Commercial Vehicle (CV) Retrofit Safety Device (RSD) Kits Project

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16. Abstract

Retrofit Safety Device (RSD) kits were developed and deployed on commercial vehicles as part of the U.S. DOT Connected Vehicle Safety Pilot to gain insight into the unique aspects of deploying connected vehicle technology in a commercial vehicle environment. These kits enable communication with other in-vehicle (commercial and passenger) and infrastructure DSRC devices via a Basic Safety Message (BSM) and multiple infrastructure-oriented messages, and various messages related to device security credential management. Implemented safety applications include Curve Speed Warnings (CSW), Emergency Electronic Brake Light (EEBL), and Forward Collision Warning (FCW). Each of the RSD kits includes a DSRC radio and antenna(s), GPS receiver and antenna, embedded gyroscope, J1939 Controller Area Network (CAN) interface, human machine interface (HMI), and interface to a Data Acquisition System (DAS). Some of these vehicles were also equipped with a DAS designed to record data from several sources including the DSRC radio and safety applications, GPS, the vehicle's J1939 CAN bus, video cameras, and a forward-facing radar. The Human-Machine Interface (HMI) was implemented as a 7-inch Android tablet mounted to the dash of the vehicle in such a way as to be easily visible to the driver but not impede or obstruct the driver's view of the roadway. The interface is presents both auditory and visual warnings and serves as the interface for the driver to enter required configuration information. In order to prevent misuse of the tablet interface, interaction by the driver is limited while the vehicle is moving. The report includes recommendations for future development and deployment.

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Executive Summary

Beginning in the fall of 2012, the U.S. Department of Transportation (U.S. DOT) began a scientific evaluation of real-world connected vehicle technology, aptly named the Safety Pilot Program. This effort is providing crucial metric data used to evaluate the capability, maturity, and robustness of connected vehicle safety technologies, applications, and systems using everyday drivers. Additionally this effort will provide data regarding test performance, human factors and usability, and policies and processes, and will collect empirical data used to create a more accurate and detailed understanding of the potential safety benefits. As part of the ongoing Safety Pilot Program, approximately 3,000 personal and commercial vehicles were outfitted with Dedicated Short Range Communication (DSRC) devices. Although these devices were of various form factors, had varying degrees of capabilities, and came from multiple vendors, each device was capable of transmitting and receiving basic safety-related messages.

Retrofit Safety Device (RSD) kits were developed and deployed on commercial vehicles to gain insight into the unique aspects of deploying connected vehicle technology in a commercial vehicle environment. These kits enable communication with other in-vehicle (commercial and passenger) and infrastructure DSRC devices via a Basic Safety Message (BSM) and multiple infrastructure-oriented messages, including Traveler Information Messages (TIM) that contain Curve Speed Warnings (CSW), and various messages related to device security credential management. Some of these vehicles were also equipped with a Data Acquisition System (DAS) designed to record data from several sources including the DSRC radio and safety applications, GPS, the vehicle's J1939 Controller Area Network (CAN) bus, video cameras, and forward-facing radar.

Each of the RSD kits includes a DSRC radio and antenna(s), GPS receiver and antenna, embedded gyroscope, J1939 CAN interface, human machine interface (HMI), and interface to a DAS. Hardware was selected such that there are standardized interfaces between components, allowing individual pieces to be upgraded or replaced as necessary without requiring changes to other components. The two main components of the RSD kit are the DSRC radio and the HMI. The radio contains the majority of the interfaces required for the complete kit, including two wireless communications modules (DSRC radios), an embedded GPS receiver, a CAN interface to receive data from the vehicle's J1939 bus, and an Ethernet connection to provide data to the HMI and DAS (if installed). The HMI is implemented with a tablet that communicates wirelessly, via IEEE 802.11g, with the DSRC radio and its respective safety applications.

The RSD Kit is composed of three primary software components: BSM generation, onboard safety applications, and driver interaction. Supporting software related to external interfaces, including GPS and the J1939 databus, were also developed. The BSM generation component is responsible for collecting on-board data as well as packaging, encoding, and transmitting that data over the DSRC radio; data includes vehicle position, movement, history, and predicted path of the vehicle. All messages transmitted and received by the RSD kits follow a common set of SAE and IEEE standards, including SAE J2735-200911, IEEE 1609.2-4, and IEEE 802.11p. The BSM consists of the required Part I elements and optional Part II elements. The Part I elements are generated and broadcast at 10Hz and includes basic vehicle dynamics such as speed, heading, and position information. The optional Part II elements include supplementary information including the vehicle's path history, path prediction, and an indication of hard braking events; they are generated at 10Hz and added to the Part I elements for transmission when generated.

The safety applications incorporated into the RSD Kit include Emergency Electronic Brake Light (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW). Each safety application generates a distinct warning message to the driver via the HMI tablet. In the event that multiple applications are triggered simultaneously, the highest priority warning is displayed to the driver. The EEBL safety application is designed to help drivers avoid or mitigate rear-end collisions with vehicles that are braking in their forward path. The FCW application is designed to aid the driver in avoiding or mitigating collisions with vehicles in the forward path of travel through driver notification or warning of the impending collision. The CSW safety application is intended to target crashes approaching horizontal curves on segments or interchange ramps that are speed-related, providing a warning to drivers approaching a curve or ramp at an unsafe speed or decelerating at insufficient rates to safely maneuver the curve.

The HMI is the central interface to the driver and is implemented as a 7-inch Android tablet mounted to the dash of the vehicle in such a way as to be easily visible to the driver but not impede or obstruct the driver's view of the roadway. The interface is capable of presenting both auditory and visual warnings and additionally serves as the interface for the driver to enter required configuration information. In order to prevent misuse of the tablet interface, the tablet operating system was modified to start the HMI's RSD safety application immediately upon boot. Additionally, there is no direct way for the operator to minimize or exit the program. When the vehicle is in motion, all user input is disabled on the device and the screen is blank unless a safety application generates an alert.

