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Interoperability Issues for Commercial Vehicle Safety Applications

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13. ABSTRACT (Maximum 200 words)

A connected-vehicles program has been undertaken by the U.S. Department of Transportation and its partners, with the goal of exploring and possibly enabling a new generation of technology to address highway transportation safety, mobility, and environmental challenges. This program has been underway for several years, and one area of intensive work has been the development of enabling devices, to be installed onboard vehicles, which use wireless technology to communicate with nearby vehicles and the infrastructure. This can be achieved through 5.9 GHz dedicated short-range communications (DSRC). Such technologies represent highly capable, low-cost alternatives or complements to vehicle-based crash avoidance systems. The wireless-enabled systems may enable vehicle-to-vehicle (V2V) applications as well as vehicle-infrastructure (V2I) applications, and would be capable of interfacing with other devices as well (V2X). This study sought to identify and prioritize issues unique to commercial vehicles that affect the interoperability of DSRC communications, and especially V2V safety applications. V2V safety applications represent a primary set of applications for DSRC because they leverage the unique aspects of DSRC: low latency, and design for broadcast mode (as opposed to peer-to-peer). A series of ground-breaking projects and activities have been underway, and are still ongoing. The results presented in this report identify and prioritize issues related to connected vehicle systems and applications that are unique to commercial vehicles. In particular, the technical aspects of the exchange of information were studied. This project considered the current state of the art, and identified areas in which commercial vehicle considerations may result in revisions to past decisions or changes to future plans. This focus was necessary to support upcoming activities to equip heavy trucks with these connected vehicle systems, and because the breadth of commercial vehicles was not possible to consider in the scope of this project.

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Table of Contents

Executive Summary

A connected vehicles program has been undertaken by the U.S. Department of Transportation and its partners with the goal of exploring and possibly enabling a new generation of technology to address highway transportation safety, mobility, and environmental challenges. This program has been underway for several years, and one area of intensive work has been the development of enabling devices, to be installed on board vehicles, which use wireless technology to communicate with nearby vehicles and the infrastructure. This can be achieved through 5.9 GHz dedicated short-range communications (DSRC). Such technologies represent highly capable, low-cost alternatives or complements to vehicle-based crash avoidance systems. The wireless-enabled systems may enable vehicle-to-vehicle (V2V) applications as well as vehicle-to-infrastructure (V2I) applications, and would be capable of interfacing with other devices as well (V2X).

This project sought to identify and prioritize issues unique to commercial vehicles that affect the interoperability of DSRC communications, and especially V2V safety applications. V2V safety applications represent a primary set of applications for DSRC because they leverage the unique aspects of DSRC: low latency, and design for broadcast mode (as opposed to peer-to-peer). A series of ground-breaking projects and activities have been underway, and are still ongoing. To date, however, relatively few efforts have focused on commercial vehicles; the work has been conducted largely on passenger vehicles.

The results in this report identify and prioritize issues related to connected vehicle systems and applications that are unique to commercial vehicles. In particular, the technical aspects of the exchange of information were studied. This project considered the current state of the art, and identified areas in which commercial vehicle considerations may result in revisions to past decisions or changes to future plans. This study emphasizes heavy vehicles, particularly trucks, and does not directly treat many classes of commercial vehicles. This focus was necessary to support upcoming activities to equip heavy trucks with these connected vehicle systems, and because the breadth of commercial vehicles was not possible to consider in the scope of this project.

Nineteen issues were identified as having possible impacts. Sixteen recommendations were offered for future work or decisions that address those issues. Important actions that are recommended include: beginning to address how articulated commercial vehicles will be accommodated within connected vehicle processes; how trailer parameters might be determined; and how technical standards may be affected by considerations unique to commercial vehicles. Testing is also suggested for determining the effects of large vehicles on DSRC communications performance, such as blockage effects, multipath issues, and ground-reflecting nulls that are influenced by antenna heights. Other suggestions include developing approaches to certifying aftermarket safety devices, encouraging technical experts from the commercial vehicle industry to engage in standards development, and determining whether rogue broadcasters on the SAE J1939 bus can cause connected vehicle systems to behave inappropriately.

1 Introduction

The U.S. Department of Transportation has been supporting research in the area of connected vehicles for several years. Much of that work has been done by, or in conjunction with, the passenger vehicle industry, including suppliers of DSRC wireless communication. As this work moves toward a stage at which the functionality appears to be maturing, the U.S. DOT and its partners are moving toward including heavy vehicles such as trucks and transit vehicles. A large "model deployment" project is also planned, which will take the technology into a DSRC-enabled environment with normal drivers.

The purpose of this project is to determine whether the introduction of commercial vehicles will create unique issues that affect the exchange of information, or interoperability, between vehicles of all types. This project did not address policy issues, such as data privacy or ownership. Furthermore, the project was based on work reported in mid and late 2010, so that more advanced exploratory areas, such as relayed wireless messages, were not incorporated.

This work was done primarily through the three main work tasks of the project:

- Task 2 – Reading, discussing, and collecting information about the use of DSRC for safety applications from pilot studies, as well as magazine articles.
- Task 3 -- Conducting a telephone interview to ask experts about interoperability topics for V2V systems,
- Task 4 –Considering both Tasks 2 and 3 to formulate a set of prioritized interoperability issues, and a set of recommended actions that might be considered in facilitating the integration of commercial vehicles into the connected vehicles program.

Task 1 included the generation of a work plan, and Task 5 was the development of this final report.

A section of this report is dedicated to each of the three work tasks, followed by a conclusion section. References and appendices follow the main body of the report.

2 Background Information and Candidates for Commercial Vehicle-Unique Issues

This section presents the tasks and outcomes of Task 2. This task identified a set of potentially significant interoperability issues that could result as commercial vehicles are added to the set of connected vehicles in the next few years. These issues were identified by first reviewing research reports, published literature, and technical standards, and then interacting with subject matter experts in the areas of connected vehicles systems and commercial vehicles. This background information was synthesized into a set of candidate issues unique to commercial vehicles. Those candidate issues are the outcome of Task 2. The candidate issues were the basis for a set of telephone interviews, to be described as part of Task 3, in Section 3.

This section is organized as follows. Section 2.1 presents an overview of previous completed projects that address V2V safety applications on light vehicles, as well as a project addressing connected vehicle applications on a small set of commercial vehicles. Sections 2.2 to 2.7 each present one or more candidate issues that emerged during the examination of the literature, technical reports, and/or developed through conversations with experts.

2.1 Prior Connected Vehicle Projects

2.1.1 Vehicle-to-Vehicle Safety Applications Projects

The U.S. DOT has conducted three major programs related to connected vehicle technologies, working primarily with the Crash Avoidance Metrics Partnership (CAMP). These are reviewed briefly here.

The Vehicle Safety Communications Consortium (VSCC), working through the CAMP mechanism, conducted a program of research addressing a set of potential safety applications. Some of the activities reported were:

- Estimated potential safety benefits of connected vehicle safety applications,
- Developed high-level communication requirements for several applications,
- Looked into specific technical aspects of DSRC communication that could affect deployment,
- Identified eight possible applications for connected-vehicle safety, including signal violation warnings, curve speed warning (CSW), emergency electronic brake lights (EEBL), pre-crash warning, lane change warning, left turn assistant, cooperative forward crash warning (FCW), and stop sign movement assist. (CAMP, 2005),
- Confirmed DSRC as having unique and critical capabilities, including low latency, broadcast capabilities, and high-availability. A working range of about 200m was determined to be feasible,
- Determined that fewer than 100 bytes of data could support most V2V applications.
- Determined that V2I packets were larger, with a maximum of approximately 430 bytes for a left-turn assistant application, and
- Cited concern for the bandwidth required for security.

The CICAS-V program addressed the requirements and technology to address stop sign and traffic signal violation using DSRC communication between roadside equipment units (RSEs) and onboard equipment (OBEs) (Maile et al., 2008). This study focused on driver interface research and design to develop driver warnings for stop sign or traffic signal violations. This included the developments of requirements for warning timing and other algorithmic elements, system design considerations and tradeoffs, and prototype system design activities.

The Vehicle Safety Communications – Applications (VSC-A) program continued many of the themes of earlier projects. The VSC-A project investigated whether DSRC-based vehicle safety applications could improve or replace autonomous vehicle-based safety systems, or enable new safety systems (Ahmed-Zaid et al., 2010). This included developing crash scenarios to be targeted, system requirements for countermeasures, the development of prototype test beds, and the design and execution of objective test procedures for applications. This study also investigated technology for absolute and relative positioning, and the potential performance levels of that positioning. The work continued earlier efforts to support technical standards development, addressed security concerns, and conducted scalability testing with multiple vehicles in close proximity.

A set of candidate V2V safety applications for initial deployment onboard light vehicles and commercial vehicles has emerged from the projects above. One indication of this is drawn from a recent U.S. DOT solicitation, and is copied directly into Table 2.1 below. Note that these are sample applications, but the table indicates the type and breadth of applications being considered.

Table 2.1 Example Initial Safety Applications (from FHWA, 2011))

Vehicle Type	Device Type	
	Aftermarket Safety Device	Integrated Device (On-Board Equipment [OBE]) or Retrofit Device
Light Vehicle	• BSM broadcast[6] • Receipt of SAE J2735 messages broadcast by other vehicles and by infrastructure devices • Curve Speed Warning • Forward collision warning • Emergency electronic brake lights warning • Cooperative Intersection Collision Avoidance System – Violation (CICAS-V) warning	• BSM broadcast • Receipt of broadcasted SAE J2735 messages • Blind spot warning • Do not pass warning • Emergency electronic brake lights warning • Forward collision warning • Intersection movement assist warning • Lane change warning • CICAS-V warning
Heavy Vehicle	N/A	• BSM broadcast • Receipt of broadcasted SAE J2735 messages • Lane change assist warning • Curve over-speed warning • Forward collision warning • Intersection movement assist warning • CICAS-V warning

2.1.2 Commercial Vehicle-Specific Projects

The U.S. DOT has launched a Smart Roadside initiative for commercial vehicle operations (FMCSA & FHWA, 2010). The Smart Roadside initiative is working to develop a set of V2I applications to address issues that include wireless roadside inspection (Capps, 2009), parking information for commercial vehicle drivers, and other information exchanges. Applications such as these are not specifically addressed in this report, which focuses on the V2V safety applications, but it is recognized that the type of applications represented by the Smart Roadside initiative may be very attractive to the industry.

The Commercial Vehicle-Infrastructure Initiative (CVII) project is an ongoing project administered through the New York State Department of Transportation, with Federal Highway Administration support (Siebert, 2010). The goal of this project is to develop and demonstrate a set of primarily V2I applications for commercial vehicles, using existing testbeds along New York roadways. The applications include driver identification and credentials confirmation, wireless vehicle safety inspections, and commercial vehicle-to-maintenance-vehicle communication. Volvo Technology is a primary technology provider, with Kapsch providing radio technology support. This is another of the early federally funded projects addressing both DSRC communication and commercial vehicles.
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2.2 Technical Standards

One overview of DSRC-related standards for connected vehicles is Kenney's 2010 report, "Standards and regulations." The standards for the safety-focused, low latency portion of the protocol stack are summarized in Table 2.2, and citations for each are provided in the references section at the end of this report. References discussing individual standards include Jiang and Delgrossi (2008) addressing the IEEE 802.11p wireless local network variant for DSRC, and Hedges and Perry (2008) providing a high-level overview of the SAE J2735 message set contents.

Table 2.2 Standards relevant to DSRC communication (U.S.)

Standard (or draft standard)	Scope of standard	Potential for commercial vehicles to affect the standard
SAE J2735	Message set dictionary for DSRC	Yes
SAE J2945-1	Minimum performance requirements for the J2735 basic safety message	Yes
IEEE 802.11p	Physical and medium access control layers	No
IEEE 1609.1	Application layer	No
IEEE 1609.2	Security	Not likely
IEEE 1609.3	Network and transport layers	No
IEEE 1609.4	Upper MAC and multi-channel operations	No
IPv6	For non-safety applications.	No

2.2.1 Message Sets

The message set draft standards SAE J2735 and J2945-1 provide the data dictionary and the minimum performance requirements, respectively, for data. Since these were developed by a committee without the benefit of deep commercial vehicle expertise, the message sets may need to be examined from the perspective of commercial vehicles. This hypothesis will be tested during the remainder of this report.

The SAE J2735 draft standard defines a set of 13 messages intended to support several types of applications. The most important for this report on V2V safety issues is the basic safety message (BSM). The BSM definition includes a Part I and Part II (Part II is optional). Part I is required and is likely to be broadcast periodically; the common opinion at the time of this report is a 10 Hz rate is likely. Part II is optional for any particular BSM broadcast, and may be broadcast periodically at a lower rate (perhaps 2 Hz), and/or would be broadcast upon request. The SAE J2945 draft standard on minimum performance requirements for the BSM is under development with few strong positions on most of these issues. The J2945 standard would address the frequency of message broadcasts, but this standard is rather early in its development at the time of this writing. Note that various schemes have been proposed for when and how to broadcast information; for instance, an adaptive scheme to reduce wireless traffic is reported in order to reduce the wireless traffic (Rezaei et al., 2010).

Part I consists of a one-byte identifier as well as 38 bytes of content, including the vehicle position estimates, vehicle motion signals, brake system status, and information about the vehicle width and length. Part II includes more details about the vehicle type (number of axles, whether a trailer is present), the vehicle and cargo weight (when available), and elements of vehicle configuration (e.g., whether a rain sensor is present), and vehicle motion information such as accelerations and yaw rate.

Two immediate concerns arise for commercial vehicles:

- How should an articulated vehicle broadcast SAE J2735 messages without misleading other vehicles?

- How would onboard equipment (OBE) on the tractor in a tractor-trailer arrangement know about the trailer size and weight parameters?

The first concern is discussed here, and the second will be the subject of Section 2.3. The left side of Figure 2.1 shows an articulated with a double-axle semi trailer making a turn. Consider a remote vehicle receiving the BSM from the articulated vehicle, and its perception of the articulated vehicle's spatial boundaries. Part I of the message would define the position and heading of the vehicle's geometric center information and Part II would identify that the vehicle has a trailer. The right side of Figure 2.1 shows what a remote vehicle could perceive as the boundaries of this vehicle, since the heading is applied to the entire vehicle. This could result in false alerts on the remote vehicle. Overall, it is clear that the contents of the SAE J2735 and J2945 standards may well require modification as commercial vehicles become important users of the DSRC communication channels.

Candidate issues: The SAE J2735 message set does not allow for combination (articulated) vehicles. All data is associated with a single “rigid body” vehicle that could have impacts for safety application performance.

