3][4]). Cigarette connector is an optional interface for the OBE device.

(EEBL) functions, the OBE should receive the braking signal through the CAN bus interface.

- HMI (auditory, visual, haptics)

To support drivers in a critical situation, the design of HMI (Human-Machine-Interaction) is of major importance. The applications embedded on the OBE can engage the drivers in different manners, and there are several possible alternative HMI modes (auditory, visual, or haptics) for such interactions. For example, an aftermarket safety device often has a speaker and a display for use as a human machine interface to convey safety alerts to drivers. Haptic interfaces for in-vehicle safety as well as comfort functions are now commercially available. In-vehicle functions are increasingly available and controlled via maneuverable buttons for activation and deactivation.

2.2 Dynamic configurability of multi-band wireless communication and desired applications

In this section, we summarize the performance features of wireless communication in relationship to the desired OBE applications.

- Integration of different wireless communications on an OBE device

The appropriate integration of wireless communications on an OBE device to meet user needs and wants is dependent on how the functionality of the system can best be accomplished. The popular types of wireless communications appropriate for an OBE device and their suitability for applications are summarized as follows.

- Cellular application assessment

  Data communications over cellular networks tend to be lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. The latency (typically at least several seconds) limitations will likely preclude the use of cellular communications for the majority of time-critical vehicle safety applications. Cellular communication is well equipped for convenience functions and many non-time critical safety features. Internet connectivity via cellular 3G services can also support entertainment application.

- DSRC application assessment

  The 5.9GHz DSRC latency, typically at tens of milliseconds, is three orders of magnitude lower than other existing wireless technologies. It is uniquely positioned to meet the essential communication requirements for most of the vehicle safety applications that have been proposed for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications. The 5.9 GHz DSRC also supports a wide range of efficiency and mobility applications such as electronic toll collection and eco-driving. DSRC 5.9 GHz is best suited for most time-critical safety features, which require short latency and high-bandwidth data transmission.

- Wi-Fi application assessment

  Wi-Fi networking equipment is widely available, inexpensive and popularly used in home, commercial, and industrial environments. The Wi-Fi protocols themselves are described by the IEEE 802.11 standards. Bandwidth has increased substantially from the original protocol implementations, and the most recent standards provide capacities comparable to wired connections. Wi-Fi is appropriate for convenience features that do not necessitate constant connection. For example, 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 application assessment

  Bluetooth is a low-power, low-cost, short-range (10m) wireless communication system. It is suitable for in-vehicle data transmission among sub-systems. For example, hands-free calling with mobile phones is typically accomplished via Bluetooth communication. It can support commercial applications like electronic payments at fast food drive-thru restaurants. In addition, Bluetooth can provide the gateway communication between a smartphone application and an OBE that in turn is connected to the DSRC network.

- Dynamic configurability of an OBE device

As discussed in Task 3 Guidance Document report, the OBE is preferred to be dynamically configurable between multi-band wireless communication channels, depending on its application requirements. The timing of switching the communication interface depends on several factors – transmission range, data rate, packet reliability, and network connectivity. Exemplar scenarios of an OBE device with dynamic configurability are explained as follows.

- From the point of view of transmission range, the system can be set up with a default communication interface such as DSRC for safety features. If the distance between the sender and receiver exceeds the DSRC transmission range (around 500m~1000m), the channel can then be switched to cellular to allow data transmission smoothly.
- From the point of view of data rate, if download for multi-media data (more than few Mega bit per second data rate is required) is activated, the OBE can be configured to cellular interface.
- From the point of view of packet reliability, the packets can be transmitted by using DSRC interface and cellular interface concurrently. The drawback with this scenario is the redundant packet overhead within the network.
- For inter-vehicle communications, the system can be set up with a default communication interface such as DSRC for safety features. When access to Internet backbone is needed, the OBE can switch to cellular or Wi-Fi dynamically.