The DAS, or Data Acquisition System, is a stand-alone system from the RSD kit and includes its own dedicated hardware and software. It is designed to provide real operational data that can be used to assess safety applications operating on the RSD kit by recording the triggering of a safety warning, and recording data related to the circumstances causing a warning. The DAS is built around a central computer implemented as a PC/104 stack, and consists of a Central Processing Unit (CPU) module, Power supply module, Video capture module, and a CAN module. The central computer runs the main operating software and is responsible for collecting operational data and storing it to removable media, allowing data to be collected quickly and directly without the need to connect the DAS to another computer using Ethernet or serial interface. Outside of the central computer and removable media, the DAS includes three (3) cameras, a link to the J1939 CAN interface, a forward looking radar unit, an interface to the RSD Kit, and appropriate cables for connections between components.

Looking forward, this team has put forth some recommendations that would benefit future development and deployment of similar RSD devices.

1. Additional research into a more integrated antenna solution to allow the antennae to be better protected while still meeting the strict needs of 5.9GHz communications, in particular unobstructed, line-of-sight placement.
2. A more integrated antenna mounting solution would allow for a more direct routing and thus shorter cable length resulting in a positive effect on RF attenuation. If flexibility in routing options is required, a larger (lower-loss) conductor should be considered to offset increased attenuation.
3. Minor modifications to the radio and computing equipment installation through slight modifications to the vehicle cab to provide improved physical and environmental protection as well as better cable routing options.

4. Broadcast two separate BSMs, one each for tractor and trailer, when the vehicle is turning, resulting in a more accurate model of the physical footprint of the entire vehicle to those following.
5. Improved TIM location representation over the current circle, region, and shape point set options.
6. Improved TIM direction representation, perhaps by removing the overall ‘direction of use’ attribute and adding direction as an inherent attribute of each segment within the vehicle path.

1.0 Commercial Vehicle Retrofit Safety Device Kits

While the majority of the vehicles utilized for the Safety Pilot are standard passenger vehicles, commercial vehicles account for a significant portion of the transportation sector. As such, the evaluation of benefits and limitations of connected vehicle technology as they apply to commercial vehicles is an important data point in understanding the full implications of the technology. The implementation of connected vehicle technology for commercial vehicles took the form of Retrofit Safety Device (RSD) kits. These kits provide direct insight into the unique aspects of deploying connected vehicle technology in a commercial vehicle environment as opposed to only passenger vehicles.

Within the Safety Pilot Program, RSD kits were specifically designed for installation on Class 6/7/8 commercial vehicles with a Gross Vehicle Weight Rating (GVWR) greater than 19,500 lbs that have completed their build process at their OEM facility and are already in service. Once installed in the vehicles, the RSD kits enable communication with other deployed DSRC devices. These devices include in-vehicle devices (commercial and passenger) and infrastructure devices deployed within the Ann Arbor region for the U.S. DOT Safety Pilot.

At a minimum, every vehicle equipped with connected vehicle technology communicates a BSM along with multiple infrastructure-oriented messages, including TIM that contain CSW, and various messages related to device security credential management. All messages transmitted and received by the RSD kits follow a common set of SAE and IEEE standards, including SAE J2735-200911, IEEE 1609.2-4, and IEEE 802.11p.

A subset of the vehicles on which an RSD kit was installed was additionally equipped with a DAS. The DAS is designed to record data from several sources including the DSRC radio and safety applications, GPS, the vehicle’s J1939 CAN bus, video cameras, and a forward-facing radar.

The development and implementation of the RSD kits builds on previous U.S. DOT programs that have identified overall concept of operations, application requirements, and common system requirements for devices of various capabilities.

2.0 Retrofit Safety Device (RSD) Kit

For this project, eight complete RSD kits (including hardware, software, and applications) were designed, tested, and integrated onto commercial vehicles. These kits were specifically designed and built to be vehicle-agnostic and capable of retrofit integration with all participating cooperative vehicles in the Safety Pilot Program. Once installed, the RSD kits provided the host vehicles with vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) safety application capability.

With regard to overall RSD design, an integrated system design was chosen (see Figure 2-1). Specifically, safety applications were integrated directly into the DSRC radios. This design had the advantages of reducing hardware, minimizing vehicle installation complexity, and reducing both the development and build cost.

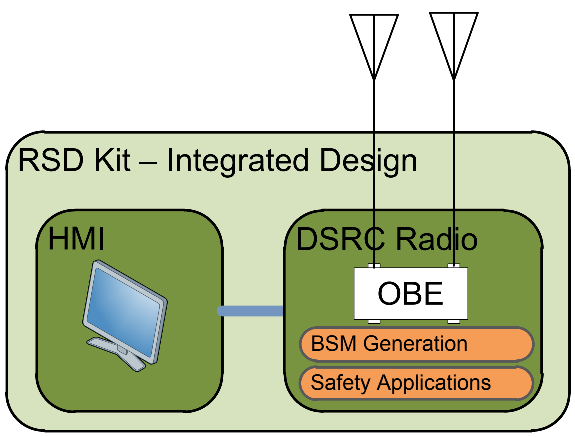

Figure 2-1. RSD Kit Integrated System Design
(Source: Southwest Research Institute, 2012.)

Hardware

Each of the RSD kits includes a DSRC radio and antenna(s), GPS receiver and antenna, embedded gyroscope, J1939 Controller Area Network (CAN) interface, human machine interface (HMI), and interface to a DAS. The primary hardware components included in the kit, as well as their respective connections and relation to the overall system, are shown in Figure 2-2. Hardware was selected such that there are standardized interfaces between components, allowing individual pieces to be upgraded or replaced as necessary without requiring changes to other components. The two main components of the RSD kit are the DSRC radio and the HMI.