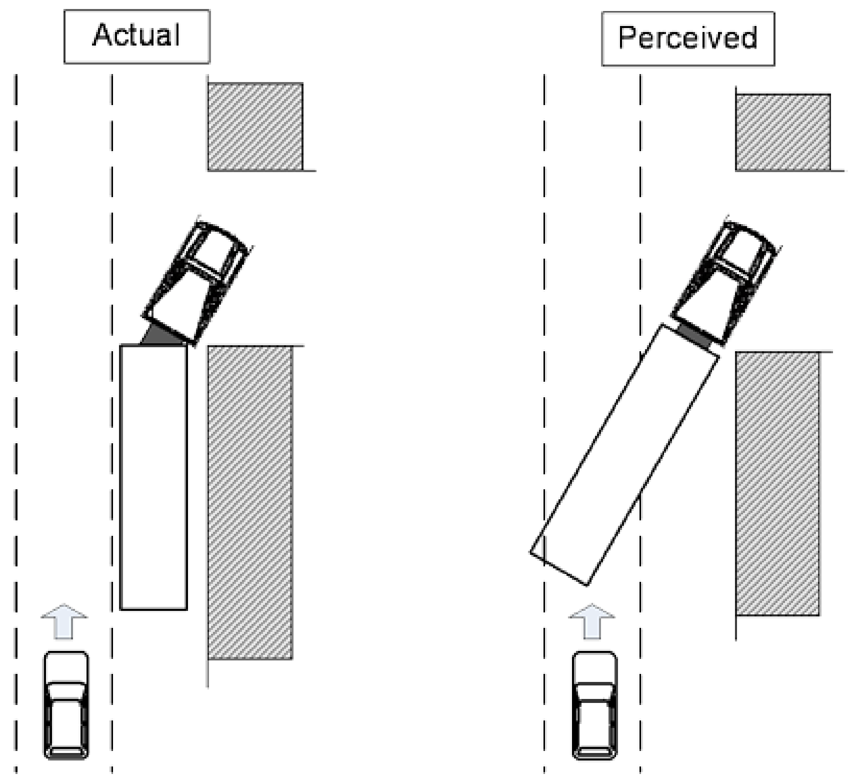

Figure 2.1. Possible effect of populating November 2009 J2735 messages with towing unit information to represent an articulated vehicle (towing unit plus trailer)

2.2.2 IEEE 1609.x Standards

Regarding other standards, note that the IEEE 1609.2 standard (still in draft form) addresses authentication and encryption. During Task 2, it seemed conceivable that some commercial vehicle operations applications, such as those reporting compliance with regulations, would interact with a diverse set of public and private entities via encrypted DSRC messages.

Thus it appears worth verifying that his standard does not need to be revisited for reasons introduced by commercial vehicles. This study also considered other areas and concluded that commercial vehicle considerations will not introduce unique issues. One of these is the area of security, which includes certificates and authentication (Weimerskirch et al., 2010).

A significant assumption in this report is that Channel 172 of the DSRC spectrum will be dedicated to safety messages. This is a recommendation from CAMP. If this is not true, then there may be concerns that the large messages being conceptualized for motor carrier operations purposes may pose problems for scalability.

Candidate issues: Are there any significant concerns within the IEEE 1609.x stack with commercial vehicles?

2.3 Obtaining Trailer Parameters

For vehicles that are towing a trailer, as well as other vehicles near the trailer, it is necessary to know the length and width of the trailer. Trailer length, for instance, is useful for safety applications onboard vehicles behind or alongside the trailer, such as FCW, EEBL, and LCM. There are also applications that are likely to desire the trailer weight, such as pre-crash systems on other vehicles that may need to estimate the crash severity in order to enable advanced occupant protection systems.

At least three methods can be used to ensure that trailer information is available to the towing unit as well as other vehicles:

- Equipping the trailer with a simple DSRC-equipped unit, such as the “Here I Am” modules currently being used in U.S. DOT research projects, and broadcasting the trailer parameters to the towing unit as well as other vehicles,
- Having the trailer provide information to the power unit electronically, through conductors or wireless means other than DSRC , or
- The power unit uses onboard estimation of whether a trailer is being towed, and if so, then assumes default values for the trailer parameters and uses those for its own purposes and also broadcasts those parameters to other vehicles.

The first method assumes new equipment is installed on all trailers. The second method assumes new equipment is installed on all trailers and on all DSRC-equipped towing units. Since in the United States there are several trailers for every towing unit, and since the trailers are often over 20 years old and often not owned by the same organization that owns the tractor, installing electronic equipment on trailers would be a major undertaking. Maintaining wireless equipment would require a power source on the trailer as well. The third method is clearly the simplest since no hardware is required onboard trailers, and only new software is required on the towing unit. Obviously the disadvantage of the third method is that trailers can be short or long, with differences in trailer lengths for common configurations easily being 9 or 10 m. Thus obtaining information about the trailers appears to be a concern for deployment of connected vehicle technology.

Candidate issue: The SAE J2735 message set reflects a need for V2V safety applications to have information about trailers, so it can be used onboard the towing vehicle and broadcast to other vehicles. Is there a viable way to obtain this information and make it known?

2.4 DSRC Communications and Physical Factors of Vehicles

The large size and the specific physical configurations of some commercial vehicles may interfere with DSRC communications for those vehicles, as well as other nearby vehicles. This section addresses some possible modes of concern.

2.4.1 Blockage, Multipath Effects and Ground Nulls

One area of early concern within this project was the potential for the commercial vehicle's physical factors to negatively affect communication through three mechanisms:

- blockage of DSRC messages by trailers or other physically-obstructed lines of sights,
- introducing additional reflections due to some commercial vehicles' large size and surfaces, creating multipath effects, and
- affecting the range at which ground interference "nulls" (or dead spots) occur.

Blockage was observed in experiments reported in several papers (Gallagher et al., 2006; Miucic & Shaffnit, 2009; and Boban et al., 2011). The 5.9 GHz DSRC waves have very little travel through objects, and therefore non-line-of-sight (NLOS) communication relies upon waves reflected from the surrounding environment. One specific concern related to large commercial vehicles is communications performance in when a large vehicle obscures the line of sight between two vehicles' antennas. One situation where this occurs is shown in Figure 2.2. The communication between vehicles A and C are affected by the obstruction of vehicle B. Likewise, communication between B and C are affected because of the tall trailer that blocks the line of sight between those vehicles' antennas.

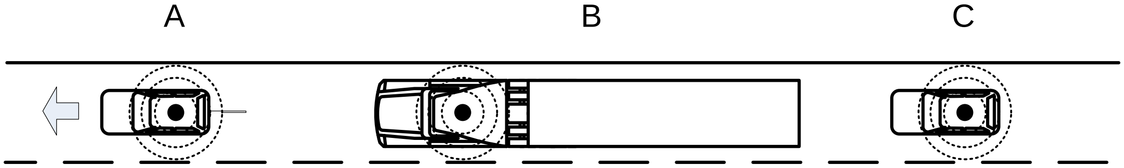

Figure 2.2. Blockage scenarios in which DSRC communication between vehicle pairs (A, C) and (B, C) are negatively affected by the tall trailer of vehicle B

Multipath effects for DSRC are also increased when large vehicles are involved. Multipath can have positive effects, such as providing the means for vehicle pair (A, C) to communicate at all, but the delays and phase shifts resulting from the reflections also poses challenges for DSRC receivers to capture messages reliably.

Finally, ground nulls have been observed in DSRC experiments with two passenger vehicles; the distance for those is between 70 and 110 m. That is not considered to be problematic by a few application designers that were contacted for this report, since at those ranges the primary concern is closing situations. In closing situations, the effect of the null disappears as the range decreases by a few meters, so the function is not compromised. For commercial vehicles with antennas higher off the ground, the nulls can be expected to be a different distance, likely a shorter distance. Thus the concern is whether the distance is at a critical point for a safety application,

At the application level, the primary effect of blockage and multipath is to introduce delays since messages are not received by the application layer, since the receiver is not able to capture the message. The effect of delays on application performance is discussed in Santa et al., 2010, and Huang and Tan (2007). Also, positioning and communication latency effects are addressed in Santa et al., 2010 and Tan and Huang (2006). The primary effect of these delays is to introduce delay in the application layer's decision-making. The effect depends, of course, on the application layer's handling of these gaps. Various metrics have been used to characterize the errors, such as packet error rate (how many messages are not received); inter-packet gap (the period during which no packets are received); and the distribution of the interpacket gaps. Besides the pure lack of messages, missing messages also challenge the application layer's ability to track other vehicles and to quickly build confidence in its understanding of the situation.

Candidate issue: Will the physical size and configurations of commercial vehicles introduce issues that will uniquely affect DSRC communication performance? What are the mechanisms, and are there ready solutions?

2.4.2 Scalability: Robust Performance in DSRC-Dense Environments

The term scalability has been used to denote the question of whether DSRC performance in a local area with many broadcasting vehicles would degrade substantially because of the message collisions and the sheer computational power required for each vehicle to track many others. Tests at CAMP in the VSC-A project suggest the former issue is the most critical, and the performance can be quantified by the same packet error rate measures mentioned earlier.

The presence of large commercial vehicles is likely to introduce significant blockage and multipath effects in the area immediately adjacent to a large vehicle, as described in Section 2.3. If DSRC receivers in the area are already struggling to receive the large number of messages and the increased rate of collisions, the question is whether the local blockage and multipath effects will cause the performance to further degrade. A hypothesis is that this is possible, and that the potential for this should continue to be considered.

Candidate issue: In a local area with many DSRC-broadcasting vehicles, will communication performance be negatively affected by the existence of large commercial vehicles, due to the DSRC blockage and DSRC multipath effects they induce?

2.5 Absolute and Relative Positioning Near Large Vehicles

Many V2V safety applications require estimates of the absolute position of the host vehicle, and/or the relative positions of the host and nearby remote vehicles. Absolute position accuracy is important for certain applications, such as signal violation warnings or curve-speed warning. Relative positioning is especially important for applications such as lane-change/merge warnings and forward collision warning. The most stringent requirements for current applications may be for relative positioning accuracy in the lateral direction (perpendicular to the direction of travel) for applications such as blind spot or lane-change warnings. For those, errors of a meter are unacceptable. Longitudinal-direction accuracies are very important, but generally applications can tolerate larger uncertainties. For absolute positioning, the smallest allowable errors are likely to be related to intersection safety applications, or similar time-urgent applications in which it is critical that the absolute position is known with respect to specific physical locations.

One initial concern that is unique to commercial vehicles is illustrated in Figure 2.3, which depicts a smaller vehicle traveling adjacent to a larger vehicle. Assume the vehicles are moving in the same direction. The large vehicle's presence may affect the positioning accuracy of nearby smaller vehicles, or the relative positioning estimates of both vehicles, through one or more of these three mechanisms:

- The surfaces of the large vehicle can create multipath effects on the GPS signals reaching the smaller vehicle, possible affecting the smaller vehicle's position estimates significantly.
- The large vehicle will mask the small vehicle's view of parts of the sky, so that GPS positioning on the smaller vehicle is affected, especially along the direction of masking (laterally, in this case).
- The masking effect may also lead to the two vehicles using different sets of GPS satellites for positioning, which can affect relative positioning accuracy.

(We use the term GPS here to represent not only the GPS system, but also other systems such as GNSS and Galileo.)

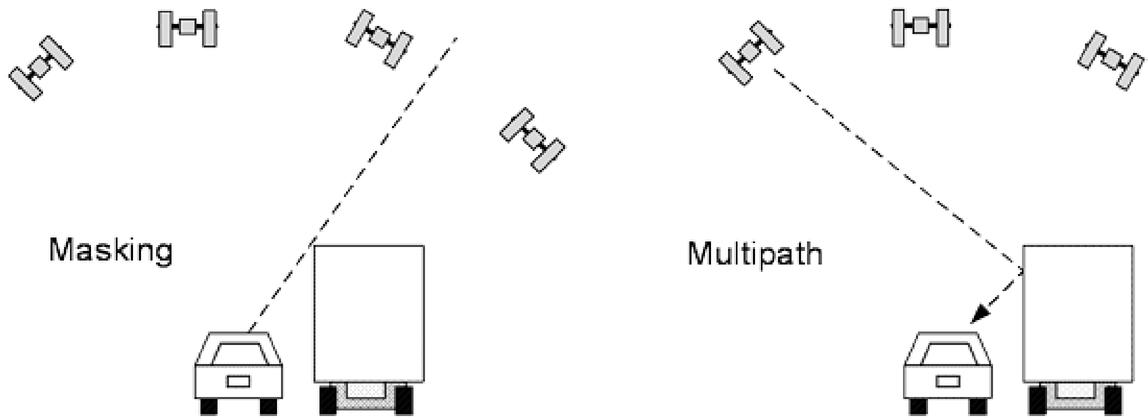

Figure 2.3. Impact on GPS signals received by a small vehicle adjacent to a large vehicle

Thus the concern is primarily with same-direction vehicles traveling adjacent to a larger vehicle at a similar speed. The magnitude of the effect may also depend on the content of information exchanged between the two vehicles. The VSC-A report documented experimental work in which two methods of relative positioning were addressed: single point (SP) and RTCM. The SP method consists of simply exchanging selected outputs of the individual GPS receivers, including latitude, longitude, time, heading, and so on. The RTCM method consists of exchanging lower-level, pseudo-range data consistent with the existing RTCM v3.0 message used in many positioning contexts other than highway vehicle use (Ahmed-Zaid et al., 2010). The SP method requires far less data exchange and is computationally less intensive. The standards are in place for either approach, but concerns about performance in areas that are dense in DSRC broadcasting vehicles may result in the SP method being used.

Note that there is far less concern about *absolute* positioning accuracy of the smaller vehicle traveling adjacent to the large vehicle. The requirements for absolute positioning are more forgiving than they are for relative positioning. Also, the same effects and consequences of GPS multipath and limited views of the sky occur in any urban canyon operation, so that the absolute positioning problem resulting from the scenario shown in Figure 2.3 would be resolved by solving the urban canyon problem.

Candidate issue: Will there be a significant degradation of V2V safety application performance due to relative positioning errors that may occur when a smaller vehicle travels alongside a larger vehicle?

2.6 Aftermarket and Retrofit Safety Devices

The rate of penetration of DSRC devices into the on-road fleet can be accelerated, if effective and acceptable retrofit or aftermarket solutions are created. Chang (2010) demonstrates how the uptake of this feature can accelerate the penetration of DSRC-equipped vehicles into the U.S. fleet. In fact, for commercial vehicles, the aftermarket/retrofit path may have more potential for increasing the penetration of DSRC-enabled systems than does the light vehicle segment. This is for three reasons:

- The data buses on most heavy-duty vehicles adhere to the SAE J1939 standard that includes definitions of most common signals that the DSRC applications would use, simplifying the integration of aftermarket/retrofit devices into an existing vehicle.
- Carriers may be more likely than consumers to adopt technologies that can improve their business efficiency through applications such as those mentioned earlier for the Smart Roadside initiative and others.
- Heavy-duty vehicles are often upfitted with aftermarket equipment when they are sold after two or three years in service. Thus the installation of aftermarket/retrofits is more natural in this segment than in the consumer-focused light vehicle one.

The challenges to aftermarket/retrofit devices onboard commercial vehicles do have some unique aspects, however:

- Currently the types of data signals on the J1939 bus are not required, nor is there a quality requirement for those signals. Thus it may be a false assumption to state that aftermarket/retrofit devices can be installed on all J1939-compliant vehicles without customizing the devices software.
- Because of the blockage/multipath concerns with large vehicles, the placement of antenna(s) and tuning of the receiver for that antenna set is likely to be required, and may depend on the specific vehicle and its optional equipment and trailers. Thus, again, successful performance of an aftermarket/retrofit device requires adapting it to a specific vehicle and its configuration.
- Certification of such devices needs to take into account the two items above; certification may need to be associated with a specific vehicle and configuration.