As described in the above scenarios, several similar devices (e.g., Kapsch, Savari, Denso, ITRI and NEXCOM) discussed in Section 2.3 below support multi-band wireless communication hardware interfaces (e.g., DSRC/Cell/Wi-Fi/Bluetooth). The choice of the communication interface depends on the application requirements. In addition, the similar devices offered by industry also need software development efforts to meet the above dynamic switching scenarios. Therefore, the above scenarios are typically highly customized to conform to the application requirements.

- Implementation of V2V and V2I applications on an OBE device and selection of communication technologies

V2V communication is typically demanded for short range data exchange between vehicles. Exemplar applications of V2V include safety alert notifications and probe data sharing for mobility applications. V2I communication can utilize a variety of wireless technologies for a vehicle to communicate with the infrastructure and to enable seamless handover from one communication medium to another. The popular wireless communication technologies of an OBE device for V2V and V2I application assessment are explained as follows.

- DSRC is uniquely suited to mobile vehicular applications needing high bandwidth and low latency in short range communications (on the order of a few hundred meters). Security is managed through a certificate management scheme that issues new certificates to each radio at regular intervals. Radios can be deployed in vehicles and in roadside equipment to enable V2V and V2I communications.
- Cellular network services are not generally appropriate for real-time localized V2V or V2I data exchange. They are, however, very suitable for data transmission that can span over long distances and across a wide area network.
- Wi-Fi is another wireless technology, suitable for selective V2I applications. It has been accepted in a wide variety of products ranging from mobile phones, laptop PCs, and tablets. It is a low-cost alternative for non-critical missions.
- Bluetooth may serve as the communication link between the OBE and smartphone or PDA. This will allow the smartphone or PDA to act as the driver interface for V2V and V2I applications.

2.3 Current OBE devices

This section summarizes OBE capabilities from the USDOT Safety Pilot Model Deployment and Japan Smartway program, as well as other industry developed devices.

- USDOT Safety Pilot Model Deployment OBE

In USDOT Safety Pilot Model Deployment project, the in-vehicle devices to be tested include embedded or integrated systems, Aftermarket Safety Device (ASD), and a “simple” communications beacon (Vehicle Awareness Device, or VAD). All of these devices emit a basic safety message 10 times per second, which forms the basic data stream that other in-vehicle devices can use to determine when a potential conflict exists.

- VAD

  In an earlier definition, HIA (Here I Am) [1] devices periodically send vehicle and location message based on the Basic Safety Message (BSM) defined in SAE J2735. A newly named VAD [3] devices provide revised functional capabilities from the HIA device. VAD devices implement one 5.9 GHz DSRC radio as called out in IEEE 802.11p and IEEE 1609.

- ASD

  ASD can send and receive BSMs. The ASD has display, audio and selective built-in safety applications (such as FCW, EEBL, CICAS-V and CSW [4]). The ASD have two 5.9GHz DSRC radios as called out in IEEE 802.11p and IEEE 1609. In addition, the ASD equipment includes one or more optional non-DSRC radios of the following types (3G Cellular and WiMAX). Therefore, the ASD device could be configured to multi-band DSRC/Cell/WiMAX communication technology interface.

- Japan Smartway OBE

The Japan Smartway [5] program incorporates VICS (Vehicle Information and Communication System) [6] and ETC (Electronic Toll Collection) functions plus navigation into an integral OBE. OBE communicates with RSE via DSRC (5.8 GHz). In addition, Japan also uses infrared beacons and FM multiplex broadcasting in their VICS and Smartway systems. In their VICS system, the OBE can receive information about expressways and ordinary roads as far as 30 km ahead, and 1 km behind from the car. FM multiplex broadcasting can provide information about the user location, neighboring area and regional borders. The Smartway OBE is configured to utilize multi-band DSRC/Wi-Fi/FM/Infrared communication technologies.

- Similar Devices offered by Industry

There are several similar devices throughout the industry developed by Kapsch, Savari, Denso, ITRI and NEXCOM.