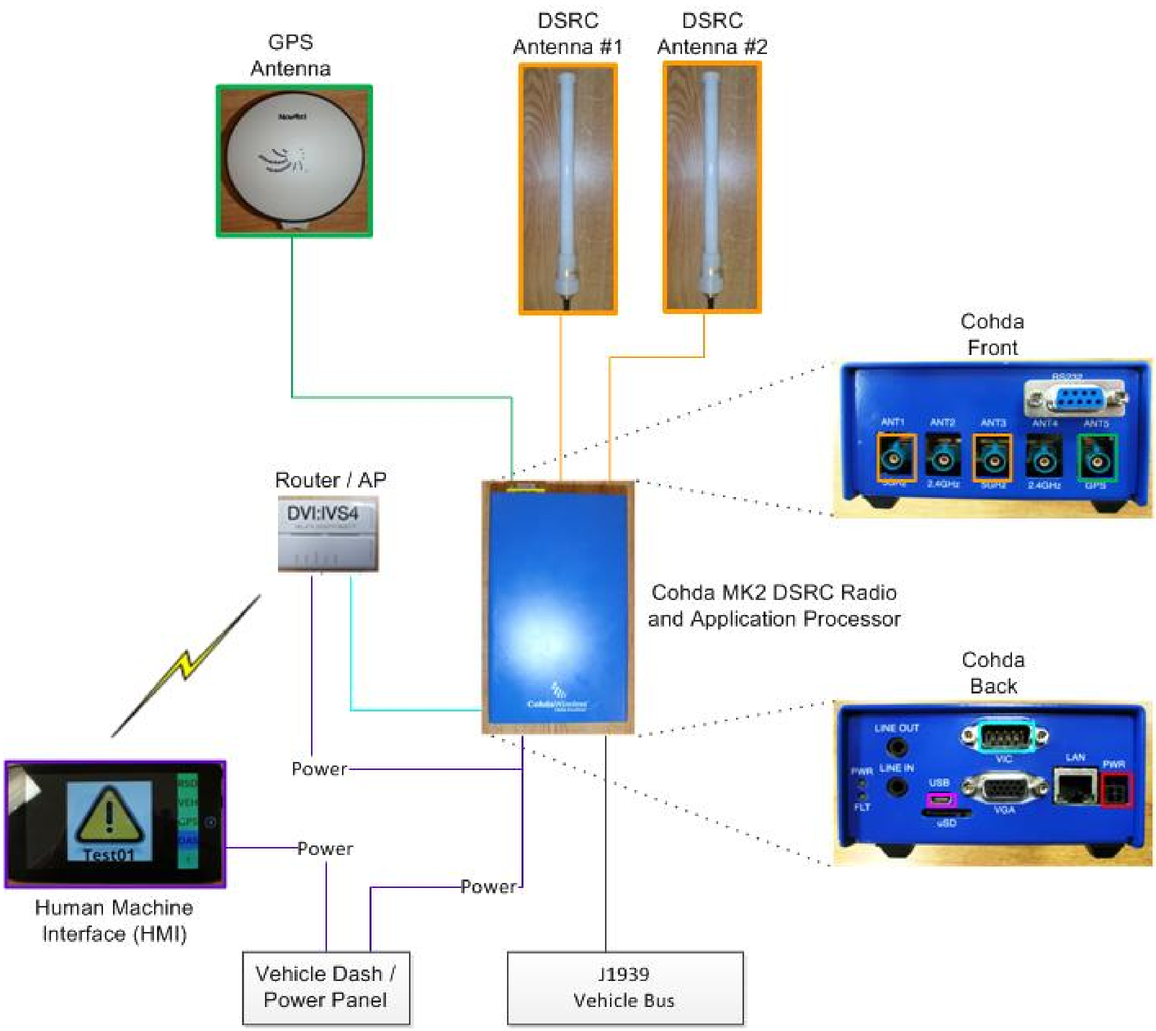

Figure 2-2. RSD Equipment
(Source: Southwest Research Institute, 2012.)

DSRC Radio

The main component of the RSD Kit is the DSRC radio. "DSRC radio" can refer both to the embedded chipset that enables 802.11p wireless communications, as well as the entire hardware unit that encloses the chipset and provides additional lower level hardware components and interfaces.

The radio contains the majority of the interfaces required for the complete kit, including two wireless communications modules (DSRC radios), an embedded GPS receiver, a CAN interface to receive data from the vehicle's J1939 bus, and an Ethernet connection to provide data to the HMI and DAS (if installed).

Although the radio is configurable for either single antenna or dual antenna operation, the physical configuration of typical commercial vehicles creates line of sight occlusion issues. As such, it was necessary to have both DSRC antennae installed on the vehicle to provide sufficient communications coverage with nearby vehicles. More specifically, DSRC antennae were installed on each side of the vehicle, mounted on custom-fabricated mounts near the edge of the cab's roof fairing. This configuration provided sufficient coverage along both sides of the vehicle and to the front. While communications coverage directly behind the vehicle still contains small areas of limited coverage, the majority of typical vehicle locations behind the commercial vehicle are still covered to a sufficient extent to enable safety applications to function as designed.

Human Machine Interface

The HMI provides a medium for communicating visual and auditory warnings to the driver and allows the driver to input any required configuration information, discussed in the next section. This HMI is implemented with a 7" dash mounted android tablet, as shown in Figure 2-3. This tablet is mounted in such a way as to be easily visible to the driver but not impede or obstruct the driver's view of the roadway. The tablet communicates wirelessly, via IEEE 802.11g, with the DSRC radio and its respective safety applications.

Figure 2-3. HMI Tablet
(Source: Southwest Research Institute, 2012.)

Software

The RSD Kit is composed of three primary software components: BSM generation, onboard safety applications, and driver interaction. In addition to the three main components, supporting software related to external interfaces, including GPS and the J1939 databus, were developed.

BSM Generation

The BSM generation component is responsible for collecting on-board data as well as packaging and transmitting that data. More specifically, the BSM generator monitors and collects the vehicle position, movement, history, and predicted path of the vehicle. This data is then encoded and broadcast over the DSRC radio (See Figure 2-4).