Another potential concern with the use of a public data bus, such as the J1939, is that without special consideration on DSRC units, there would be an easier path for introducing false information into the DSRC environment, through nefarious users broadcasting false messages onto the J1939, and having those forwarded by the onboard equipment to other vehicles. This is possible on any vehicle, of course, but given the open nature of J1939, it is more likely on these vehicles. One partial countermeasure to this would be for DSRC units to detect when there are multiple messages for the same signal, and to employ care in broadcasting such signals.

Candidate issue: While the widespread use of the SAE J1939 standard on heavy commercial vehicles may accelerate the deployment of aftermarket/retrofit safety devices on these vehicles, will the differences in the signals on that bus and the bus's public nature create unforeseen challenges that need to be addressed now?

2.7 Certification and Application-Level Testing

In this document, certification refers to the process, procedures, and metrics that would one day be used to certify an onboard equipment (OBE) device. This certification is required because the FCC has defined DSRC as spectrum requiring licensing. Certification is of interest in this study because of its importance in a focus for defining the function, whether of a DSRC radio or possibly an OBE or OBE/antenna set. Therefore, if CVs demand unique functional changes, either because of application needs or because of issues CVs introduce into communications or sensing or application performance, then certification may be affected.

Certification may be done for a device in conjunction with an antenna configuration and possibly in association with specific vehicles and/or vehicle configurations. This would apply to OEM installations as well as aftermarket or retrofit units. Application-level testing refers to procedures and metrics that would involve scripted maneuvers of equipped vehicles on closed courses, and would evaluate whether the safety application is acting in accordance with some specified criteria. Application-level testing would presumably be executed using certified devices.

2.7.1 Device Certification

The U.S. DOT and OmniAir, Inc., have been developing approaches to certification. At the time of this report, the information available to this research team is that certification is being conceived as activities that apply to different levels, possibly including radio level testing and vehicle-level testing. The latter could require that an OBE deliver compliant messages to test equipment located at specific points around a vehicle, such that the test equipment could capture the information.

For commercial vehicles, the questions raised in Sections 2.4 suggest that the outcome of vehicle-level tests may be sensitive to the antenna configuration used on the host commercial vehicle, as well as the nature of the test equipment and the environment in which testing occurs. The latter is relevant because the successful reception of trailer-only OBE information in the shadowed regions aft of the tractor will depend on the multipath effects of the test environment as well as the ability of the receiver to tolerate or even leverage the multipath effects.

Another unique aspect of commercial vehicles is that for many vehicles, the physical configuration is not constant, even for the same model and model year. For instance, the purchaser of a class 8 tractor can define many variations, including various air dams and mirrors. The purchaser then operates the vehicle with various trailers – flatbeds, drop-decks, box trailers, and so on. These variations can be expected to affect performance of DSRC communication. For certification, however, a very few number of test configurations are practical. Thus there must be a definition of standard configurations for testing those vehicles.

Section 2.5 discussed that there may be issues with relative positioning accuracy when small and large vehicles are very close to one another. If this is a significant issue that affects application-level performance, then there may or may not be determinations that such situations are appropriate as test points, whether for certification at the device/antenna level, or at the application-level testing.

Given that commercial vehicles introduce significant blockage and multipath effects, then it is conceivable that receivers on all vehicles will need to demonstrate a minimum level of robustness to these effects.

Candidate issues: In addition to the device levels of certification, are higher levels of communication tests needed, short of application testing?

2.7.2 Application-Level Testing

The automotive industry, governments, and standard development organizations have developed and used various vehicle-level test procedures for crash warning and avoidance systems. This involves vehicle-level testing with scripted maneuvers that are intended to exercise specific safety systems and validate that they meet minimum performance levels. Connected vehicle programs have adapted these existing tests and added new tests in order to explore or validate performance with DSRC-equipped vehicles.

It is known, of course, that certain parameters of testing must be adjusted from light vehicle to heavy vehicle testing to account for the different causal factors of crashes and the different maneuverability and size characteristics of commercial vehicles. A potential issue unique to commercial vehicles, however, is whether test procedures and the definition of test vehicles need to account for the issues that may affect application-level performance. That is, do the aspects of communication and positioning that are challenged by the presence of large vehicles affect application-level performance? Is it enough to consider including standardized versions of these situations in application testing?

Candidate issue: Should application-level testing account for the impact of commercial vehicles on DSRC communication performance or relative positioning performance?

3 Telephone Interviews With Subject Matter Experts

The previous task developed a set of candidate issues that may arise as commercial vehicle become part of the development and deployment work for V2V safety applications. This section addresses Task 3 of the project, which consisted of designing, conducting, and analyzing the results of a set of structured telephone interviews with experts in the areas of DSRC communication, V2V safety applications, and commercial vehicle industry development and use of advanced safety features.

The goals of the interviews were:

- to finalize the set of commercial vehicle-unique issues, by confirming, rejecting, or revising candidate issues developed in Task 2, and to add any new issues that emerge during the interviews,
- to further understand the nature of the issues,
- to understand the possible impact of the issues,
- to capture the interview respondents' opinions of the relative importance of each issue in the resulting set of issues, and
- when possible, to collect respondents' thoughts about possible resolution of the issues.

The following subsections present the interview scripts and procedures and selection of the interviewees (Section 3.1), describe the analysis process (Section 3.2), and report the responses and summarize the findings (Section 3.3).

3.1 Interview Methodology

3.1 Interview Questions

Given the candidate issues from Task 2, a set of 12 questions was developed. Table 3.1 below shows the topics for each of the questions. The script for each question is shown in Appendix A.

3.2 Three Interview Groups

During Task 2, it became clear that there are currently very few experts knowledgeable in all three areas (DSRC, V2V safety application development, and commercial vehicle industry). Also, the questions are fairly technical and many require direct experience and not simply exposure to the topics. Therefore three sets of interviewees were defined, and the 12 questions were partitioned to the most appropriate groups. In this way, only a subset of questions were posed to each respondent. All respondents were asked the final three questions: about the engagement of the commercial vehicle in technical and policy discussions; whether they could think of other issues that had not been discussed in the previous questions; and their ratings of how important the issues in the interview were to moving toward deployment.

The three interview groups were:

T: Technical subject matter experts (SMEs) in DSRC or V2V safety applications

I: Commercial industry experts who are knowledgeable about the industry and safety system deployments.

B: Persons who qualify as both technical SMEs and commercial vehicle industry experts.

Table 3.1 describes which of the questions each interview group received. For instance, the technical SME group was asked Questions 1-3, 5-7, 10-12. The table also tallies up the number of subjects who were interviewed on each topic; the number of respondents were between 7 and 16.

Table 3.1 Interview topics and the three interview groups

Question	Topic	Questionnaire numbering Technical SMEs "t" N = 7	Industry Experts "i" N = 4	Technical SMEs & Industry Experts "b" N = 5	Persons asked this question
Q1	Adapting the SAE J2735 basic safety message to commercial vehicles	1		1	11
Q2	DSRC performance and physical factors	2		2	11
Q3	Relative positioning and physical factors	3		3	11
Q4	Objective testing of safety applications		1	4	9
Q5	Scalability and commercial vehicles	4	2		11
Q6	Commercial vehicles and the IEEE 1609 protocol stack	5			7
Q7	Certification of onboard equipment communication	6	3		11
Q8	Information about trailers		4	5	9
Q9	Aftermarket and retrofit devices		5	6	9
Q10	Engagement of commercial vehicle industry in discussions	7	6	7	16
Q11	Other factors	8	7	8	16
Q12	Ratings: importance of each topic	9	8	9	16
	Questions posed per questionnaire:	**9**	**8**	**9**	**--**

The subjects for the interviews were selected based on a combination of their personal expertise and the organization's experience. The organizations represented are listed in Table 3.2.

The interviewees included multiple persons from the following activities: CAMP VSC-A team, SAE DSRC committee, IEEE 1609.x committee, and Commercial Vehicle-Infrastructure Initiative. The interview set included staff from three heavy truck manufacturers, three DSRC radio supplier organizations, a Tier 1 supplier active in commercial vehicle V2V work, consultants, academia, and a few non-governmental organizations.

Table 3.2. Organizations whose members participated in the telephone interview

· American Trucking Research Institute	· Kapsch
· Armstrong Consulting	· Maverick Transportation
· Battelle	· Mixon Hill
· Cohda Wireless	· Navistar
· Daimler R&D North America	· NYS DOT
· DENSO	· Southwest Research Institute
· General Motors	· Virginia Tech
· Honda R&D America	· Volvo Technology

3.3 Recruiting and interviewing

Candidate interviewees were contacted by email and asked to participate. Furthermore they were asked to suggest a date and time for the interview, and the material in Appendix A was also sent (although only the appropriate subset of questions was sent). If the candidate did not respond within a few days, a phone call was placed. Finally, if this did not result in contact with the candidate, a final email inquiry was sent.

Four candidates did not respond, or declined to be interviewed. Other candidates were selected and contacted. In all, sixteen respondents were interviewed. Their association with each of the interview groups is indicated in Table 3.1. The introductory material described the project, the purpose of the interview, and included a statement that the respondent's comments would not be associated with that person or their organization, but would be presented along with comments from many others.

The interviews were approximately 45 minutes long, and consisted of one of two UMTRI faculty researchers posing the set of questions that had been sent to the respondent. Follow up questions were often asked to clarify the respondent's comments, to make sure that it was known whether the respondent felt an issue existed and what that issue was, and to probe for possible impacts and resolutions to the issue. The respondents sometimes offered new thoughts and these were captured by the interviewer who was making notes. The audio from the conversations was not recorded.

3.4 Analysis of Interview Responses

The analysis of the interviews is depicted in Figure 3.1. The top of the figure shows that the written notes from the interviews were examined for each question to determine whether each respondent felt there was a related issue unique to commercial vehicles. This step resulted in 124 data samples, each of which had one of the following values:

- yes (issue involved with the topic),
- no (no issue involved), or
- no data (respondent did not know, or did not respond directly).

The questions were developed so that always they asked whether an issue was present. Sometimes respondents did not directly respond to the question, and the interviewer would return to the topic. Despite this, at times there was not a direct response.

Each question could lead to respondents citing different issues or multiple issues. The questions were developed to be open, so respondents would offer their own view and not be directly or subtly influenced to agree with the UMTRI team's hypotheses.

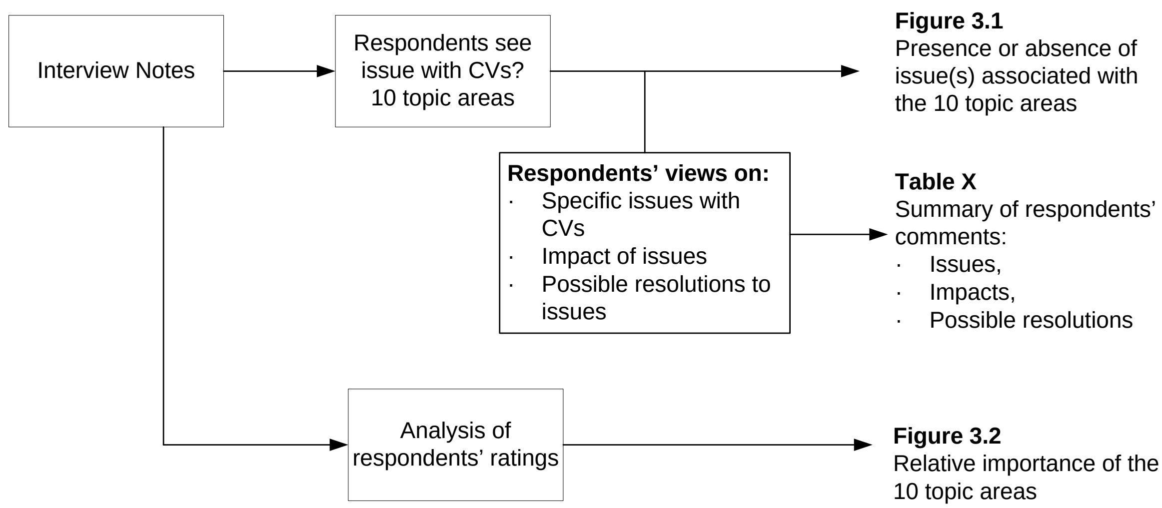

Figure 3.1 Analysis steps for Task 3

3.2 Results from the Telephone Interviews

3.2.1 Reactions to the Initial Candidate Issues

The first analysis step was to examine the respondent's comments and tally the number of times that specific questions were cited as issues by the respondents. Figure 3.2 shows this result. The bars correspond to the percent of respondents who felt there was an issue associated with the topic. Respondents who did not respond were not included in the calculation of these percentages.

All respondents who addressed the topic of DSRC performance and commercial vehicle physical factors felt that there was an issue related to the topic. At least 70 percent of respondents felt there was an issue for five other topics. Three topics had 30 percent to 55 percent of respondents citing an associated issue, while one question had no respondents agree that there was a related issue (whether IEEE 1609.x standard set would be affected by considerations of accommodating commercial vehicles.

To get a sense of how important the respondents thought each issue was, they were asked to rate the relative importance of each issue. The question was, “How important is it to understand and, if necessary, address the issue for a successful deployment?” Respondents were asked to assign a value from “1,” corresponding to “not important,” to “5,” corresponding to “very important.” An ordering of each respondent’s ratings were made, from highest importance to lowest. Figure 3.3 shows the respondents’ assessment of each issue’s importance, as expressed in response to the interview question. In this scale, of course, lower numbers denote most important (since the ratings were translated into rankings by analysts).

Figure 3.3 shows the issues in the same order as Figure 3.2. Standard error bars are used; a rule of thumb is that if there is an overlap in the error bars associated with two of the issues, there is not likely to be a statistically significant difference between the two issues. Thus the results in the figure can be grouped into three categories, as shown on the right side of the figure: more important (top set), less important (middle set); and not important (the bottom issue, addressing whether the IEEE 1609.x stack will be affected by commercial vehicles). Note that the two figures are very consistent in terms of the relative rankings of the issues by the respondents. From these responses alone, the following findings are derived:

1. None of the responding experts believes that the IEEE 1609.x stack will be affected by commercial vehicle considerations.

2. Less than 60 percent of the respondents believe that there is a commercial-vehicle-unique issue associated with the following issues (and the respondent set rates these as significantly less important the most important seven issues):
   - Aftermarket/retrofit safety devices and J1939 issues;
   - Scalability: performance in areas of dense DSRC; and
   - Impact of commercial vehicles on relative positioning accuracies.

3. Ninety percent or more of respondents felt there was an issue associated with two topics:
   - DSRC performance and commercial vehicle physical factors; and
   - SAE J2735 basic safety messages and articulated vehicles.

4. Four other topics received substantial support for being issues of moderate importance:
   - Engagement of commercial industry in discussions;
   - Power unit OBEs knowing trailer parameters;
   - Certification of onboard equipment; and
   - Using commercial vehicles in objective testing.

A note on the details of Figure 3.3 and the fact that even the most important items have mean values above 2: often a respondent would give the same rating for multiple topics. In that case, each of those values were averaged, e.g., if the respondent rated three topics as the most important, with the level "5," then that topic would have an average order value of 2 (average of 1, 2, and 3). If the same respondent gave a value "4" to two other issues, then those issues would be assigned a value of 4.5, which is the average of 4 and 5.