- Kapsch Devices

  The Multiband Configurable Networking Unit (MCNU) R1551 [7] 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 DSRC band. The MCNU dual radio platform also provides simultaneous communications in licensed (4.9 GHz) and unlicensed (2.4 GHz and 5 GHz) frequency bands offering wireless broadband access to VII. In addition, 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. The MCNU supports transportation management (e.g., Electronic Toll Collection, Commercial Vehicle and Fleet Management), safety (e.g., Vehicle Safety/Crash Avoidance) and security applications including support of Intelligent Transportation System (ITS) VII Initiative. Therefore, the MCNU could be configured to multi-band DSRC/Wi-Fi communication technology interface.

The TS3306 [8] On-Board Unit is designed for the 5.9 GHz DSRC. It is provided for applications serving commercial vehicle operations and road tolling markets as well as for the USDOT's Connected Vehicle Safety Pilot program. In addition, it can link to a smartphone or a PDA via Bluetooth interface. It also supports USB and an optional CAN vehicle interface which can expand device versatility. Therefore, the TS3306 OBU could be configured to multi-band DSRC/Bluetooth communication technology interface.

- Savari MobiWAVE

  MobiWAVE [9] is a wireless vehicular onboard unit, designed as a flexible open platform based on Linux for deploying ITS applications to improve mobility and safety on the roadways. 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. In addition, MobiWAVE offers display and touch-panel functionality for touch-panel based HMI. MobiWAVE provide several safety applications such as 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. For efficiency application, MobiWAVE support several electronic payment applications such as toll collection, open road tolling and gas payment. Therefore, the MobiWAVE could be configured to multi-band DSRC/Cell/Wi-Fi communication technology interface.

- Denso Wireless Safety Unit (WSU)

  Denso WSU [10] supports WAVE/DSRC solution with video/audio, suitable for vehicle safety applications. In addition, the WSU also support single automotive connector such as power, ignition sense, RS-232 (GPS/PPS/serial data), CAN, Ethernet, USB and GPIO. Denso WSU provide several types of applications such as Forward Collision Warning, Lane Change Assist, Intersection Movement Assist, Electronic Emergency Brake Light, Curve over-speed Warning (e.g., speed distribution, or min curve speed methods) and in-vehicle signage applications (e.g., speed limit, construction zone, or other). The WSU could be configured to DSRC communication technology interface.

- ITRI WAVE/DSRC Communication Unit (IWCU)
  IWCU 4.0 OBU [11] is a WAVE/DSRC communication equipment mounted in a vehicle. It also provides CAN bus, Wi-Fi and 3G communications, suitable as vehicle communication gateway. It supports automotive grade operating temperature range from -40° C to +85° C. In addition, IWCU can support many different types of communication including intra-vehicle, vehicle-to-vehicle (V2V), vehicle-to-roadside (V2R). IWCU 4.0 OBU also provides several types of applications such as cooperative safety applications (e.g., Road Construction Warning, Car Accident Warning), Electronic Emergency Brake Light, Electronic Toll Collection, Vehicle Group Communication applications and RSU Management System. Therefore, the IWCU 4.0 OBU could be configured to multi-band DSRC/Cell/Wi-Fi communication technology interface.
- NEXCOM VTC 6200
  NEXCOM VTC 6200 [12] supports internal wireless communication (3.5G, GSM/GPRS, WLAN, Bluetooth). It also provides an industrial grade computing solution for in-vehicle surveillance applications. In addition, NEXCOM VTC 6200 support dual VGA output (clone mode) and one isolated GPIO interface. The NEXCOM VTC 6200 could be configured to multi-band Cell/Wi-Fi/Bluetooth communication technology interface.

Table 2.1 has been included to provide list of possible OBE devices that could be developed as Aftermarket Safety Devices for consumers. The table is an example to illustrate what industry devices are available and not meant to be a recommendation for sourcing.