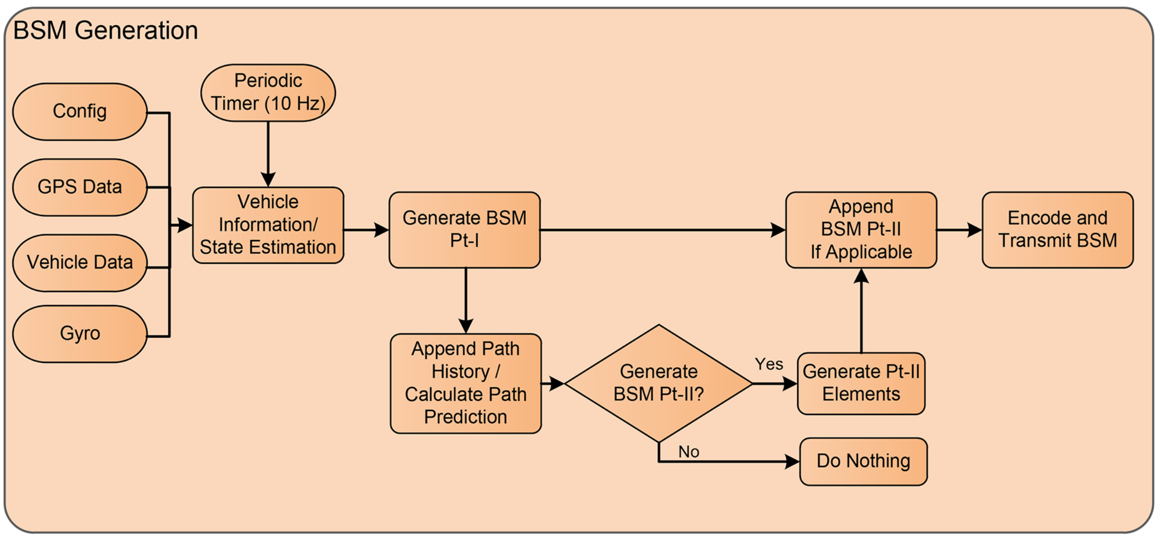

Figure 2-4. BSM Generation
(Source: Southwest Research Institute, 2012.)

The BSM encoding is defined in J2735-200911 as implemented for the Safety Pilot Model Deployment per the Model Deployment Safety Device DSRC BSM Communication Minimum Performance Requirements. The BSM consists of the required Part I elements and optional Part II elements. The Part I elements are generated and broadcast at 10Hz and includes basic vehicle dynamics such as speed, heading, and position information. The optional Part II elements include supplementary information including the vehicle's path history, path prediction, and an indication of hard braking events. Within the Safety Pilot, the Part II elements are generated at 10Hz and added to the Part I elements for transmission when generated.

Safety Applications

The safety applications incorporated into the RSD Kit include Emergency Electronic Brake Light (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW). Each safety application generates a distinct warning message to the driver via the HMI tablet. In the event that multiple applications are triggered simultaneously, the highest priority warning will be displayed to the driver. Figure 2-5 details a high level operational flow chart of the incorporated safety applications.

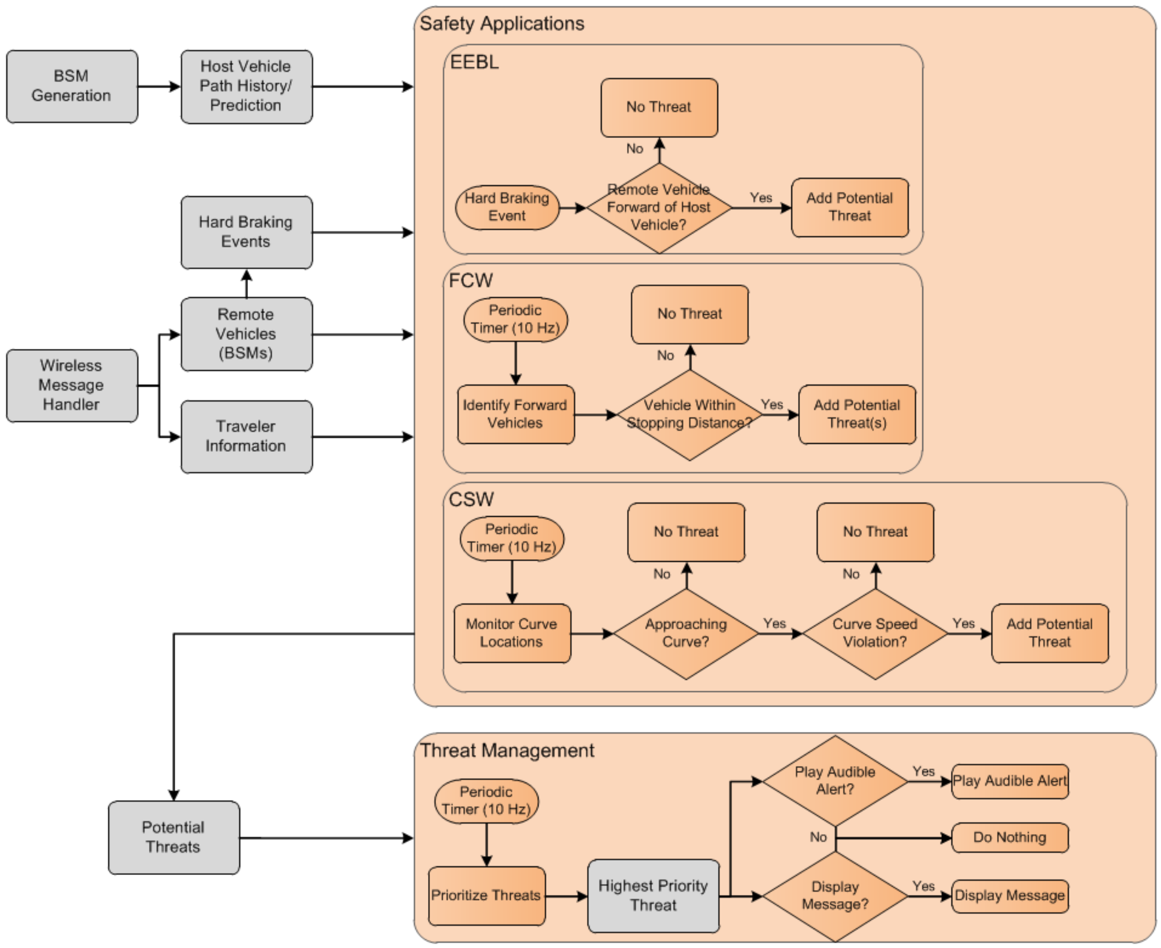

Figure 2-5. Safety Applications
(Source: Southwest Research Institute, 2012.)

Emergency Electronic Brake Light

The EEBL safety application is designed to help drivers avoid or mitigate rear-end collisions with vehicles that are braking in their forward path. This application is implemented as a Part II element of the BSM.

In this implementation, it is the responsibility of the braking vehicle to recognize the “hard” braking event and transmit a warning notification. This requires the vehicle to calculate or directly sense its current accelerations and monitor those values for decelerations that constitute a “hard” braking event, i.e. decelerations exceeding 0.4 g for passenger vehicles and 0.3 g for commercial vehicles. In addition to the deceleration event, the vehicle must also be traveling at a sufficient speed to warrant a “hard” braking event, between 11.4 and 30 m/s (25-67 mph). If both the minimum speed threshold and maximum deceleration threshold are exceeded simultaneously, the hard braking event will be activated which will trigger the encoding and transmission of a BSM Part II EEBL event.