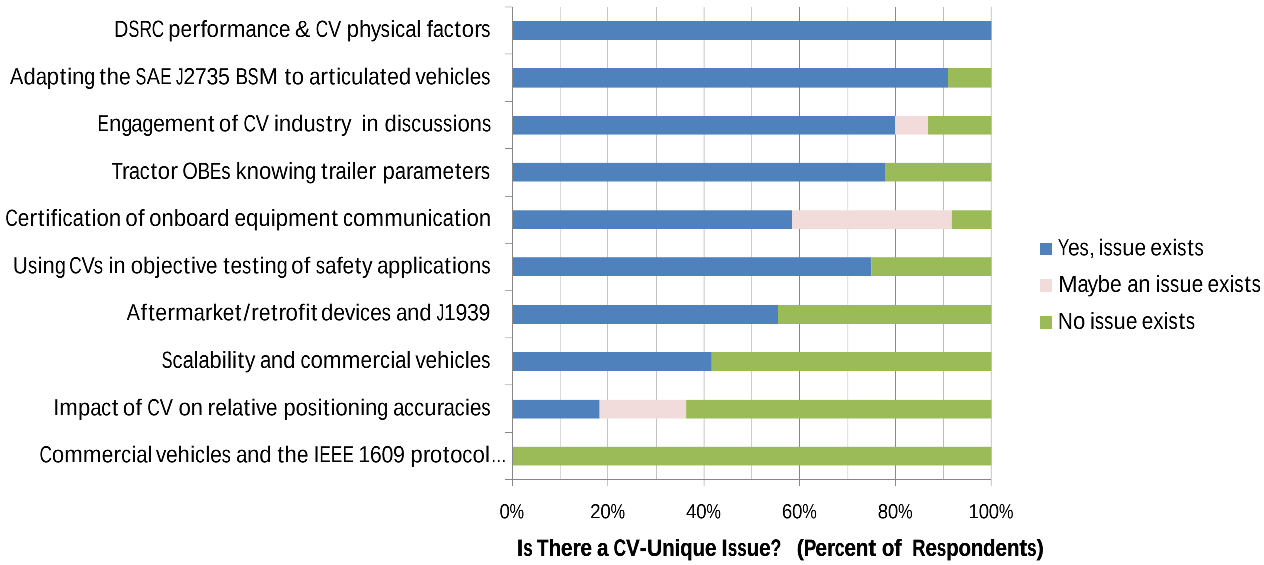

Figure 3.2. Percentage of respondents agreeing with each of the 10 candidate issues

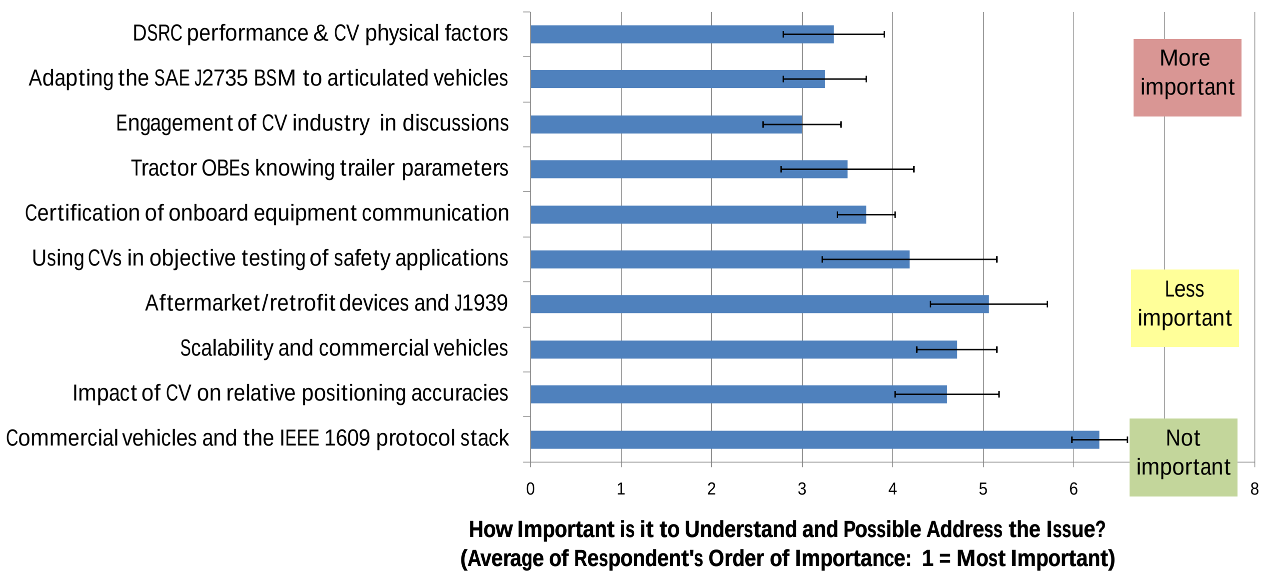

Figure 3.3. Average order of importance for the 10 candidate issues

3.2.2 Interview Responses

A comprehensive list of respondents' contributions is given in Appendix B. That appendix was derived from the researchers' interview notes, and represents the researchers' capturing of answers from the 16 respondents. These answers were used to generate the table in Appendix B. This has:

- 137 responses regarding whether a candidate issue is an issue, or is related to an issue,
- 192 descriptions of potential issues or impacts of an issue, based on discussions with the respondents, and
- 123 respondent statements about potential resolutions of the issues, or general comments.

This data was used to generate Appendix C, which aggregates the respondents' comments into potential issues, insights and/or considerations, and possible resolutions. In this section, a summary of the issues that the respondents described is given in Table 3.3. There are 19 primary and 7 secondary issues in this list. The second column in Table 3.3 classifies each issue as primary or secondary. In this table, primary issues means that the issue may exist now. Secondary issues are related to the primary issue immediately above it in the table, and describe issues that may arise, depending on how its parent primary issue is addressed. Thus secondary issues are anticipated complications of addressing the parent primary issue. Table 3.3 is not the final list of issues; rather this list reports the issues that respondents described. Later, in Section 4, a final issue list is presented.

Table 3.3 List of All Issues Described by Respondents

Issue Category	Primary or Secondary?	Issue and Impact
SAE J2735 Basic Safety Message	Primary	Turning motions by articulated vehicles will induce false positive alerts and possibly late alerts, because the SAE J2735 BSM does not allow accurate representation of articulated vehicle boundaries and paths.
SAE J2735 Basic Safety Message	Primary	The resolution of the vehicle weight signal needs to be changed to allow vehicle weights over 6,350 Kg.
Trailer Parameters	Primary	There is a need for remote vehicles to know the trailer length of a host vehicle. This is not unique to commercial vehicles, since light vehicles tow trailers as well, but the issue is especially important for commercial vehicles because their use of trailers is so common. The information should be detected automatically with no manual entry.
Trailer Parameters	Secondary	Retrofitting trailers is seen as a big issue because of the cost. Trailers outnumber tractors by several-fold, and they are older and often not owned by the same company that owns or operates the tractors. "Investing money on trailers is something people are not interested in doing."
Trailer Parameters	Secondary	Trailers have a longer life than tractors, so that relying on newly equipped trailers to populate the U.S. fleet could lead to a slower-than-desired introduction of DSRC-equipped trailers.

Issue Category	Primary or Secondary?	Issue and Impact
Trailer Parameters	Secondary	Regarding retrofitting trailers/tractors with DSRC equipment: The commercial vehicle industry has had several recent regulations occur, so that the industry may feel some reluctance.
DSRC Blockage	Primary	Large vehicles that are located between two DSRC-equipped vehicles have been observed to substantially affect the communication between the DSRC-equipped vehicles. Thus the large vehicles may affect the communication and application-level performance of DSRC systems on passenger vehicles as well as large vehicles.
DSRC Blockage	Primary	Large vehicles are sometimes "self-blocking," that is, they may have physical elements that obstruct the vehicle's own DSRC antennas from direct line of sight with other vehicles. This may create "shadows," in which a remote vehicle has reduced communication capability with the large vehicle. An example is a vehicle that is closely following a tractor-trailer, where only the tractor has antennas.
DSRC antennas	Secondary	When there are two antennas on the same vehicle, they need to be coordinated to avoid interference patterns that could affect communication performance.
DSRC Multipath	Primary	Large surfaces induce reflections of DSRC signals, creating multipath effects that can lead to a decrease in how many messages are successfully received. This may add latency to decisions made at the application level by nearby vehicles.
DSRC Ground Nulls	Primary	Antennas that are mounted high off the ground, on large commercial vehicles, will alter the position of "ground nulls." This distance should be identified for tall commercial vehicles and the impacts ascertained. Ground nulls result from reflections of DSRC signals off the ground, and they occur at ranges that depend on antenna heights.
DSRC	Secondary	One approach to reducing the self-blockage issues cited above is the use of two or more antennas to increase the space around the vehicle that has direct line of sight to at least one antenna. For example, on a tractor that is towing a large trailer, a common idea from the respondents is to mount an antenna on each side view mirror. There are implementation issues with this: the system should avoid doubling the amount of DSRC signals in the area, and avoid self-cancellation effects. This might be done by using hemispherical antenna patterns, or customized logic within the transponding or receiver systems.
Scalability	Primary	Blockage and multipath effects induced by large vehicles may compound the problems of DSRC communication in congested areas. These effects may exacerbate the delays that may occur as receivers attempt to achieve successful reception of signals that are reflected, that are colliding with other messages, and so on.
Scalability	Secondary	Two respondents mentioned discussions of reducing DSRC transmission power in congested areas, in order to reduce the scalability concerns. This led the respondents to wonder whether power reduction would lead to problems communicating with, or past, large vehicles because of their blocking effect. (Two other respondents said that changing power does not help alleviate blockage issues.)

Issue Category	Primary or Secondary?	Issue and Impact
Relative positioning	Primary	Errors in relative position estimates between two vehicles can occur due to differences in GPS satellite sets being used by a tall vehicle and a smaller vehicle traveling adjacent to the tall vehicle.
Aftermarket	Primary	J1939 is not well populated on all vehicles. The device manufacturer must discover which vehicles have which data signals populated, determine the signal qualities, and customize the aftermarket unit to that vehicle.
Aftermarket	Primary	Need a countermeasure to phony signals that a hacker could broadcast onto the J1939, which would be broadcast by an authenticated DSRC system.
Certification	Primary	Three respondents said that there should be vehicle-level certification, in addition to certification at various device levels. Two other respondents appeared to assume such vehicle-level certification.
Certification	Primary	For vehicle-level testing of communications with large vehicles, performance may be sensitive to blockage effects and therefore vary greatly depending on where the test probe is located. . Vehicle configuration (e.g., which fairings are installed) may also affect performance. Certification needs to recognize and consider these factors.
Certification	Secondary	If transmission power is to be increased around large vehicles, then this capability may need to be verified in certification.
Certification	Primary	Aftermarket device certification: how will this be done if the communication performance depends on the vehicle and trailer?
Certification	Primary	Commercial vehicles often undergo significant change during life, or even (for vocational vehicles) before the first purchase. Can original certification remain a useful indicator of function?
Application-level testing	Primary	It may be necessary to understand the communication performance degradations due to blockage and multipath effects in common pre-crash situations, and then define a “standard” commercial vehicle and its DSRC configuration. This would be included in test procedures so that V2V devices are exposed to realistic conditions.
Industry involvement	Primary	It was widely believed that there is not enough involvement by technical members of the commercial vehicle industry.
Volunteered issue	Primary	Technical work is too far ahead of the institutional issues, such as data privacy, FOIA, and Sunshine laws (one respondent).
Volunteered issue	Primary	Citizen band (CB) radios are common on some classes of commercial vehicles. These were mentioned as potential sources of communication problems due to common use of illegal amplifiers by drivers.

4 Priority Issues Unique to Commercial Vehicles

Task 4 consisted of finalizing the list of major interoperability issues associated uniquely with commercial vehicles, prioritizing the issues, and offering recommendations for specific actions to address the issues. This task builds on the results and insights from the telephone interviews (Task 3) and the prior existing knowledge (Task 2).

Section 3 presented a table of issues that telephone interview respondents cited as potential interoperability issues unique to commercial vehicles (Table 3.3). The background knowledge of Task 2 and researcher considerations are used to consolidate the list into overall issues. Consolidation was done in two ways: coupled issues were combined if a single activity could address both, and some issues were judged by the research team to be minor and unlikely to significantly affect deployment.

Furthermore, these issues are prioritized according to the their potential impact on success in three different stages of deployment: model deployment (an initial piloting of connected vehicles); early deployments in products, and deployments in the longer term. These goals drive the prioritization:

- Seek to preserve the potential safety application performance levels, no matter which vehicle hosts the application (e.g., promote the robust exchange of quality information),
- Avoid delaying the time at which each deployment stage occurs (e.g., attempt to keep these issues from being pacing items on a schedule),
- Avoid risk that stakeholders will not engage in the deployment (e.g., attempt to retain the interest of fleets and others in the commercial vehicle industry).

Then a priority level scheme is created, as shown in Table 4.1. This is used to assign a priority level for each issue from “1” (highest priority) to “3” (lowest priority).

Table 4.1. Definition of priority levels

Priority level	Definition
1	Potentially critical for the conduct of initial deployments, Or, threatens long-term deployment success
2	Potentially critical for reaching the expected performance levels in early deployments, Or necessary to avoid delaying the first large-scale deployment
3	Potentially necessary for long-term successful deployments Or necessary to be efficient in development and/or deployment

Table 4.2 shows the list of consolidated issues, potential impacts, and recommendations that result from this project. Furthermore, the table shows priority levels corresponding to the definitions in Table 4.1.

Table 4.2. Summary of Prioritized Issues and Recommendations

Issue Category	Issue Priority Level	Issue	Potential Impact	Recomm. Priority Level	Recommendation	
SAE J2735 basic safety message	2	Articulated vehicles are not yet incorporated into the SAE J2735 basic safety message standard.	The occupied space and path for articulated vehicles cannot be accurately broadcast when turning.	2	Revise the SAE J2735 basic safety message to accommodate articulated and heavy vehicles.	
	3	The SAE J2735 scaling for vehicle weight does not allow for broadcasting the actual weight of medium and heavy commercial vehicles.	With an incorrect weight estimate, other vehicles may make inappropriate choices.			
Trailer parameters	1	Trailer size parameters are not known by most power units, e.g., tractors in a semi-trailer configuration. While trailers are not unique to commercial vehicles, this is a critical issue for commercial vehicles.	Vehicles pulling trailers do not currently know length or weight. Safety application performance can be affected on both the host and remote vehicles.	1 (left), 1 (right)	Determine requirements for trailer parameter signals in the basic safety message. (Is weight really needed? How accurate must trailer length be?)	Investigate ways for a power unit to know trailer parameters, e.g., trailer electronics, power unit-based estimates, use of remote vehicle data, etc.
	1	To broadcast trailer size parameters, there are choices about whether to equip trailers with hardware or to estimate trailer parameters using a tractor-only solution. Determining whether there is a best solution would likely enable faster resolution of this issue.	Ability of remote vehicles to know trailer length. Equipping trailers will meet resistance from the carrier industry, and estimating trailer parameters on the tractor would be difficult to do reliably. Thus an issue is to find a feasible way to obtain and broadcast the trailer length.			