Table 2.1 Comparison of different OBE suppliers

OBE Device	Kapsch*	Savari*	Denso*	ITRI*	NEXCOM*
Recommended memory	512 MB	512 MB	512 MB	512 MB	512 MB
Recommended storage	4 GB	4 GB	4 GB	4 GB	4 GB
Recommended GPS	Yes**	Yes**	Yes**	Yes**	Yes**
All above recommendations are satisfied	Yes	Yes	Yes	Yes	Yes
FCW	Yes	Yes	Yes	Yes	Optional***

EEBL	Yes	Yes	Yes	Yes	Optional***
CICAS-V	Yes	Yes	Yes	Yes	Optional***
CSW	Yes	Yes	Yes	Yes	Optional***

* The assessment is based on hardware capabilities, software would need to be developed for each application.

** 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. WASS function is optional and should be developed by suppliers.

*** In order to support safety applications, NEXCOM product should combine with IEEE 802.11p mini-PCI card (e.g., UNEX 5.9 GHz DSRC wireless mini-PCI [13]) to provide DSRC communication technology.

3 Analysis of OBE Market Forces

This section provides an analysis of market forces that may affect consumer adoption of aftermarket OBE devices.

3.1 Market products relevant to introduction of OBE

Several types of in-vehicle products are emerging in the market place and they could influence the purchasing behaviors of consumers with regards to aftermarket OBE. We review the most relevant products in this section.

- Industry Telematics Products

Telematics companies like OnStar (GM), ATX Technologies, and Hughes Telematics are well established in the global market. The comparison of various factors (such as Basic Plan, Basic Plan Pricing, Advanced Plan, Advanced Plan, Advanced Plan Pricing and Customers) for the three companies is shown in Table 3.1.

Table 3.1 Comparison of different Telematics products

Company	OnStar	ATX Technologies	Hughes Telematics
Basic Plan (Safety)	Safe & Sound Plan Automatic Crash Response, Emergency Services, Crisis Assist, Stolen Vehicle Assistance/slowdown, Remote Door Unlock, Roadside Assistance, Remote Horn & Lights and OnStar Vehicle Diagnostics	Safety Plan Automatic Collision Notification, Emergency Request (SOS), Enhanced Roadside Assistance, MyInfo, Stolen Vehicle Recovery, Door Unlock, Tele Service and Customer	Safety Plan - Automatic crash notification, roadside assistance, vehicle diagnostics and stolen vehicle tracking, as well as voice recognition to operate cell phones, audio systems and iPods

		Relations - BMW	
Basic Plan Pricing	Safe & Sound - $18.95 / month - $199 / year	Safety Plan - No charge for 4 years/ unlimited miles, then $199 per year	Basic Plan - $18.95 / month
Advanced Plan	Directions & Connections Automatic Crash Response, Emergency Services, Crisis Assist, Stolen Vehicle Assistance/slowdown, Remote Door Unlock, Roadside Assistance, Remote Horn & Lights, OnStar Vehicle Diagnostics and Hands-Free Calling, Turn-by-Turn Navigation includes eNav and Destination Download and Information/Convenience Services.	Automatic Collision Notification, Emergency Request (SOS), Enhanced Roadside Assistance, MyInfo, Stolen Vehicle Recovery, Door Unlock, TeleService, Customer Relations, Directions, Real-Time Traffic, Weather, Concierge, BMW Search and Critical Calling- BMW	Automatic crash notification, roadside assistance, vehicle diagnostics and stolen vehicle Tracking, as well as voice recognition to operate cell phones, audio systems and iPods, news, weather, sports scores, stock quotes, fuel prices and movie times.
Advanced Plan Pricing	Directions & Connections - $28.90 / m - $299 / year Convenience Plan - Safety Plan plus $199 per year	Convenience Plan - Safety Plan plus $199 per year	Convenience Plan - $28.95/month and additionally may be on a per-use basis
Customers	General Motors, Lexus	BMW, Mercedes-Benz (till end of 2009), Toyota (from MY2010), Rolls-Royce and Maybach	Chrysler and Mercedes-Benz (2009)