Every vehicle within receiving range of the EEBL event will first calculate its relative position to the event using BSM Part I data. Once calculated, each vehicle determines if the message requires a warning be presented to the driver. This is accomplished by checking:

- Direction – EEBL warnings are only applicable to vehicles traveling in the same direction as the vehicle that generated the EEBL event.
- Distance – EEBL warnings are only applicable to vehicles within 300 meters (longitudinally) of the EEBL event and within one lane width (laterally) of the EEBL event.
- Host Deceleration – EEBL messages can be suppressed if the host vehicle is already decelerating at the time the EEBL message is handled by the host vehicle.

If the host vehicle is within the distance threshold (both laterally and longitudinally), traveling in the direction of the event, and is not decelerating at the time the event is received and addressed, an HMI warning event is trigged. This event is transmitted wirelessly to the HMI tablet which will display the appropriate warning message to the vehicle's driver and will include an audible alert as well.

Forward Collision Warning

The objective of the FCW safety application is to increase driver awareness and subsequently reduce deaths, injuries, and economic losses resulting from on-road vehicular collisions. The FCW application is designed to aid the driver in avoiding or mitigating collisions with vehicles in the forward path of travel through driver notification or warning of the impending collision.

This application is implemented on all RSD-equipped vehicles and involves examination of all received BSMs. As BSMs from remote vehicles arrive, the host vehicle attempts to add them to a cache of active vehicles. If the vehicle exists in the cache, its contents are simply updated with any new data. This cache is examined at 10Hz to remove stale vehicles, i.e. vehicles for which the host has not recently received a BSM.

Also at 10Hz, the FCW safety application examines all active vehicles for a potential FCW warning. This process involves examining the location and speed of each known vehicle against the host's location, speed, and direction of travel. Several specific attributes are examined to determine if a potential forward collision is probable and warrants a warning including:

- Path – Using the remote vehicle's path history, the host is able to determine if its current location and direction follow the remote vehicle's path of travel. FCW is only valid within half a lane width of the remote vehicle's path.
- Time to Impact – Using the remote and host vehicles' speeds, the host vehicle can calculate an approximation for time to impact. The FCW is only considered of high probability if the time to impact falls below a configured threshold (currently set to 5 seconds).
- Speed Delta – On a realistic roadway it is unlikely that high speed traffic will have large Euclidian separations. As such, a delta speed threshold is used to filter out FCW warnings that may appear in high speed dense traffic. This configurable attribute requires that there be a minimum speed difference between the host and remote vehicle for an FCW warning to be created (currently set to 5 mph).

In addition to the above attributes, the host vehicle must be within a Euclidian distance of 300m of the remote vehicle and must be traveling at a speed greater than or equal to 11.4 m/s to trigger a FCW. If a FCW is warranted, the event is transmitted wirelessly to the HMI tablet which will display the appropriate warning message to the vehicle driver and generate an audible alert.

Curve Speed Warning

Excessive vehicle speed in curves often leads to lane departure, collision, loss of vehicle control, and/or road departure, any of which may result in some combination of vehicle or property damage or loss, injury, and death. The CSW safety application is intended to target crashes approaching horizontal curves on segments or interchange ramps that are speed-related. The application provides a warning to drivers approaching a curve or ramp at an unsafe speed or decelerating at insufficient rates to safely maneuver the curve.

CSW is implemented using Traveler Information Messages (TIM) that are transmitted by static infrastructure devices to DSRC equipped vehicles as they drive past. These messages contain a list of locations with associated speeds and direction. These data sets identify roadway areas with reduced speed requirements. These data sets are logged for long-term usage by RSD equipped vehicles.

At a rate of 10Hz, all reduced speed data sets stored on the host vehicle are evaluated by the CSW application. The CSW application evaluates three states to determine if a CSW should be activated and presented to the host driver:

- Location – Reduced speed regions, within the context of the Safety Pilot, are represented as connected line segments that follow the path of the curve with a corresponding lane width. The host vehicle's position must be located within this geometry to generate a CSW alert.
- Direction – In addition to position, the current heading of the vehicle must be within a known threshold of the direction(s) stated in the data sets. This ensures that only vehicles traveling toward the reduced speed area will receive the warning.
- Speed – If the host vehicle is determined to be within the active range and direction of the reduced speed area, as determined above, the current speed of the vehicle is compared against the designated curve speed. If the vehicle's current speed is found to be in excess of the designated curve speed a CSW alert is warranted.

CSW alerts can be suppressed if the driver has recently received a warning for the given curve. When a CSW is warranted, the event is transmitted wirelessly to the HMI tablet which displays the appropriate warning message to the vehicle driver and generates an audible alert.

HMI Interface

The HMI is the central interface to the driver and is implemented as a 7-inch Android tablet mounted to the dash of the vehicle. The interface is capable of presenting both auditory and visual warnings and additionally serves as the interface for the driver to enter required configuration information.

In order to prevent misuse of the tablet interface, the tablet operating system, Android, was modified to start the HMI's RSD safety application immediately upon boot. Additionally, there is no direct way for the operator to minimize or exit the program. In order to support basic maintenance, the RSD safety application can be closed using a designated set of motion swipes. This "back door" only exists for development and initial installation and configuration purposes and can be disabled when necessary.

When the HMI starts the first time (after initial installation and configuration are complete), the driver will be presented with a set of instructional slides that detail input requirements and describe each of the alerts that may be seen during normal operation. Once the slides have been completed, the driver can opt not to see the instructional slides again by making a selection on the final slide.

The normal boot up procedure will ask the driver to designate the current configuration of the vehicle. This is implemented by presenting the driver with four images representing the most common vehicle configurations anticipated for this vehicle's installation (see Figure 2-6 which shows no trailer, 25 ft. trailer, 28 ft. trailer, and 38 ft. trailer configurations, from left to right). The options presented are defined in a configuration file on the DSRC radio during installation. The selected configuration information will be transmitted back to the DSRC radio and used by the safety applications. If the driver does not select a configuration before the vehicle begins to move, the HMI will default to the last known configuration and will continue to ask the driver for configuration information each time the vehicle comes to a complete stop. When the vehicle is in motion, all user input is disabled on the device and the screen is blank unless a safety application generates an alert.