Issue Category	Issue Priority Level	Issue	Potential Impact	Recomm. Priority Level	Recommendation
DSRC blockage	1	Blockage of DSRC may occur when the line of sight between two DSRC antennas. is obstructed. Large vehicles can affect their own communications as well as that of neighboring vehicle pairs.	Safety application performance may degrade due to the latency of lost messages..	1	Estimate the impact on safety applications of the latencies that result from common blockage scenarios due to large vehicles.
				1	Facilitate tests to understand blockage conditions, multipath issues, ground null locations, and their influence on packet receipt. Involve radio suppliers with diverse antenna/receiver setups.
DSRC multipath	2	DSRC multipath effects occur due to the large surfaces of commercial vehicles reflecting the DSRC.	Safety application performance may degrade due to latency or nulls and/or may lead to more complicated receivers.		
DSRC ground nulls	2	Antenna height changes the location of ground reflection nulls.	Dead spot at a fixed range that depends on two antenna heights. Is this at a "critical" range?	1	Determine the location and the potential negative impact of ground nulls for high-mounted DSRC antennas.
DSRC dual-antenna	3	Secondary issue: If two or more antennas are on the same vehicle,. there may be implementation issues.	Two antennas broadcasting the same information simultaneously may create self-blocking nulls and unnecessarily flood the area with redundant DSRC waveforms.	n/a	No recommendations are provided for secondary contingency issues.
Scalability	3	Will large vehicles complicate the issues of scalability, i.e., operation in an active DSRC area?	Obstruction & multipath could worsen the problem of communication in DSRC-congested areas.	2	Include large vehicles as part of scalability testing.

Issue Category	Issue Priority Level	Issue	Potential Impact	Recomm. Priority Level	Recommendation
Relative positioning	2	Errors in relative position estimates between two vehicles can occur due to differences in GPS satellite sets being used by a tall vehicle and a smaller vehicle traveling adjacent to the tall vehicle.	Safety application performance degradation.	2	Test to measure the absolute and relative positioning errors for a small vehicle that is adjacent to a tall vehicle. (Is this distinct from the urban canyon problem?)
Aftermarket	3	Do enough vehicles have the SAE J1939 bus populated with basic safety message variables?	Would slow penetration of aftermarket devices.	>3	Industry might consider standardizing a data bus gateway or other means to provide aftermarket systems access to the minimum BSM set.
Aftermarket	2	The public standard SAE J1939 makes it easier for nefarious broadcasts onto the bus. The OBE would pass along this false information.	Could compromise system safety by allowing hackers to create undesirable behavior on the road.	1	Determine whether rogue message broadcasts onto J1939 pose a risk to other vehicles. (Unconfirmed issue.)
Certification	1	Need a functional test to describe what communication performance should be.	Will allow radio vendors to focus development. May help define the remote vehicles for use in application-level track tests.	2	Consider developing a functional specification and test procedure set that defines expectations for performance around commercial vehicles. If viable for suppliers to replicate, it could accelerate industry readiness.
Certification	2	Since DSRC performance may depend on the physical configuration of vehicles, aftermarket device certification begs the question of how (and who) certifies these devices.	It is possible that OEMs may not want responsibility for certifying aftermarkets, and aftermarket manufacturers may not have the resources to certify with all makes and models.	2	Consider the certification process for aftermarket safety devices, using insights from testing (which may answer how many vehicle configurations need to be tested to have confidence in proper DSRC performance)..

Issue Category	Issue Priority Level	Issue	Potential Impact	Recomm. Priority Level	Recommendation
Certification	3	Secondary issue: If transmission power is increased around large vehicles, then this attribute needs to be tested.	Certification and application-level testing may be necessary to explore modulating of transmission power.	n/a	No recommendations are provided for secondary contingency issues.
Application testing	2	Large vehicle effects on DSRC communication are not well documented. Will this uncertainty confound testing of safety application performance?	Real-world performance may be worse than the Application testing performance on a track.	3	Consider establishing standard large-vehicle antenna configurations for remote vehicles used in application-level testing.
Industry involvement	2	Not enough technical experts from the commercial vehicle industry are on standards committees.	Will miss opportunity for efficiency in research, or improved performance, if industry contributors are absent..	2	Consider ways in which to increase the number of commercial vehicle experts in the standards committees.
Industry involvement	1	Enthusiasm, understanding, and engagement of commercial vehicle industry in connected vehicles is not yet high.	Commercial vehicle issues may remain hidden, adding risk to deployment benefits and timing.	2	Continue outreach, particularly with fleets, possibly focusing on return-on-investment aspects of DSRC equipment.
Volunteered issues	2	Overpowered CB radios are common in class 8 freight vehicles. Can this affect DSRC communication?	Unknown potential for affecting the DSRC reception onboard these vehicles.	2	Test DSRC performance with nearby overpowered CB radio antennas.

5 Summary

The objective of this project was to identify and prioritize the issues unique to commercial vehicles that affect the interoperability of connected vehicle safety applications using 5.9 GHz DSRC. The focus was therefore to examine areas where the reliable exchange of quality information to support the applications could be affected. The study emphasized heavy vehicles, particularly trucks, and did not explicitly treat many classes of commercial vehicles. This was necessary to support ongoing efforts to equip heavy trucks with these capabilities. Insight and experience with these vehicles is expected to provide substantial guidance for other classes of commercial vehicles.

The project began by examining existing literature and work. Literature in this area is still sparse, however technical reports from contractors with U.S. DOT and draft technical standards were found to be sufficient to begin the project. From this, a set of 10 candidate issues related to interoperability and application performance was proposed, which were thought to be possibly significant and unique to commercial vehicles.

Next, a telephone interview with 16 respondents (DSRC technical experts and commercial vehicle professionals) was performed, as part of a system to gain more information about the roadway environment and the driver environment. The responses were analyzed at some length. At least 60 percent of the respondents found six of the issues to be potentially significant. The interviews and subsequent analysis and research resulted in a set of 19 priority issues. Furthermore a set of 16 recommendations were made for actions that could help the connected vehicle program move forward.

Acknowledgments

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References

Ahmed-Zaid, F., et al. (2010,May 14, in review). Draft: *Vehicle safety communications - applications (VSC-A) final report*. Washington, DC: National Highway Traffic Safety Administration and Research and Innovative Technology Administration. [Report subsequently published as: Ahmed-Zaid, F., Bai, F., Bai, S., Basnayake, C., Bellur, B., Brovold, S… & VanSickle, S. (2011, September). *Vehicle safety communications - applications (VSC-A) final report*. (Report No. DOT HS 811 492A). Washington, DC: National Highway Traffic Safety Administration and Research and Innovative Technology Administration. Available at www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CFkQFjAA&url=http%3A%2F%2Fwww.nhtsa.gov%2FDOT%2FNHTSA%2FNVS%2FCrash%2520Avoidance%2FTechnical%2520Publications%2F2011%2F811492A.pdf&ei=9hAlUNDmJoyy8QSM8YCoBw&usg=AFQjCNEW1n1OiEbV1IFndxE47tenr-NY5w&sig2=U7JZ-AO7i2esJHzO-7c2_A.]

CAMP Vehicle Safety Communications Consortium. (2005, March). Vehicle Safety Communications Project Task 3 Final Report - Identify Intelligent Vehicle Safety Applications Enabled by DSRC.(Report No. DOT HS 809 859) Washington, DC: National Highway Traffic Safety Administration. Available at www.its.dot.gov/research_docs/pdf/59vehicle-safety.pdf

Capps, G., Franzese, O., Knee, B., Plate, R., & Lascurain, M. B. (2009, September). *Wireless roadside inspection proof-of-concept test*. (Report No. FMCSA-RRT-09-007). Washington, DC: Federal Motor Carrier Safety Administration. Available at www.fmcsa.dot.gov/facts-research/research-technology/report/FMCSA-RRA-09-007_WRI-POC.pdf.

Chang, J. (2010, June). "Market penetration analysis for VSC-A safety benefit opportunities estimation." (Technical report, prepared by Noblis Corporation under Contract No. DTFH61-05-D-00002). Washington, DC: National Highway Traffic Safety Administration and Research and Innovative Technology Administration . Available at www.its.dot.gov/research_docs/pdf/24Market%20Penetration%20Analysis_VSC-A.pdf.

Gallagher, B., Akatsuka, H., & Suzuki, H. (2006). "Wireless Communications for Vehicle Safety: Radio Link Performance & Wireless Connectivity Methods." (SAE paper 2006-21-0030). Warrendale, PA: Society of Automotive Engineers. Available at www.denso.co.jp/ja/aboutdenso/technology/dtr/v12_1/files/13.pdf.

Federal Highway Administration. (2011). Safety Pilot Model Deployment of Intellidrive Safety Applications. (Request for Proposal No. DTFH61-11-R-00006). Washington, DC: Author.

Federal Motor Carrier Safety Administration & the Federal Highway Administration (2010, April). "White paper: Scope of the smart roadside initiative." Washington, DC: Authors. Available at http://www.its.dot.gov/research_docs/pdf/26Smart%20Roadside%20White%20Paper.pdf.

Hartenstein, H., & Laberteaux, K. P. (2010). *VANET: Vehicular applications and inter-networking technologies*. Chichester, UK: John Wiley & Sons.

Hedges, C., & Perry, F. (2008, October). "Overview and Use of SAE 2735 Message Sets for Commercial Vehicles." (SAE paper 2008-01-2650). (doi:10.4271/2008-01-2650). Warrendale, PA: Society of Automotive Engineers.

Huang, J., & Tan, H. (2007). Impact of communication reliability on a cooperative collision warning system. In: IEEE Intelligent Transportation Systems Conference, Seattle, 30–3 September/October, pp. 355–360.

IEEE 1609.1. (2006). "IEEE Trial-use standard for wireless access in vehicular environments (WAVE) - resource manager."

IEEE 1609.2. (2006). "IEEE Trial-use standard for wireless access in vehicular environments (WAVE) - security services for applications and management messages."

IEEE 1609.3. (2006). "IEEE Trial-use standard for wireless access in vehicular environments (WAVE) - networking services.

IEEE 1609.4. (2006). "IEEE Trial-use standard for wireless access in vehicular environments (WAVE) - multi-channel operation.

IEEE P802.11p/D8.0. (2009). "Draft standard for information technology - telecommunications and information exchange between systems - local and metropolitan area networks - specific requirements; Part 11: wireless LAN MAC and physical layer specifications; Amendment 7: wireless access in vehicular environments."

Jiang, D., & Delgrossi, L. (2008). "IEEE 802.11p: Towards an International Standard on Wireless Access in Vehicular Environments," IEEE Vehicular Technology Conference, pp.2036-2040.

Kenney, J. B. (2010). "Standards and regulations," in *VANET: Vehicular applications and inter-networking technologies*," pp. 365-429. Chicester, UK: John Wiley & Sons.

M. Boban, Vinhoza, T. T. V., Ferreira, M., Barros, J., & Tonguz, O. K. (2011). Impact of Vehicles as Obstacles in Vehicular Ad Hoc Networks, accepted for publication in IEEE JSAC, issue on Vehicular Communications and Networks, Vol. 29, No. 1, January 2011

Maile, M., Ahmed-Zaid, F., Caminiti, L., Lundberg, J., Mudalige, P., & Pall, C. (2008, October). *Cooperative intersection collision avoidance system limited to stop sign and traffic signal violations,* Midterm Phase I Report May 2006 – April 2007 . (Report No. DOT HS 811 048. Washington, DC: National Highway Traffic Safety Administration and Federal Highway Administration.

Miucic, R., & Shaffnit, T. (2009). "Communication in Future Vehicle Cooperative Safety Systems: 5.9 GHz DSRC Non-Line-of-Sight Field Testing." (SAE paper 2009-01-0163). Warrendale, PA: Society of Automotive Engineers.

Rezaei, S., Sengupta, R., Krishnan, H., Guan, X., and Bhatia, R. (2010). "Tracking the Position of Neighboring Vehicles Using Wireless Communications," Transportation Research Part C., Vol. 18, pp. 335-350. Washington, DC: Transportation Research Board.

Santa, J., Toledo-Moreo, R., Zamora-Izquierdo, M. A., Ubeda, B., & Gomez-Skarmeta, A. .F (2010, June). *An analysis of communication and navigation issues in collision avoidance support systems. (*Transportation Research Part C, vol 18, pp. 351-366). Washington, DC: Transportation Research Board.

Siebert, M. (2010, June). Concept of operations: C030588 CVII task 3. Albany, NY: New York State Department of Transportation. Available at http://i95coalition.org/i95/Portals/0/Public_Files/CVII/ConOpsDriverCred%20-%20June%202010.pdf.

SAE J2735 (2009). "DRAFT SAE J2735 Dedicated short range communications (DSRC) message set dictionary." DSRC Committee. Warrendale, PA: Society of Automotive Engineers.

SAE J2945-1 (2009). "DRAFT SAE J2945-1 DSRC message communication minimum performance requirements - basic safety message." DSRC Committee. Warrendale, PA: Society of Automotive Engineers.

Tan, H., & Huang, J., 2006. DGPS-based vehicle-to-vehicle cooperative collision warning: engineering feasibility viewpoints. *IEEE Transactions on Intelligent Transportation Systems 7* (4), 415–428.

Toma, S., Swanson, E., Smith, J. D., & Najm, W. G., (in press). Description of heavy truck pre-crash scenarios for safety applications based on vehicle-to-vehicle communications. Washington, DC: National Highway Traffic Safety Administration.

Weimerskirch, A., Haas, J. J., Hu, Y-Cl., & Laberteaux, K. P. (2010). "Data security in vehicular communication networks," in *VANET: Vehicular applications and inter-networking technologies*. Chicester, UK: John Wiley & Sons.

Appendix A Telephone Interview Introduction and Questions

This appendix presents the telephone interview questions, as well as the introductory statement that was presented to each respondent. Note that Section 3.1 describes that each respondent is asked only a subset of these questions.

Connected Vehicle Issues Related to Commercial Vehicles

First of all, we'd like to thank you for agreeing to be interviewed. As we indicated in our e-mail, the University of Michigan Transportation Research Institute is working with the U.S. Department of Transportation on a connected vehicle project. The U.S. DOT, as you know, has been engaged for several years with research partners and stakeholders in exploring whether and how new safety and mobility capabilities could be enabled by connecting vehicles with each other and the infrastructure using wireless communication. In particular, dedicated short-range communications operating at 5.9 GHz (or DSRC for short) is proposed to play a central role. To this end, a large program of research on technical issues as well as policy is underway. NHTSA has also announced that it will decide by 2013 whether to require DSRC to be installed on vehicles to support V2V safety applications.

The purpose of our project is to identify and prioritize issues involving the exchange of information between vehicles related to commercial vehicles. When we talk about information exchange, this may include standards for DSRC communication devices, testing and certification, and real-world implementation. "Commercial vehicles" refers to trucks and motor coaches of all types. There are many issues with the exchange of information that are generic to any type of vehicle, but our interest is to look for issues that are specific to commercial vehicles.

You have been identified as having expertise that would be valuable for this effort. We would appreciate if you could share your expertise, and your informed opinions about this topic. We believe your responses will help to inform this research program. The information you share will not be associated with your identity or the name of your organization. Only UMTRI project staff will see your identifiable responses. We will aggregate the responses of all the experts and prepare a report for U.S. DOT that represents these responses. Our goal is to provide an independent analysis of these issues in order to inform the government and to support effective decision making.

Any questions before we begin?