In Table 3.1 the OnStar system, a General Motors product, provides Basic and Advanced plans throughout the United States, Canada, and China. The Basic plan provides safety features such as automatic crash response, emergency services, stolen vehicle assistance, and roadside assistance. The Advanced plan provides some of the comfort features such as hands-free calling, and turn-by-turn navigation. The ATX Technologies safety plan which is considered the basic plan provides automatic collision notification, emergency request (SOS), enhanced roadside assistance, and stolen vehicle recovery. The ATX Advanced plan provides directions, real-time traffic, and weather information. The Hughes Telematics basic plan provides automatic crash notification, roadside assistance, vehicle diagnostics, and stolen vehicle tracking features. The Hughes Advanced plan provides voice recognition to operate cell phones, audio connectivity, news, weather, sports scores, stock quotes, and fuel prices as convenient features.

- Insurance Telematics

Automotive insurance industry and telematics services now represent an emerging sector of utilizing aftermarket devices to enable their business models. For example, insurance telematics products like Insurethebox [14] and Octo Telematics SpA [15] are heavily marketed around the globe. By collecting information on customers' driving patterns these companies are able to reduce the cost of car insurance for safe drivers.

- Smartphone applications

A smartphone could generally be described as a mobile telephone handset with built-in personal computing applications and Internet data access. They frequently include GPS receivers and cameras. The latest models of smartphones are easy for users to download and update applications; they are equipped with additional sensors for acceleration, ambient light, and compass direction; and have become a platform for independent software development and deployment. Add-on applications may include navigation and traffic information, and smartphones are increasingly used in place of other navigation devices.

- Integration of portable computing devices (phone, iPad, tablet, etc) and portable navigation deice (PND)

In January 2012, Garmin [16] announced the launch of Smartphone Link, the first Android app to provide live services to personal navigation devices (PNDs). Smartphone Link creates a seamless navigation experience between any Bluetooth enabled 2012 Garmin nüvi and an Android smartphone allowing them to communicate and share data. Among other functionalities, the app lets nüvi users add live services, such as traffic information, traffic camera images, weather and fuel prices to their navigation device, utilizing the smartphone's mobile data plan.

3.2 STEP model analysis.

In this section a STEP model analysis is reviewed to strategize the potential enabling of Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles. The STEP model approach is an external analysis, which investigates four macro-environments scopes: social, technological, political, environmental factors. The goal is to understand the market before making operational decision. Table 3.2 provides a comparison of three factors (Concerned Issue, Pro and Con) that are taken into consideration in a STEP model.

Challenges will exist with any new product or system introduced into the market, and V2V/V2I systems are no exception. During the discussion of aftermarket OBE features OEMs provided insight on a tiered approach to deploying features and functions. They suggested that initial systems should focus on safety applications providing driver relevant information or warnings of upcoming events. Efficiency and comfort applications can be introduced at the same time to enhance the value proposition to the consumer.

Industry experts have identified challenges and opportunities in accelerating the deployment of the aftermarket OBE market. The identified challenges are infrastructure deployment, communication coverage, security, business case, bandwidth limitations, driver distraction, and product liability. Each challenge demands that all stakeholders work together collaboratively to identify solutions and take responsibility in implementing the required actions. Also identified by the industry as major initiatives are a government mandate, industry standards, and insurance industry incentives that should be part of the solutions that accelerate the deployment of aftermarket OBE product.