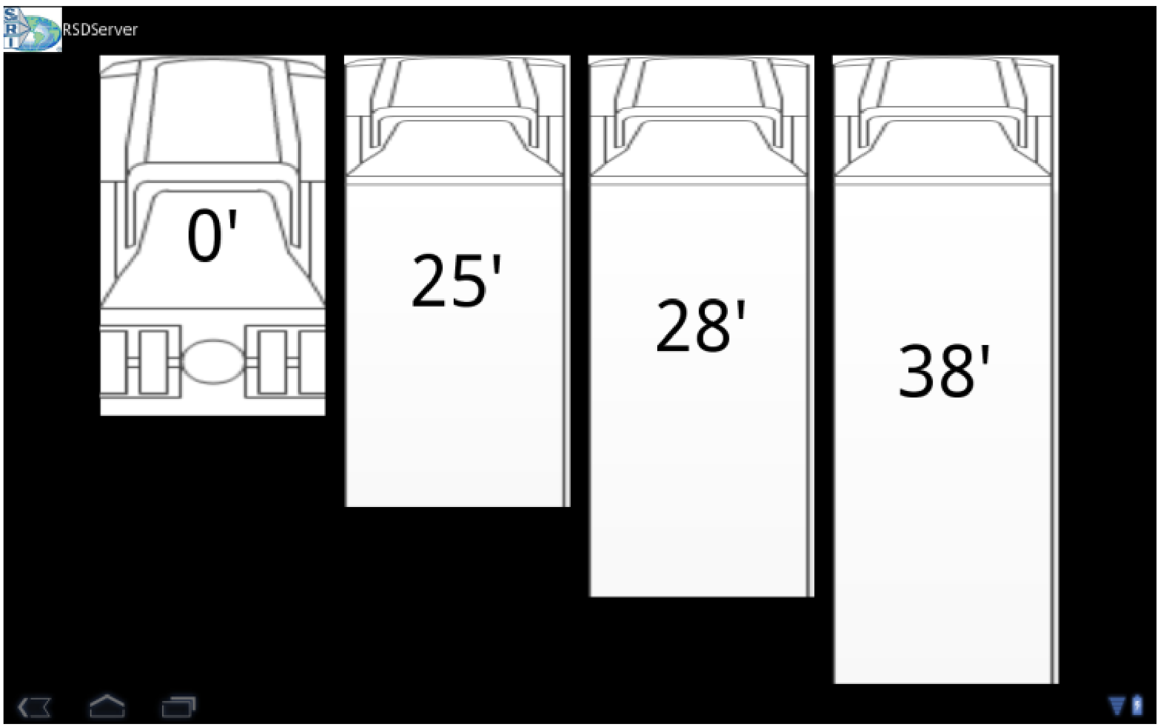

Figure 2-6. HMI Vehicle Configuration Screen
(Source: Southwest Research Institute, 2012.)

The vehicle configuration is the only input required from the user and once completed, the HMI operates only to provide warning messages (both auditory and visual) to the user. HMI visual warnings for EEBL, FCW, and CSW can be seen in Figure 2-7. Note that there is a comparable CSW warning for "right hand" curves as well.

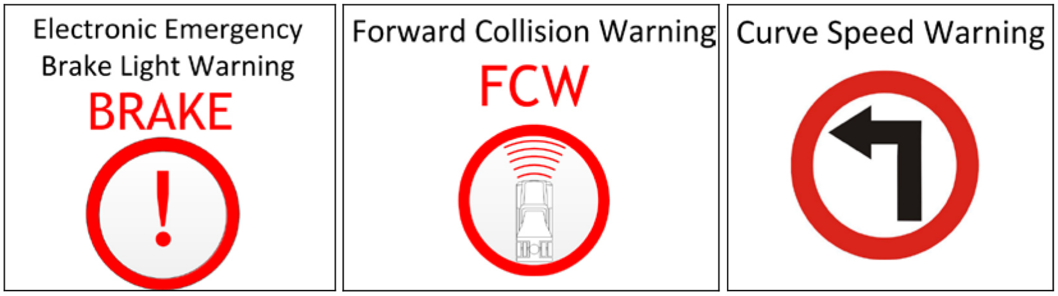

Figure 2-7. HMI visual warning messages: EEBL, FCW, and Left CSW
(Source: Southwest Research Institute, 2012.)

3.0 Data Acquisition System (DAS)

The DAS, or Data Acquisition System, is a stand-alone system from the RSD kit and includes its own dedicated hardware and software. The DAS is designed to provide real operational data that can be used to assess safety applications operating on the RSD kit.

Hardware

The DAS is built around a central computer implemented as a PC/104 stack. This central computer consists of:

- CPU module – This module includes support for Ethernet, Universal Serial Bus (USB), and serial interfaces.
- Power supply module – This module provides the multitude of regulated voltages required to run the CPU and support modules.
- Video capture module - This module supports the four external cameras and provides the CPU with access to all image streams simultaneously. Note that for Safety Pilot deployment, only three cameras were utilized.
- CAN module – This module supports the forward-looking radar.

The central computer runs the main operating software and is responsible for collecting operational data and storing it to removable media. Removable storage is accomplished through the use of the USB interface in the form of a removable thumb drive. This removable media allows data to be collected quickly and directly without the need to connect the DAS to another computer using Ethernet or serial interface.

Outside of the central computer and removable media, the DAS includes three cameras, a link to the J1939 CAN interface, a forward looking radar unit, an interface to the RSD Kit, and appropriate cables for connections between components (see Figure 3-1).