Question 1 – Adapting the SAE J2735 basic safety message to commercial vehicles
The basic safety message for V2V communication has recently been defined in the SAE J2735 standard. The standard assumes that the broadcasting vehicle is a single rigid-body vehicle, without trailers or other articulated elements. In your opinion, does the basic safety message need to be changed to deal with articulated vehicles? Please tell us why you answered yes or no.

Question 2 – DSRC performance and physical factors
Commercial vehicles vary in size and shape, such as tall box trailers, flatbed trailers with loads, cement mixers with rotating barrels, and boom lifts for utility work. The locations and lines of sight for DSRC antennas will be different for these vehicles than for passenger vehicles.

a. Do you expect that DSRC communication onboard commercial vehicles will have different performance than for passenger vehicles? If so, how will it be affected?
b. Do you think the performance of safety or mobility applications might be affected? If so, in what way?

Question 3 – Relative positioning performance and physical factors
Many V2V safety applications need to know the position of nearby vehicles fairly accurately. This is done in part by each vehicle comparing its GPS information with that of its nearby vehicles. Since commercial vehicles are often large, they may affect GPS signals received by nearby smaller vehicles.

Do you expect that the vehicle size differences could affect V2V safety application performance because of relative positioning issues? If yes, how significant would the change in application performance be?

Question 4 – Objective testing of V2V safety applications
V2V safety application performance is sometimes verified on the test track using scripted maneuvers. Commercial vehicles and their physical size and configurations may affect communications with other vehicles, or even affect communications between two passenger vehicles that are on opposite sides of the commercial vehicle.

(a) For testing passenger-vehicle V2V safety applications, do you think that commercial vehicle factors should influence test procedures?

(b) For commercial vehicle V2V safety applications, do you think that the test procedures should be significantly different than those developed for passenger vehicle applications?

Question 5 – Commercial vehicles and scalability of wireless communication
DSRC performance in congested areas is a concern because of the potential for message collisions and the loss or delay of messages. Commercial vehicles are sometimes clustered in traffic in certain situations, such as interstate traffic. Do you expect that commercial vehicles would introduce unique issues that would affect DSRC performance in such congested areas? If so, what are the issues?

Question 6 – Commercial vehicles and the IEEE 1609 protocol stack
The IEEE 1609 standard defines the upper communication layers for DSRC, such as authentication of signals, encryption, and channel switching. Aside from the topics already addressed in previous questions, do you think that any unique requirements introduced by commercial vehicle

V2Vapplications will call for special considerations within these standards? If so, what are the issues and their potential impact?

Question 7 – Certification of onboard equipment communication
The U.S. DOT concept for connecting vehicles with DSRC includes certification of devices. This would ensure basic conformance with communications standards, and ensure that operations with other agents results in information being properly exchanged. Are there unique characteristics for commercial vehicles that might affect device certification testing? If yes, what are they and how might they affect device certification testing?

Question 8 – Information about trailers
In the typical semi tractor and trailer today, the towing vehicle typically has little or no information about the trailer, so that trailer size data would be unavailable to a V2V system onboard the tractor. (a) What would the impact of this be on V2V implementation if towing vehicles remain ignorant of their trailers? (b) Do you see this situation changing in the next 10 years?

Question 9 – Aftermarket and retrofit devices
Most larger commercial vehicles adhere to the SAE J1939 CAN message protocol. This provides format definitions for common vehicle data signals. This standard may accelerate the development of aftermarket devices on J1939-equipped vehicles, compared to other vehicle types that do not have standardized data buses. Do you expect any technical or other obstacles to the deployment of aftermarket devices on commercial vehicles that use a J1939 CAN bus? If so, can you suggest how these might be addressed?

Question 10 – Engagement of commercial vehicle industry in discussions
There are several technical and policy forums for topics related to DSRC and connected vehicles. These include technical standards development organizations and U.S. DOT stakeholder groups that address policy. Do you feel the commercial vehicle industry is engaged adequately in these discussions, in order to ensure successful deployment? If not, can you comment on which types of organizations or subject matter experts are underrepresented?

Question 11 – Other factors
Are there other issues related to information exchange with commercial vehicles that you feel we have not addressed?

Question 12 – Ratings of the issues we have discussed

Finally, please rate the following: For a successful deployment of connected vehicle technologies using DSRC, how important is it to understand and, if necessary, resolve the issues below? Use the following scale:

Not important 1 2 3 4 5 Very important

How important is it that this issue is understood and, if necessary, resolved?	Rating
1. whether the DSRC basic safety message needs to be resolved to deal with articulated vehicles.	
2. whether the performance of DSRC communication onboard, or near, commercial vehicles is different than that of passenger vehicles alone.	
3. whether vehicle size differences will affect relative positioning accuracies of nearby vehicles.	
4. whether objective testing on test tracks need special considerations for commercial vehicles.	
5. whether commercial vehicles will have a unique impact on DSRC communication in areas with many broadcasting vehicles.	
6. whether commercial vehicles introduce unique issues that may affect IEEE 1609 standards.	
7. whether commercial vehicles introduce unique issues that may affect device certification testing.	
8. the fact that a combination vehicle usually does not know its trailers' characteristics.	
9. implementing aftermarket or retrofit devices on J1939 vehicles.	
10. whether the commercial vehicle industry should have more involvement in technical and/or policy groups related to connected vehicle initiatives.	
11. other issues that you identify here:	

Appendix B Data from the Telephone Interviews

Table B.1 presents a summary of each of the respondent's answers to the questions they were asked in the telephone interview. These summaries were derived from notes taken during the interviews, and represent the researchers' capturing of the respondents information. Verbatim comments are shown in quotation marks, and any researcher explanations or comments are shown in square brackets [ ].

The first few columns provide the interview subject number, the interview group (discussed in Section 3), and whether the respondent felt there was an issue associated with each of the 10 topics introduced by the researcher during the interview. (Recall from Section 3 that not all respondents were asked about each of the 10 topics.)

Table B.1 Summary of individual responses: issues and impacts, possible resolutions, and comments

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
1	1	B	YES	The resolution of the BSM weight signal needs correcting (since it allows only 6,350 Kg). Weight is needed for stopping distance estimation.	
1	1	B		There's a need to enter trailer information [on the tractor OBE], and it must not be drivers entering manually.	
1	6	B	YES	Other vehicles will perceive an articulated vehicle's position as being skewed in turns and curves. [See Figure in Section 2.]	The BSM needs to have a proper representation of antenna/vehicle relationship. [Currently the BSM position signals are assumed to be at the vehicle geometric center. However, this comment may be moot since radios allow offsets to be programmed in.]
1	7	B	YES	There is a need to broadcast and use differences in turning radius.	Use the length and/or weight estimates on those tractors that have advanced safety systems such as roll stability, which estimate weight.
1	7	B		There is a need to broadcast and have remote vehicles use weight values.	
1	7	B			Could posit a small set of possible weights/lengths, and then estimate in real time which of those applies. But this won't work for doubles or triples.
1	7	B			Comment: Doubles and triples complicate the possibility of estimating length on the tractor side.
1	8	B	NO	(No justification of response, despite questioning.)	(No justification of response, despite questioning.)
1	9	B	YES	Knowing trailer parameters is not just a commercial vehicle issue. It applies to light vehicles with boats, too.	
1	21	T	YES	The size and weight resolution needs correcting. [Not sure why size needs correcting.]	Respondent suggestion: "Force [commercial vehicle] industry to get trailer parameters electronically into the OBE."
1	21	T		J2735 assumes positioning is at vehicle center, which is not true for many commercial vehicles. [Another respondent says that DSRC radios account for offsets in their configuration setups.]	Antennas on trailers could help.
1	21	T		Safety application performance will be affected unless length is broadcast properly.	
1	22	T	YES	Impact on safety level - need to know trailer length.	Could reformat existing vehicle type signal (in BSM) to reflect not only the number of axles, but also the trailer length.
1	22	T		Articulated vehicles that are turning will mislead other vehicles due to articulation angle.	Revise J2735 so that centroid doesn't have to line up with positioning point. [Another respondent says that DSRC radios allow offsets to be entered in configuration setups.]

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
1	24	T	YES	False alerts would result from believing falsely there is "too big of a box," due to the combination of single body assumption. [See Figure in Section 3.]	Need to add an extra link to the vehicle (part 2 of the BSM).
1	25	T	YES	Trailers lead to different turning motions [than for single-body passenger vehicles].	None offered
1	25	T		Doubles and triples complicate the issue of length and paths, and so the question of articulation is more than a single trailer.	None offered
1	26	T	YES	Safety application performance will be affected.	OBEs could modulate transmission power if a truck is nearby, to increase the power and overcome the blockage issue. [Two other respondents said this was not an effective solution.]
1	26	T		Need to know the vehicle boundaries. Thus articulated vehicles cannot be well represented by a single body model.	Trailer length: maybe broadcasting a range of possible overall lengths is adequate.
1	26	T		Commercial vehicles have different turning radii, which is an issue.	
1	26	T		Weight and length resolution needs correcting.	Articulation is already a SAE DSRC committee work item.
1	26	T		Need to know stopping distance.	
1	27	T	YES	Trailer length is needed.	
1	27	T			Comment: Grade crossing and trucks is active area of work in Australia.
1	28	T	YES	Safety application performance will be affected, due to articulation angles not being accounted for.	Adjust BSM: could do as two bodies with separate motions, or with articulation fields added.
1	28	T			Comment: Can calibrate out the difference between antenna location and geo centroid.
1	28	T		Need to extend length and width in the data format. [Length is adequate: 0 to 163.83 m]	
2	1	B	YES	Obstructions of commercial vehicle physical volumes cause shadows in DSRC communication.	
2	6	B	YES	Reduced working range due to shadowing [obstruction by commercial vehicle volume] occurs in testing.	Antenna placement can help.
2	7	B	YES	Communication problems occur due to line of sight and reflections.	Antenna placement could help reduce the problem.
2	7	B			Comment: Sleeper hoods and other differences means even the "same" vehicle may need different antenna placement.
2	7	B		Antenna placement needs to be adapted to specific vehicles.	
2	8	B	YES	No justification of response	

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
2	9	B	YES	Dashboard aftermarkets will have communication problems if antennas are inside the vehicle cab.	
2	9	B			Comment: Note V2I will not be as affected as V2V by the antenna placement problem because the other antenna will be in view.
2	9	B		Snow/ice coverage may be a problem.	
2	9	B		Will commercial vehicles have suitable ground planes for antennas (DSRC & GPS)? Cabs roofs are often not made of metal.	
2	21	T	YES	Blockage is an issue (organization did testing). This leads to dropouts in DSRC messages.	Application layer algorithms can compensate for multipath and blockage, through changing safety system timing when near trucks.
2	21	T			Comment: Organization did testing and looked at dropout rates at the application layer.
2	21	T		Multipath will exist but will not be such a big problem since some receivers deal with that.	Put antennas on the trailer, although that is complicated.
2	21	T			Allow radio technology to progress and greatly mitigate the multipath issue.
2	22	T	YES	Without a fairly unimpeded line of sight, vehicles will not communicate very well.	Put second antenna at rear of trailer, perhaps with reduced function and perhaps saying, "I am a trailer," so that tractor can recognize its own tail.
2	22	T		Multipath creates a potentially big [negative] effect.	Antennas (two) on sides of cab - will still have shadow, and will cost money for hardware and tuning on radio to deal with its self-interference patterns.
2	24	T		There is a need for a method to put trailer information on the OBE.	
2	24	T	YES	Safety application performance will be affected by blockage effects, especially for EEBL and FCW.	Two antennas on tractor side mirrors is an idea to reduce blockage effects.
2	24	T		Respondent's organization performed tests with passenger cars ahead and behind a semi-trailer: "Vehicles behind a truck cannot broadcast to those ahead of a truck, and vice versa." Communication is "highly variable."	
2	24	T			Comment: "5.9 doesn't go through much at all."
2	25	T	YES	Line of sight is poor when large commercial vehicles are involved.	
2	25	T			Comment: Electronics on trailers: "I don’t see how this would happen."

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
2	25	T		Multipath reflections will be an issue for everyone nearby.	
2	26	T	YES	Reduced reliability and working range of information transfer will occur near trucks.	Multiple antennas on commercial vehicles can help mitigate the blockage and multipath effects they introduce.
2	26	T			Comment: Multiple antennas adds complexity and can add to message congestion.
2	26	T		Multipath can help at times, e.g., helping overcome blockage effects.	Adapt transmission power near trucks [as a way to reduce loss of messages caused by blockage and multipath.]
2	26	T			Comment: Messages would be delayed but not lost forever.
2	26	T		Antenna placement is an issue with commercial vehicles.	
2	27	T	YES	Loss of packets due to blockage will lead to latency in application level performance.	Use of advanced DSRC receivers will help a lot. “Can work-around at the app level, but it makes more sense to work at the level of the problem.”
2	27	T			Comment: Receiver technology is moving quickly.
2	27	T		Loss of packets due to blockage will lead to congestion.	Use not only device compliance certification, but also functional performance standards at the vehicle level, along with tests that include blockage challenges. Then let the technology solve the problem.
2	27	T			Comment: DSRC is not monolithic - there are different radios and receivers.
2	27	T			Advises against trying to find a good ‘antenna configuration’. Levy requirements at the functional level instead.
2	27	T			Advises against two antennas, in general – creates more nulls due to multipath. Focus on better receivers.
2	27	T			Include vehicle-level performance testing.
2	28	T	YES	Multipath leads to performance issues, especially near the vehicle.	“Need to study the issues. Right now there is not a clear understanding [of the impact of commercial vehicles on DSRC communication], but clearly there will be a difference [between vehicles].” Some testing is required to understand the issues and then go from there.
2	28	T		Antenna height will move the known main null to a lesser range for truck/car pairs than the 70m for pass car pairs.	“Multiple antennas on the commercial vehicle could help–some on the side, or the back.”
2	28	T			
2.5	1	B		Safety will be affected if there are antenna problems.	Need testing to confirm that safety apps themselves are affected.
2.5	6	B	YES	Modest impact only on safety application performance.	Antenna placement can help.
2.5	7	B	YES	Safety app performance will be affected.	
2.5	8	B	MAYBE	[No justification of response.]	
2.5	9	B	YES	V2V will be affected if communication is affected.	

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
2.5	21	T	MAYBE	Physical factors may affect safety application performance. Testing is needed.	
2.5	22	T	YES	Absolutely, safety application performance will be affected.	
2.5	24	T	MAYBE	May not be much trouble. "Cars can brake harder than trucks [perhaps so that latency can be tolerated?]"	
2.5	25	T	MAYBE	Need to test whether physical factors will affect performance at the safety level.	
2.5	26	T	MAYBE	Safety app performance impacts - but not certain if they would be significant.	
2.5	27	T	YES	Latency in safety application performance will occur.	
2.5	28	T	YES	Yes.	
3	1	B	YES	[No justification of response.]	Need better GPS accuracy.
3	6	B	(No response)	[No justification of response.]	No response
3	7	B	NO	GPS performance will be independent of vehicle configuration.	
3	7	B			Comment: GPS is not good enough in general for all vehicles yet. [This is an issue that is not unique to commercial vehicles.]
3	8	B	NO		
3	9	B	NO	The problem of relative positioning is not unique to commercial vehicles. The urban canyon problem is the same.	Receivers have gotten better.
3	21	T	YES	Large impact expected - could be several meters of absolute error, which affects intersection and other V2I safety apps.	Algorithms are being developed to look for jumps in GPS due to changes in satellite constellations, and compensate with yaw rate and speed [dead reckoning].
3	21	T		Could affect relative positioning as well, such as lane change warnings that are important with truck/car pairs	Levy absolute positioning requirements on GPS components (using ongoing CAMP work).
3	22	T	MAYBE	Error rate of safety application would go up with reduced accuracy.	[No justification of response.]
3	24	T	NO	Not unique to commercial vehicles. Positioning in urban canyons is a problem, and once that is fixed, the truck issue will be fixed as well.	GNSS and Galileo will help with multiband receivers: don't need to look low in sky to see satellites.
3	25	T	NO	[Not an issue.]	