Table 3.2 STEP model analysis

Factors	Social	Technological	Environmental	Political
Concerned Issue	Aftermarket OBE benefit for the fleet managers or drivers	The car, device, carrier, service operator side technology	Communication Infrastructure (e.g. DSRC Roadside Units, 3G/LTE Base Stations, Wi-Fi Access Points)	DOT obligations, mandatory regulation will be evaluated in coming years Non funded mandates will be hard to enforce
Pro	Approximately $44 billion in achievable safety benefits Marketing "safety" effectively is important Existing needs for high quality, real time, traveler information	The use 5.9Ghz DSRC for safety applications and 3G/4G/LTE for efficiency and comfort applications show the most promise for accelerated deployment	Projects like the Safety Pilot/Model Deployment program will provide collaborative environment	A mandate will require industry to deploy the technology on new vehicles. Without a mandate commercial vehicles could be the lead market to implement the technology if the value is understood

Con	High cost for OBE devices will be a barrier to entry for both commercial and normal vehicle owners	Bandwidth limitations of the wireless communication system Driver distraction for the consumer with new V2X products	Building the DSRC infrastructure will be difficult because of the cost	No clear regulation and likely no mandates for Aftermarket OBE

To garner the interest of the consumer to purchase aftermarket OBE devices, it will come down to technological and political factors. From the point of view of the technological factor, an OBE should include convenient and comfort features with safety functions. Therefore, the use of 5.9 GHz DSRC for safety applications and 3G/4G/LTE for efficiency and comfort applications show the most promise for accelerated deployment. From the political factor point of view a government mandate, though difficult to implement, should be issued to lead the industry to deployment of the technology (e.g., DSRC, Cellular and Wi-Fi) on new vehicles.

3.3 McKinsey 4P (product, price, place, and promotion) and 4C (consumer, competitor, company, and community) model analysis

In order to gain the understanding of consumer expectations with regard to aftermarket OBE hardware two focus group interview (FGI) events were conducted to discuss the following issues: product attributes, unmet customer needs, OBE hardware pricing, thoughts on when product features would come to market, and where customers would prefer to purchase as well as service OBE hardware.

In Table 3.3, we use a 4P and 4C marketing mixed analysis to address different aspects of enabling Accelerated Installation of Aftermarket On-Board Equipment for Connected Vehicles.

Table 3.3 McKinsey 4P and 4C model analysis

	Product	**Price**	**Promotion**	**Place**
Consumer	Product features: Emergency Braking Warning Curve Speed Warning, Traffic Information: Real Time Traveler	Price range is \$100-500 Most acceptable average price \$200	CES Exhibition Automotive show Electronics Show	Auto repair shops for commercial vehicles Retail stores followed by automotive electronics for

	Information Roadway Condition: Weather			Ordinary user
Competitor (Existing)	GM OnStar ATX Hughes	Basic plan (please refer to Table 3.1) Advanced plan (please refer to Table 3.1)	Insurance companies Automotive companies	Rental car Insurance companies New car
Company	Several features including potential V2V/V2I applications and non-V2V/V2I applications. The safety-related features are their top priority	Due to low volumes currently in the industry OBE price ranges from $2,000 to $4,000	Incentives or discounts for insurance companies or consumers Combine features with current products with little additional hardware costs	Online purchase can be a good venue if installation can be done by consumers themselves Aftermarket stores or Automotive dealers are nature choices
Community/ Channel	Collision warning Timely assistance of information optimized for passenger car	NHTSA will not mandate a monthly fee to consumers to have an embedded cellular connection for safety	Safety messages to promote the technology value to the customer	Products should be sold or available in all markets throughout the US

Based on the focus group interviews, Consumers would like to see some aftermarket OBE products in the market within one or two years, with safety features like emergency braking warning, curve speed warning, real time traffic information, and roadway weather condition. They believe the time to market for other applications would be three years or beyond. Feedback on pricing from consumers revealed an average price point of $200 with a maximum of $500 for an aftermarket OBE product. Consumers were comfortable with purchasing aftermarket OBE products at existing distribution channels of the aftermarket industry.

4 Recommendations

In this section, we discuss the potential approaches that can enable faster installation of aftermarket devices, based on the analysis from preceding sections as well as findings from previous reports.