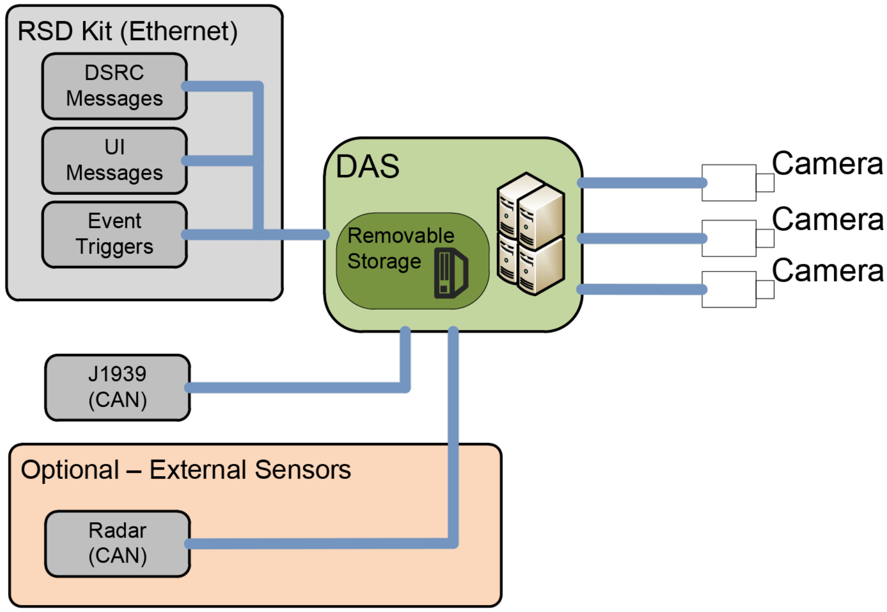

Figure 3-1. DAS High Level Architecture
(Source: Southwest Research Institute, 2012.)

Software

As previously mentioned, the DAS is designed to provide data for assessing RSD safety applications. In order to support this goal the DAS must not only record the triggering of a safety warning, it must also record data related to the circumstances that caused the warning. To capture all of these attributes the DAS supports recording:

- Imagery – this includes three (3) onboard video cameras providing views of the driver's area, the dash including the HMI interface, and the roadway ahead of the vehicle (see Figure 3-2 through Figure 3-4).
- Vehicle state data (J1939 vehicle data).
- RSD data – this includes all messages presented to the driver (including all warning messages), data used to determine the need for each warning, and all over-the-air messages, broadcast and received, by the RSD.
- Radar data.

To support the capture of data leading up to an event, the DAS maintains a running buffer of all camera data. In the event a warning is triggered, these buffers are stored in their entirety to removable storage. Additionally the three image streams are piped to storage for a predetermined time after the event has concluded. The amount of time captured by the buffers and after the event has concluded are configurable variables that are loaded during boot.

In the event that an error or malfunction occurs on the DAS, a message is transmitted to the RSD and forwarded to the HMI indicating the error to the driver.

Figure 3-2. Still Image from DAS Video – Driver Area
(Source: Southwest Research Institute, 2012.)

Figure 3-3. Still Image from DAS Video – Dash with HMI
(Source: Southwest Research Institute, 2012.)

Figure 3-4. Still Image from DAS Video – Forward Roadway
(Source: Southwest Research Institute, 2012.)

4.0 Limitations and Lessons Learned

This section provides details related to some of the obstacles or limitations experienced during the project, and is intended to aid in the continual improvement of V2V and V2I technology.

Vehicle Installation

While a primary goal of this specific implementation was to facilitate removal of the kits during decommissioning so that the vehicles would not be noticeably modified in any way, implementation of this goal considerably restricted installation options. Of key interest is the placement and mounting of the DSRC antennae. Fabricating antenna brackets that could be used on available mounting points led to the antennae being mounted in exposed and non-optimal locations. This subsequently led to the antennae potentially being damaged by tree limbs overhanging the roadway, particularly in urban areas. Additional research into a more integrated antenna solution should be done that allows the antennae to be better protected while still meeting the strict needs of 5.9GHz communications, in particular unobstructed, line-of-sight placement.

Additionally, due to the need for flexible and removable installation, cables were installed in non-optimal paths, generating longer sections of cable, and used smaller conductor cores, supporting smaller bend radii. Unfortunately, reduced conductor size and increased cable length both contribute to RF attenuation. More specifically, attenuation is a linear function of cable length and a quadratic function of cable size, thus shortening the cable and using a larger diameter conductor will improve overall functionality of the system. As such, a more integrated antenna mounting solution would allow for a more direct routing and thus shorter cable length. If flexibility in routing options is required, a larger (lower-loss) conductor should be considered to offset increased attenuation.

In addition to supporting more integrated antenna capabilities, the radio and computing equipment could significantly benefit if minor vehicle modifications were supported. As installed, the components were exposed in the cab, generally out of sight, but still subject to environmental exposure and potential physical damage by loose objects in the cab. While only minimal actual damage was noticed, there were signs of objects in the cab in close proximity to the equipment, with obvious potential to damage antenna connectors, cables, or other components. The ability to make small modifications to the vehicle cab to allow the units to be installed behind the passenger side dash, for instance, should provide sufficient physical and environmental protection while providing better cable routing options as well.

Shape Representation

Current connected vehicle standards utilize a static bounding box representation to define the length and width of all vehicles. This bounding box is transmitted as part of the BSM and utilized by remote vehicle safety applications. This design is functionally limiting when commercial vehicles are introduced.

First, commercial vehicles contain a dynamic component that significantly affects the size and shape of the vehicle bounding box, i.e. the vehicle trailer. Within the commercial vehicle industry, it is not uncommon for a tractor trailer to drop off and pick up multiple loads over the course of a single day. These loads may change the vehicle's length, width, or both.

Secondly, a tractor-trailer is an articulating unit that can significantly change its footprint geometry over the course of a turn. This articulation can have significant impact on safety applications that will incorrectly discern roadway hazards. Figure 4-1 provides a single example where a passenger vehicle would incorrectly detect a forward collision due to the rigid nature of how vehicle shape is defined and transmitted.