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
3	26	T		Different satellite sets is NOT expected to cause issues.	CAMP is addressing different satellite sets and may recommend antenna designs for a conical, not hemispherical, field of view. This would reduce the impact of an obstructed view of the sky.
3	26	T			Comment: GPS confidence reduction (from multipath) could impact safety app's actions. So even without errors in lat/long, there could still be safety app performance change.
3	26	T			CAMP could help force suppliers to improve performance in the presence of multipath.
3	26	T	MAYBE	GPS signal multipath is the bigger issue.	
3	27	T	NO	An issue, but not generic to trucks. Is a special case of urban canyons.	
3	28	T	NO	Believes there will only be minor performance issues.	Recommends some studies, though.
3.5	26	T	MAYBE	Hasn't measured, so cannot say for certain if this is an issue.	
4	1	B	YES	Need commercial vehicles in passenger car testing.	
4	2	I	YES	Testing needs to be with mixed vehicle types.	
4	2	I		Commercial vehicles will have antennas that are different from LVs, and will not be as good (not low-profile like LVs). This may be an issue with positioning of all types involving commercial vehicles.	
4	2	I		Commercial vehicles will have blind spots, even with two antennas.	
4	3	I	YES	Must consider line of sight limitations and physical size in test procedures.	Real life interactions are important.
4	3	I			"LOS limitations have to either me mimicked or have the vehicles there."
4	4	I	YES	At least part of the testing needs to be in the real world traffic environment.	
4	4	I		Consider size and weight of larger vehicles [in test design].	
4	5	I	YES	"Our testing shows substantial concerns with DSRC performance…completely blocked by a single unit truck."	Need "comprehensive and fundamental test performance" on commercial vehicles.
4	5	I		"Expect…reflectivity issues for DSRC traveling past commercial vehicles."	
4	5	I		Antenna positioning is important.	
4	6	B	YES	Different size and weights of commercial vehicles, and different stopping distances, will affect test procedures.	Safety app algorithms must consider difference in stopping distances.

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
4	7	B	YES	DSRC communication issues from question 2 can affect safety apps on any type vehicle, so testing of all vehicle types should consider these effects.	Include commercial vehicles in testing of all host vehicle types.
4	8	B	NO		
4	9	B	NO	Commercial vehicles do not introduce unique issues.	Consider that commercial vehicle-commercial vehicle crashes are rare. It is the LV-commercial vehicle crashes that add up.
4.5	7	B	YES	Unique kinetic energy of commercial vehicles needs to be considered. [??]	
4.5	7	B		Unique communications conspicuity needs to be considered. Sometimes there is an advantage in being tall - DSRC will communicate better in the forward direction.	
4.5	7	B		Unique variation in loads and stopping distances needs to be considered.	
5	2	I	YES	Consider urban canyons with trucks around, as part of scalability investigation.	
5	2	I		Policy issue, but policy takes 10 times longer than technical progress.	
5	3	I	NO	Commercial vehicles are not a unique issue in itself [for scalability].	
5	4	I	NO	No unique issue.	
5	5	I	YES	"Not sure about CB radios. We've had problems with them in the past."	
5	5	I		Blockage and reflection could be an issue.	
5	5	I		commercial vehicles could block traffic signal controller traffic.	
5	21	T	YES	Minor issue: blockage issue suggests not reducing transmission power near trucks. Yet CAMP is considering adaptively reducing power in congested areas.	Perhaps the idea of reducing transmission power in congested areas is revised by limiting that technique to cases where there are no trucks nearby.
5	21	T			Application layer algorithms can compensate for multipath and blockage, through changing safety system timing when near trucks.
5	22	T	NO	Congested areas present generic problems, and truck blockages will probably not affect the communication enough to worry about.	
5	24	T	NO	Density goes down with commercial vehicles in the mix. So overall performance may improve with commercial vehicles.	Work by U.S. DOT is going on to address relaying messages, to ensure that messages get through. Once car hears a message and broadcasts it hears 3 others. Second car can hear only 2 others, and asks the first car to relay information. Potential of this is TBD.

Topic	Subject	Grp	Unique Issue?	Issue / Impact	Possible Resolutions and Comments
5	25	T	NO	No issue seen.	
5	26	T	NO	Trucks decrease the spatial density of broadcasting DSRC sets. So this may help performance.	None needed
5	26	T			Comment: Multipath can help at times.
5	27	T	YES	Commercial vehicles will add more interference problems, leading to delay in information. Probably not a major effect.	CAMP will have mixed traffic in their scalability work. If the problem is really bad, they will probably come across it.
5	27	T			Comment: It is "a bit of a myth that increasing power will work to mitigate the blockage issue." A standard receiver will be helped in a static situation by an increase in transmission power. "When in motion, the fact that the channel is time varying is causing them grief."
5	28	T	NO	There will be no unique issue if channel 172 is dedicated to safety messages only. (If not, heavy message traffic for commercial vehicle mobility could flood the channels and delay safety actions.)	
6	21	T	NO	No issue, unless channel 172 is not dedicated to safety only. If it is not, then the larger encrypted truck messages may cause message congestion.	None needed
6	21	T			Comment: CAMP is recommending 172 as safety-only channel.
6	22	T	NO	None needed.	None needed.
6	24	T	NO	No issue. (Studied standard for us.)	None needed
6	25	T	NO	No issue seen.	
6	26	T	NO	No	None needed
6	27	T	NO	No issue seen.	
6	28	T	NO	So long as channel 172 is dedicated to safety messages only.	
7	2	I	MAYBE	Commercial vehicles will have some blind spots.	OmniAir is doing work and may provide solution.
7	2	I		Need to look at function performance, not just protocol stack.	
7	3	I	MAYBE	CB radio interference may be an issue.	Consider CB radio interference.
7	4	I	NO	Challenge: who certifies systems on commercial vehicles, even an OEM installation.	
7	4	I			Comment: "It is still uncertain how DSRC would get into the industry."
7	4	I		Certify aftermarket units differently than OEM installed units.	

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
7	5	I	YES	Need to include receiver/antenna interactions somehow in certification, as commercial vehicles will have more complicated setups for DSRC.	
7	5	I		Light vehicles vs. commercial vehicles with physical factor issues: may want different antennas on the two vehicle types.	
7	21	T	YES	Tractor radios need extra onboard logic to determine/use trailer parameters.	Two sets of certification tests: passenger cars, and commercial vehicles.
7	21	T		Tractor radios may need to deal with two antennas, whether on the sides or on the trailer. That could affect the receiver design somewhat.	One suggestion is lab tests with obstructions that mimic trailers, etc.
7	21	T		Trucks may need higher transmission power level to overcome blockage. That could affect certification requirements.	
7	22	T	MAYBE	Reduction in reception reliability may lead to newer and costlier designs that go onto trucks.	
7	22	T			Comment: (This participant seems to accept that it is not critical to worry about the loss of communications near trucks.)
7	24	T	YES	Commercial vehicles need a different radio than passenger cars to accommodate trailer information, possibly to handle multi antennas. Commercial vehicle radio certification should be different than LV radio certification.	
7	25	T	YES	Antenna placement, trailers, and different physical factors mean the radio may need additional functionality.	
7	26	T	YES	Need to include blockage and multipath in testing.	Solve the blockage/multipath problem generally and don't rely on antenna placement - you will have to solve that problem a thousand times a year instead of doing it once.
7	26	T		If adaptive power transmission is used, this needs to be included.	Receiver design can be improved.
7	26	T		Need to address antenna placement issue first.	
7	27	T	YES	Need vehicle-level performance tests, in addition to radio tests. This means commercial vehicle tests.	
7	28	T	YES	Modest changes to the vehicle-level tests would be required for commercial vehicles.	Modest changes to the vehicle-level tests required.
8	1	B	YES	Need trailer information, and manual entry would compromise safety. Must automate how the trailer information gets onto the tractor OBE.	One method: use weight in motion detectors [with a means to know speed of the truck over the sensors], and communicate the length to the truck.
8	1	B			Axle weight sensors could be useful for weight.

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
8	1	B			Some trailers provide some information to tractors but it is not the physics information need by the active safety systems.
8	1	B			Using max weight/length could overestimate how quickly the truck can brake.
8	2	I	YES	BSM doesn't have weight in it. [This is untrue.]	Wireless roadside inspection may provide way to piggyback on that sort of trailer information.
8	2	I		Entering in trailer information manually is an issue.	
8	2	I		Doubles will be a challenge [in terms of knowing trailer information.]	
8	3	I	YES	There are diverse trailer configurations.	"It will take an advance in safety systems to educate a tractor about its trailer."
8	3	I		Need length and width, weight, to compute stopping distances.	
8	4	I	YES	"Must know the weight of the trailer because of stopping distance."	
8	4	I			Comment: "100 thousand dollar question." [Trailer info.]
8	4	I		It is hard to put electronics on trailers, and trailers last a long time so penetration of factory-install systems would take a long time.	
8	4	I		Business case (ROI): "We have found a couple good solutions but not sure how much potential they have in terms of the business case for trailer companies or the fleets who buy them."	
8	5	I	YES	Big time problem. Need trailer information for V2V.	
8	6	B	YES	Need to know trailer length.	Can be addressed in ongoing IntelliDrive projects.
8	7	B	YES	Would need to estimate the trailer parameters.	Not a problem if default average weights and lengths are used, for singles..
8	7	B			Comment: Issue with trailers is only on some commercial vehicles.
8	8	B	NO		
8	9	B	YES	"Investing money on trailers is something people are not interested in doing."	Owner may be able to input the common length of trailer.
8	9	B		"Trailer fleet has a low turnover." [Therefore penetration of new systems will take a very long time.]	
8	9	B		"Logistics providers are stressed by new tractor prices for emissions improvements. The average age of trailers will only increase."	
8.5	7	B	MAYBE	"Ten years?" Possibly.	Use defaults or estimates - use a tractor solution and don't put anything on trailer.

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
9	1	B	NO	None.	
9	2	I	YES	J1939 is not well populated on actual vehicles.	Consider research to determine what the actual J1939 population levels are, in the fleet.
9	3	I	NO	No issue.	
9	4	I	YES	Bus security is very sensitive to us [OEM]. That is why braking commands for safety systems are not on the J1939.	
9	4	I		"Access to proprietary messages": how would this be done?	Gateways (including software ones) could be used to provide aftermarkets with standard-formatted data sets across models/OEMs.
9	4	I		No countermeasure to phony J1939 messages is defined.	
9	5	I		Antenna height matters as well.	
9	5	I	NO	[Response not justified.]	
9	6	B	NO	J1939 population issue can be dealt with by aftermarket vendors - it will be taken care of.	
9	7	B	NO	None mentioned.	
				Skeptical about aftermarkets' commercial success. Fleets prefer OEM installations, in part because they can claim depreciation on them.	
9	8	B	YES	[Response not justified.]	
9	9	B	YES	J1939 is not always populated well.	
9	9	B		Antenna placement will be a problem for aftermarket devices. How will the system be tuned automatically, and be robust to wherever the purchaser decides to put the antennas?	
9	9	B		Dashboard aftermarkets will have communication problems if antennas are inside.	
9	24	T	YES	May be slightly easier with trucks than LVs, but J1939 signal population and quality will be uneven. So it's "not exactly plug and play."	
10	1	B	YES	Not enough involvement - only the CVII team and one or two from ATRI at the ATA. Need whole spectrum: OEMs, suppliers, fleets.	Need to involve also telematics, Verizon. Maybe turn the whole thing over to them.
10	2	I	YES	May be an issue. It is getting better. Not sure if they (FMCSA heavy vehicle folks) are engaged adequately.	Get more HV people into U.S. DOT. Pairing IntelliDrive with AASHTO was a good idea. CVSA another good one.
10	3	I	YES	Need core industry involved. Not yet the "right faces" in the meetings.	Need core industry: OEMs, suppliers, fleets.
10	3	I		Must have a ROI plan for industry involvement.	Engage SAE commercial vehicle group. On the fleet side: ATA T&M Council.

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
10	4	I	YES	no justification.	
10	5	I	NO		Wal-Mart and U.S. Express are aware of V2V.
10	6	B	YES	When I meet with CVSA and FMCSA, there are a lot of wide eyes that this is new information.	Safety alliances, general government agencies, and trucking companies need to get together to show the benefits that are provided by this technology.
10	7	B	YES	Industry is not engaged.	Industry is confused by U.S. DOT outreach: it seems there are several different activities with different names across agencies. How are they related? Are they?
10	8	B	YES	"Lay the future groundwork for the acceptance of the technology and how to justify the cost for quicker adoption."	ATA T&M Council; Off or Onboard Vehicle Communication Council. Develop a technical advisory paper.
10	8	B			Have a "focus group approach with innovative fleets could provide positive results" for apps development ideas.
10	9	B	YES	"AC-OBD regs, stopping distance, emissions every 3 years make it difficult to get companies to participate in standards development."	Bus and truck council for SAE. "ATA T&M Council will talk about how busy companies have been trying to meet standards."
10	21	T	YES	Technical side involvement is not enough.	Commercial vehicle industry needs to get on the SAE DSRC technical committee and bring up any issues.
10	21	T			Comment: AASHTO is good interface to policy issues.
10	22	T	YES	Possible that DSRC/safety will have problems with truck factors, and it will be too late to make changes if truck industry does not involve itself.	SAE committee needs more commercial vehicle folks. Need OEMs of cabs and trailers ("are they the same?"), and tier 1 staff.
10	24	T	YES	Need to know what the commercial vehicle issues are before it is late.	Some LV corporations have a commercial vehicle side. That will help.
10	24	T			U.S. DOT has a track 7, which will help create and involve experts.
10	25	T	YES	Truck community doesn't have the money to look into things that may not come to pass.	U.S. DOT could fund involvement.
10	25	T			Comment: Earlier SAE truck and bus council committee looked at antenna placement many years ago. Rear axle of trailer seemed viable.
10	26	T	YES	Technical standards.	Encourage industry.
10	26	T			Comment: Help avoid situation where a commercial vehicle issue "throws a wrench into things too far down the road."
10	27	T	NO OPINION		

Topic	Subject	Grp	Unique Issue?	Issue /Impact	Possible Resolutions and Comments
10	28	T	YES	Issues in this interview prove that commercial vehicle industry needs to be involved - someone has to chase these.	Track 7 of the NHTSA roadmap. Involvement by OEMs of the truck world.
11	1	B	YES	Rules of engagement with inspections changes when automated data transfer occurs. This is an issue.	
11	2	I		Lack of trailer information is a problem, especially since only a tractor-only solution is practical.	
11	3	I	YES	Antenna placement is a big deal.	
11	4	I		ROI case is needed. Otherwise DSRC will not happen.	
11	5	I	Yes	Antenna placement and BSM issues.	
11	6	B	YES	Need to address I2V issues, to get value added to truckers, carriers, state agencies.	Need to address I2V issues, to get value added to truckers, carriers, state agencies.
11	7	B	YES	Unclear what the cost/benefit payoff is, and why commercial fleets have to pay for crashes that are mostly passenger vehicle drivers' faults.	U.S. DOT should present a roadmap and guide to the commercial vehicle industry.
11	7	B	YES	Technical work is too far ahead of institutional issues, such as data privacy, FOIA, Sunshine laws.	
11	9	B	YES	EU harmonization (or lack thereof) is a problem. 802.11p is not approved, which means there is a use of prototype parts instead of final standards systems.	
11	21	T	YES	Concern is that trucking industry could kill Connected Vehicles deployment with political clout, if that industry doesn't see a compelling case for the technology.	Need to have, then make, the case to the trucking industry.
11	22	T	NO	None offered.	
11	25	T	YES	Need to have a different SAE committee for the commercial vehicle side examine the J2735, and then reconcile the two committees' views.	
11	25	T	YES	Truck community may be turned off by the LV-only club.	
11	25	T	YES	Need a firewall now on J1939 so that nefarious users cannot broadcast public messages that could lead aftermarkets to broadcast hard braking.	
11	27	T	YES	Application for DSRC on trains, for train-truck crashes that can have large consequences.	
11	28	T	YES	Concern that commercial vehicles won't have yaw rate and acceleration sensors for the BSM.	Could require OBE has such sensors in the certification process.
11	28	T		Lack of trailer information - how does this get tested?	