4.1 Recommendations to foster the rapid introduction of Aftermarket OBE

- Government Mandate & Connected Vehicles Deployment
    - It is well documented in studies by government and industry that consumers typically don't pay for safety features directly. Instead, they expect safety in the vehicles they purchase. Traditionally, many safety features have been introduced through a mandate to achieve a high market penetration rate. Since the envisioned benefits in Connected Vehicles will be greatly enhanced by high market penetration, it can be realized with a government mandate especially when safety and mobility benefits can be justified. On the other hand, with regards to convenient and confront features, consumers currently pay for these types of products without the need for a government mandate.
    - It would be more sensible to issue a mandate for commercial vehicles before consumer vehicles. The main reason is that commercial vehicles can leverage fleet operational considerations to justify a business case to deploy OBE devices with safety features. In addition, the added equipment cost of an OBE is a relatively lower percentage of vehicle capital investment costs. The commercial vehicle fleet, if successfully marketed, would be a large scale deployment that extends beyond the current safety pilot program, and it could provide further validation of the technology for all stakeholders prior to a full scale consumer vehicle deployment. Furthermore, the commercial vehicle platforms, due to its tradition of being more flexible and receptive with supplementary components and add-ons, would be highly suitable for adopting an aftermarket OBE device.
    - It will take the automotive industry a great deal of resources and a stringent evaluation process to justify, develop, and deploy V2V safety features into new vehicles without a government mandate. The focus of the industry will remain on convenient and confront features that currently have viable business cases in telematics and connectivity products. The rapid deployment of aftermarket products will be difficult to materialize before a formal introduction of OEM OBE products.
    - Another venue to exercise significant deployment of Connected Vehicles technologies will be the operation of special vehicle fleets, such as public transit

buses, police vehicles, and fleets maintained and operated by government agencies. These vehicles tend to operate frequently in a local region or on fixed routes, thus offering a structured and defined platform to demonstrate the featured functions of an OBE. These types of deployment initiatives may also lead to greater awareness by the public, which will promote faster market penetration of aftermarket OBE devices.

- Insurance Incentives
  - Since safety is the top priority of the government with regards to V2V and V2I products the insurance industry plays a key role in the aftermarket OBE market. Similar to insurance premium reduction to good drivers, the insurance industry can promote the acceptance of OBE by leveraging the potential safety features of aftermarket OBE products with incentives as a catalyst for OBE installation. The government mandate, coupled with insurance incentives, will entice greater consumer demands as well as faster introduction of OEM products. Jointly, these market forces will help realize the envisioned benefits thus leading to greater acceptance by the public.
- Enriched OBE Capability

To enhance the appeal of OBE, technological developments should be leveraged to offer the greatest potential utilization.

- Dynamically configurable multi-band OBE devices
  - As discussed in Task 3 Procurement Guidance report, the OBE should ideally be dynamically configurable between multi-band wireless communication interfaces (such as DRSC/Cellular/Wi-Fi/WiMAX/Bluetooth), depending on its application requirements.
  - For safety applications and inter-vehicle short range (500~1000m) communications, the OBE can be configured to DRSC interface to satisfy low latency and high bandwidth requirements.
  - For efficiency applications, the OBE can be configured to Wi-Fi or Bluetooth interface to get real-time traffic information via portable navigation devices (PND).
  - For entertainment or V2I data exchange applications, the OBE can be configured to Cellular or WiMAX interface to access Internet backbone.
- Integration with existing in-vehicle products
  - The OBE should interface with onboard vehicle communication network to leverage the available data elements into OBE functionalities.
  - In order to access the on-board data network for detailed display and analysis of the vehicle's performance (such as safety inspection), the OBE should connect to the vehicle's On-Board Diagnostic (OBD-II) port for probing

vehicle data.

    - When possible, the HMI of Aftermarket OBE should also be seamlessly integrated with on-board HMI to minimize the potential overload of interaction demands on the drivers.