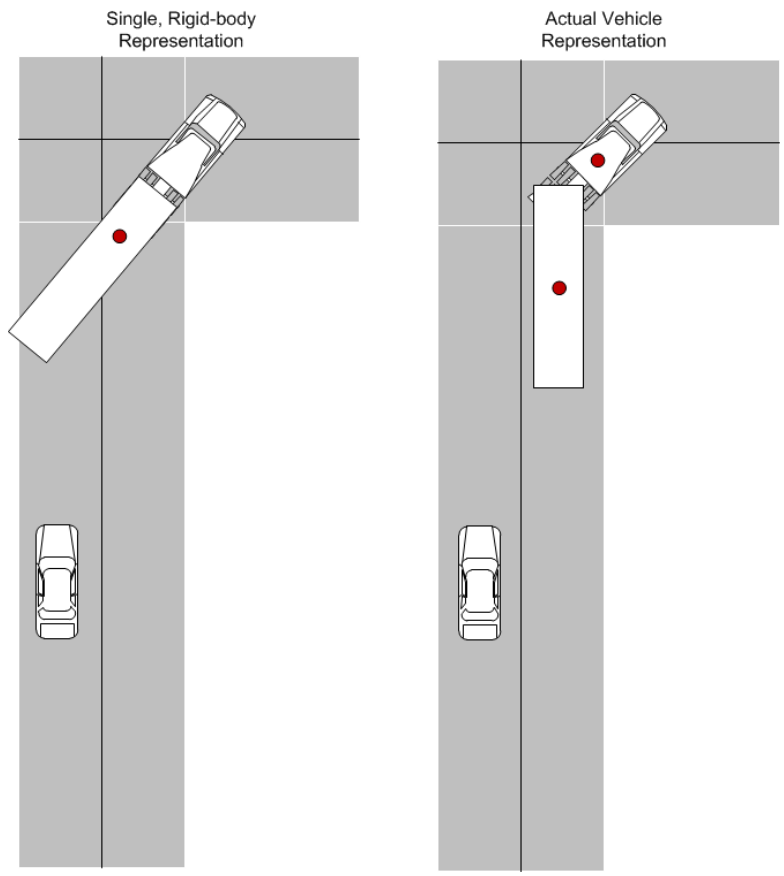

Figure 4-1. Vehicle Representation
(Source: Southwest Research Institute, 2012.)

The currently proposed solution to this problem is to broadcast two separate BSMs, one each for tractor and trailer, when the vehicle is turning. The benefits of this approach are that there is no need to change the J2735 standard format of the BSM, and vehicles following the commercial vehicle have a better model of the physical environment ahead of them.

It should not be an issue that the commercial vehicle is not necessarily perceived as a single unit in this case. Vehicles following the commercial vehicle do not need to know that a BSM is generated from a trailer, only that there is a physical object that matches the dimensions and location that are broadcast in the BSM.

TIM Location Limitations

Traveler Information Messages, as defined in the SAE J2735-200911 DSRC Message Set Dictionary, contain information to be presented to a driver and a definition of when, where, and under what circumstances it should be presented. Options for where information should be displayed include:

- Circle - a center point and radius, generally used for very large areas
- Region - a sequence of vertices that define a polygon, generally used to isolate stretches of a highway or a particular jurisdiction
- Shape point set - a sequence of points that define a path with a particular width

While the shape point set seems the obvious choice for a message that should be displayed in a relatively small area along an approach to and through the path of a given curve, there are a couple of key limitations with its usage. For instance, attempting to define the path of a road around a curve requires a dense set of path points. Unfortunately these path points will not fully cover a particular lane, as seen in Figure . Although using a geometry that is wider than a lane width will capture the missing sections of the lane, the extended geometry may cover unintended and non-applicable lanes.

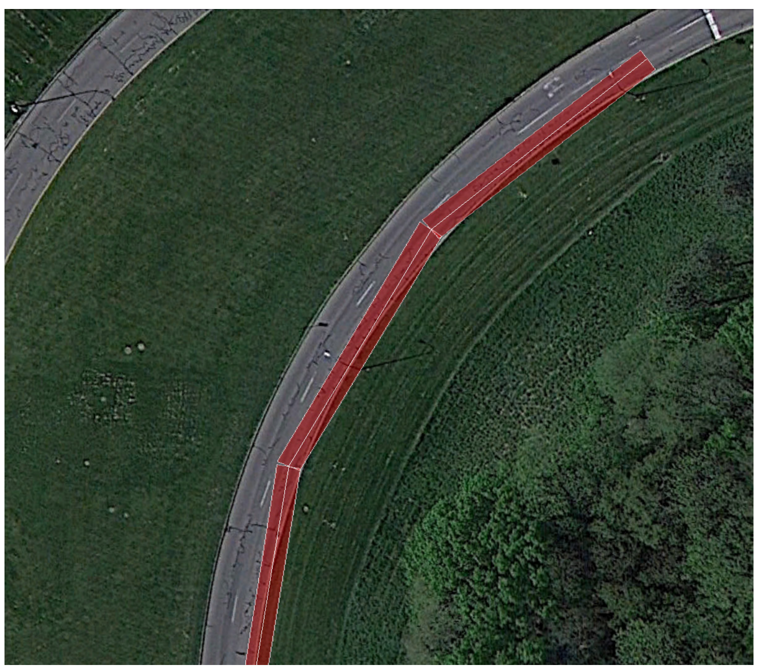

Figure 4-2. Example Curve Speed Warning Definition
(Source: Southwest Research Institute, 2012.)

TIM Direction Limitations

An additional limitation related to TIM that was noted during the course of this project was the applicable heading associated with TIM regions. The current standard uses a single 'direction-of-use' element that is applied over the entire list of segments. This implementation has led to issues when applied to longer curves and especially those at highway interchanges such as a cloverleaf (see Figure 4-3). By including a sufficient range of directions to cover all of the segments (white arrows), those segments must be very strictly defined such that they do not include adjacent roads that are not applicable (red arrows) which increases the complexity of the region structure and thus increases the processing requirements and load on the on-board equipment (OBE). The recommendation is to remove the overall 'direction of use' attribute from that region type and let the direction be an inherent attribute of each segment within the path.

Figure 4-3. Curve Speed Warning Direction Issue
(Source: Southwest Research Institute, 2012.)

5.0 References

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APPENDIX A. List of Acronyms

BSM	Basic Safety Message
CAN	Controller Area Network
CPU	Central Processing Unit
CSW	Curve Speed Warning
CV	Commercial Vehicle
DAS	Data Acquisition System
DSRC	Dedicated Short Range Communication
EEBL	Emergency Electronic Brake Light
FCW	Forward Collision Warning
GPS	Global Positioning System
GVWR	Gross Vehicle Weight Rating
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
RSD	Retrofit Safety Device
SAE	Society of Automotive Engineers
TIM	Traveler Information Message
USB	Universal Serial Bus
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

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