4.2 Recommendations to garner consumer interest to purchase aftermarket OBE

- Tailored Product Features to Meet Customer Needs

User of different type of vehicle platforms may demand different features in OBE.

    - For light passenger vehicle, drivers will prefer a package that includes comfort and convenience functions along with safety functions.
    - Transit vehicle drivers will prefer functionalities that help enhance driving safety and provide ease of operations.
    - Commercial vehicle drivers are likely to appreciate applications that can help alleviate workloads and minimize driving risks as well as maximize operational efficiency and mobility benefits.

- Price and Packaging
    - In terms of economic benefits, consumers are generally very sensitive to the costs that are to be incurred with the installation of any device on their vehicles and will base their purchasing decisions on perceived values.
    - A value proposition will ideally include convenient and comfort features to stimulate the interests of consumers, while incorporating safety functions.
    - In the focus group interviews consumers were interested in purchasing aftermarket OBE products through current aftermarket retail channels. The distribution channel should allow access to easy purchase and installation.
    - It was found in the focus group interviews earlier in the project that consumers are only willing to pay at most a few hundred dollars for an OBE.
- Insurance Incentives
    - Not only will insurance incentives be a catalyst for the industry to rapidly deploy aftermarket OBE devices they can also assist with the pricing challenges that may inhibit consumers interest in purchasing OBE's. For example, currently in the US Progressive offers a product called Snapshot [17] where the customer's driving is monitored with a device that is installed in the vehicle. Based on the driver's usage and behavior a discount of up to 30% received.

5 Conclusions

There are several primary themes that have emerged through all of the reports that are generated in this project with regards to V2V and V2I technologies. These themes, representing both challenges and opportunities, have a significant impact on the deployment of aftermarket OBE devices. The main challenges are viable business cases, infrastructure deployment, security, scalability, driver distraction, and product liability. The main opportunities are a government mandate, standards, and insurance incentives.

For each of the challenges, a key area of strategic approaches can be identified. For example, safety features bundled with comfort and convenient features or a current aftermarket product may be required to develop a viable business case. When looking at infrastructure deployment the key stakeholders - federal, state, and local governments will have to collaborate on a sustainable plan. The challenge of network security will require industry and government experts working together toward a common goal to resolve this issue. For scalability large scale deployments like the safety model deployment project conducted by USDOT will help identify potential issues. To address driver distraction, guidelines developed in cooperation between government and industry can overcome this challenge. Finally, product liability will require the commitment from all stakeholders to identify appropriate solutions. In all, any of the challenges mentions can be resolved with commitment and collaboration by all involved.

For each of the identified opportunities, a key stakeholder is critical for its success. For example, the government will play the most critical role in mandating V2V and V2I technologies. As for standards, the key stakeholder will be industry and their able to develop robust and reliable standards for the technology. Finally, the insurance industry will be the main stakeholder with regards to incentives to encourage consumer acceptance of OBE devices. In all, for the opportunities to make a difference each of the stakeholders will need to lead their respective area with support from one another.

The rapid introduction of Aftermarket OBE devices will require a government mandate, demonstrable advantages, user incentives, and OBE's with enhanced capabilities. It is certain that a government mandate will drive the development and deployment of V2V and V2I technologies quicker than no mandate. Consumers will be motivated to adopt aftermarket devices if they can obtain perceivable benefits and receive financial incentives. Finally, the enhanced capabilities of OBE devices are important in order to accommodate all possible vehicles and markets.

The interest of the consumer to purchase aftermarket OBE devices will come down to product features, product pricing, installation costs, and insurance incentives. Not all product features are created equally therefore it will be critical to match the product features with the appropriate customer/market. Product pricing will be the greatest challenge for OBE devices; the value must be evident to consumers for success. Installation will also play a key role in consumer acceptance it should be low cost and simple. Insurance incentives will be a big plus to promote consumer acceptance in accelerating the deployment of OBE devices.

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