Appendix C-- Distillation of Interview Data into Respondent Feedback on Issues, Impacts, and Possible Actions

This appendix presents the results of distilling the Appendix B data to generate a comprehensive list of the respondents' feedback, which include:

- potential issues associated with each topic,
- insights or considerations in addressing these issues, and
- offerings of potential methods to resolve the issues.

The information in this appendix does not constitute the final findings of this project, but instead are considered to be inputs.

Two other observations are useful. First, some of the topics that were raised in the interviews are coupled with others in the interview. For instance, the topic of the SAE J2735 message set is related to the topic about obtaining accurate information on trailer size. Therefore related comments often appear under different topic headings, e.g., comments about how to obtain information about trailers appears in two places in this appendix. Thus the sections in this appendix need to be considered as a whole. One role of Section 4 in the main body is to pull together such threads and present a clearer and more concise description of the issues. The role of this appendix, however, is to give readers a summary of the interviews themselves without the project authors revising the content.

A second note on this appendix: not all respondents are experts in all areas. Therefore the lists below include square bracketed comments by the authors where the respondent feedback conflicts with other known information.

C.1 Standards and Message Sets

C.1.1 SAE J2735 basic message set and articulated vehicles

Ten of 11 respondents who were asked about this topic felt that there was an issue involved. Of all 10 specific questions posed, this one was rated as the most important.

Issues Raised by Respondents

Respondents noted that:

- Turning motions by articulated vehicles will induce false positive alerts and possibly late alerts, because the SAE J2735 BSM does not allow accurate representation of articulated vehicle boundaries and paths. (See the figure in Section 2) Various solutions were suggested, but there was not a consensus.
- There is a need to know trailer length. This is not unique to commercial vehicles, since light vehicles tow trailers as well, but the issue is especially important for commercial vehicles because their use of trailers is so common.
- SAE J2735 should not use the assumption that the position information is coincident with the center of geometry. [Authors of this report believe this is not an issue: Two other respondents noted that DSRC units can be configured so that the position information that is broadcast is for a point that is at a selectable offset from the GPS antenna.]

- The resolution of the vehicle weight signal needs to be changed to allow vehicle weights over 6,350 Kg. Weight is needed for stopping distance calculations for some safety applications, such as emergency electronic braking lights (EEBL). [This has been on the SAE DSRC committee's work list for awhile. The authors also note that stopping distances may be influenced more by brake maintenance issues than by weight.]
- The resolution of the vehicle length signal needs to be corrected. [Authors of this report believe this to be unnecessary for commercial vehicles: the VehicleLength variable in the standard allows lengths up to 163.83 m.]
- Two antennas on the same vehicle need to be coordinated to avoid interference patterns that could affect communication performance.

<u>Insights, assumptions, and considerations</u>

The telephone interview resulted in the respondents offering many insights into the issues raised above. These are summarized below.

- The changes to SAE J2735 BSM depend on whether the approach to articulated vehicles is to have the towing unit, e.g., tractor, broadcast information for the entire combination vehicle, or whether each unit is broadcasting its own information.
- Some commercial vehicles will include tractors that know some information about the trailers from safety systems. This would include weight, but probably not length.
- Tractor-only solutions are attractive because it reduces the number of units and the rate of penetration into the fleet. Retrofitting trailers is complicated (to be discussed elsewhere). However, antennas on trailers are possible since there is power.
- Doubles and triples (two and three trailers) complicate the possibility of estimating length with a tractor-only solution.

<u>Possible approaches to resolving these issues, as offered by interviewees</u>

Although the interview did not request suggestions for how to resolve the issues described above, the respondents did offer several thoughts:

- The SAE J2735 basic safety message should be updated to allow for articulated vehicles. The challenge in doing this is answering the following questions:
    - Shall the approach be a tractor-only solution, and if so, how does the tractor OBE know about the trailer parameters?
    - Shall the approach be to assume the trailer(s) is providing information to the tractor? Such an approach would require new hardware to be installed on trailers. The respondents noted that such hardware could either be other DSRC-enabled systems, or unintelligent data provider information. (See the trailer information discussion below for more on the challenges of installing equipment on trailers.)
    - Would an approach work in which the tractor OBE estimates the trailer parameters? (See discussion later on this item.)

  There is substantial discussion of these options under the topic of trailer information.

- At the system level, there needs to be certainty that remote vehicles are able to reconstruct the boundaries and path of the articulated vehicles, to the accuracy needed for safety applications. Currently, remote vehicles can know from the BSM that the vehicle ahead is articulated (assuming that vehicle itself is broadcasting that fact), and it could associate the yaw rate and heading of the signals as applying to the towing unit, but then it would need to make assumptions about the tractor and trailer configurations in order to estimate paths.
- One respondent with experience in the SAE truck and bus standards community suggested that a commercial vehicle group needs to be convened in order to review and propose changes to the existing standard. Several respondents cited the need for commercial vehicle industry technical experts to be involved in the standards development. (See the topic of industry involvement for further feedback on that topic.)

C.1.2 IEEE 1609 Protocol stack

None of the seven respondents felt there would be an issue with these protocols. This was expected, but it was considered prudent to verify that experts in these standards agreed.

C.2 Obtaining Trailer Information

Trailer information was discussed in two candidate issue areas. Seven of nine respondents who were queried directly said that there was a related issue (this is 78%). Note that discussion occurred as well under the topic of the SAE J2735 message set.

<u>Issues Raised by Respondents</u>

Issues raised by respondents include:

- Having drivers or fleets manually enter information to define the length and weight of a trailer is not likely to be a successful solution. An automated solution is necessary. (One respondent said it should be the responsibility of the commercial vehicle fleets to solve this issue.)
- Retrofitting trailers was seen widely as a big issue because of the cost. Trailers outnumber tractors by several-fold, and they are older and often not owned by the same company that owns or operates the tractors. “Investing money on trailers is something people are not interested in doing.”
- Trailers have a longer life than tractors, so that relying on newly equipped trailers to populate the U.S. fleet would cause a very slow introduction of DSRC-equipped trailers.
- Trailers are diverse in shape and size and use, so the retrofitting of equipment on trailers is not as straightforward as doing so on tractors or passenger vehicles.
- Investments in the commercial vehicle industry have been stressed by other recent regulations, so that the industry is not likely to be looking forward to another investment.

<u>Insights, assumptions, and considerations</u>

These are summarized below.

- Advanced safety systems such as roll stability systems estimate trailer weight, but not mass. This data could be useful.

Possible approaches to resolving these issues, as offered by interviewees

- Equipping trailers may come about through non-safety applications, such as wireless roadside inspections.
- Use weight in motion sensors at scales (with a means to estimate speed) to estimate trailer lengths, based on axle spacing, and then pass that information to the tractor.
- One way to populate the BSM with trailer information is to estimate the approximate weight and then populate the length by some other means.

C.3 DSRC Communication and Physical Factors of Large Vehicles

C.3.1 Blockage, Multipath Effects, and Ground Reflection Nulls

Issues with communication and application-level performance that are induced by the physical factors of large vehicles are expected by all 11 respondents who were asked about this topic. This was one of the two highest-rated topics as well. The respondents had mixed views on whether safety application performance will be affected by some of these issues. Comments by researchers are appended to some of these, and are enclosed within square brackets [ ] .

Issues Raised by Respondents

Respondents expected at least three mechanisms to have the potential to affect communication performance: blockage, multipath effects, and ground-reflection nulls. The individual issues are:

- Large vehicles that are located between two DSRC-equipped vehicles have been observed to substantially affect the communication between the DSRC-equipped vehicles. Thus the large vehicles may affect the communication and application-level performance of DSRC systems on passenger vehicles as well as large vehicles.
- Large vehicles may often be “self-blocking,” that is, have physical elements that obstruct the vehicle’s own DSRC antennas from direct line of sight with other vehicles. This may create “shadows,” in which a remote vehicle is not communicating well with the large vehicle. An example is a vehicle (or any type) that is closely following a tractor-trailer that has antennas on the tractor alone.
- Large surfaces induce reflections of DSRC signals, creating multipath effects that can lead to a decrease in how many messages are successfully received. This may add latency to decisions made at the application level by nearby vehicles.
- Multipath effects have a positive side as well: the reflections make possible the reception of signals from antennas that do not have a direct line of sight.

- Antennas that are mounted high off the ground, on large commercial vehicles, will alter the position of "ground nulls." This distance should be identified for tall commercial vehicles and the impacts ascertained. Ground nulls result from reflections of DSRC signals off the ground, such that for a pair of DSRC antennas at specific distances, there is a specific distance at which the DSRC signals are self-canceling because of the phase shifts in the direct and the reflected signals.

Some respondents said that the working range of the DSRC units would be affected by the blockage effects. Respondents agreed that degradation in communication due to blockage and multipath effects would result in latencies in applications. Some felt that these latencies would have significant impact on application performance, while a minority of others felt it would not. Some respondents suggested that testing was needed to determine this impact.

The impact of the ground nulls being at a different (probably lesser) range was not known, but those who introduced this issue in the interview felt it was worth determining the ranges at which the nulls would occur, and whether it overlaps with critical timing for applications.

<u>Possible approaches to resolving these issues, as offered by interviewees</u>

- Receiver technology is progressing. The challenges of reception in the midst of multipath effects may be mitigated over time by the continuing progress in radio technology. Of course, it is important that industry has a target functionality, in order to drive technology developments.
- One approach to reducing the self-blockage issues cited above is the use of two or more antennas to increase the space around the vehicle that has direct line of sight to at least one antenna. For example, on a tractor that is towing a large trailer, a common idea from the respondents is to mount an antenna on each side view mirror. There are implementation issues with this: the system should avoid doubling the amount of DSRC signals in the area, and avoid self-cancellation effects. This might be done by using hemispherical antenna patterns, or customized logic within the transponding or receiver systems.
- Some respondents suggested the idea of installing DSRC communications on trailers, either as an independent device that broadcasts its position and motion, or one that is coordinating with the tractor unit OBE, as a coordinated device.

C.3.2 Impact of Large Vehicles on Scalability

"Scalability" is used here to refer to the ability of DSRC-connected vehicles to function properly in areas with a high number of DSRC-broadcasting elements (either vehicles or fixed sites). Five of 12 respondents felt that commercial vehicles would introduce an issue related to scalability. This issue was rated in the bottom 4 of 10 issues posed to respondents.

A key assumption that several respondents mentioned was that the current proposal that channel 172 in the DSRC spectrum would be dedicated to V2V safety messages. The importance of that assumption for scalability with commercial vehicles is that it removes the possibility that the encrypted messages that will be used by commercial vehicles for mobility and regulatory purposes would affect safety message throughput.

Issues Raised by Respondents

A few potential issues were raised:

- Blockage and multipath effects induced by large vehicles may compound the problems of DSRC communication in congested areas. These effects may exacerbate the delays that may occur as receivers attempt to achieve successful reception of signals that are reflected, that are colliding with other messages, and so on.
- Citizen band (CB) radios are common on some classes of commercial vehicles. These were mentioned as potential sources of communication problems. While this was mentioned by a respondent in a discussion about scalability, it is not unique to the scalability concern.
- There have been thoughts of reducing DSRC transmission power in congested areas, in order to reduce the scalability concerns, reported two respondents. Reducing transmission power while traveling near trucks led them to wonder whether this would lead to problems communicating with, or past, large vehicles because of their blocking effect. (Two other respondents said that changing power does not help alleviate the blockage problem of larger trucks.)

Insights and considerations

Respondents offered insights into the issues raised above, including:

- Larger vehicles mean that there can be fewer DSRC broadcasting units, just because of the space they occupy on the road. Many respondents felt that this would more than compensate for blockage and multipath effects.

Possible approaches to resolving these issues, as offered by interviewees

Although the interview did not request suggestions for how to resolve the issues described above, the respondents did offer several thoughts:

- Including large vehicles in any scalability testing was suggested, in order to determine which effects introduced by large vehicles would dominate: positive effects of lowering the spatial density of DSRC broadcasters, or exacerbating receivers' challenges by adding to multipath and blockage effects.
- Regarding CB radios, it was suggested that the testing should include those as well. CB operates in a much different band, but it is common for truck drivers to use unlicensed, high power amplifiers to extend the range of those radios, and the overpowered antennas will be mounted in areas where DSRC antennas may be located.

C.4 Absolute and Relative Positioning Near Large Vehicles

Two of 11 respondents for this topic felt that there was an issue associated with this topic, and 2 others felt there might be an issue. Seven of 11 (64%) felt there was not an issue associated with this topic.

This is one of four issues for which fewer than 60 percent of respondents agreed that there was a issue unique to commercial vehicles. One respondent noted that this issue is not unique to relative positioning – that absolute positioning of a smaller vehicle near a tall vehicle could affect absolute position as well.

Issues Raised by Respondents

Some respondents felt that one mechanism hypothesized by the interviewers was appropriate:

- Errors in relative position estimates between two vehicles can occur due to differences in GPS satellite sets being used by a tall vehicle and a smaller vehicle traveling adjacent to the tall vehicle.

Most respondents felt that the hypothesized issue of a small vehicle's GPS signals being degraded by multipath effects from a nearby larger vehicle was a special case of the so-called "urban canyon" situation. (Note that the authors wonder whether there is a significant difference, since nearby vehicles in an urban canyon still see the same satellite set, while a smaller vehicle traveling adjacent to a larger vehicle does see a different sky than its neighboring tall vehicle.)

Some respondents referred to an ongoing project at CAMP addressing issue of GPS receivers, and assumed that tall vehicles would be used in that study. That may have reduced the number of respondents who felt that there was a commercial vehicle-unique issue.

Insights, assumptions, and considerations

The respondents offered insights into the issues raised above. These are summarized below.

- There are two methods for sharing position data between vehicles using the SAE J2735 message set. The simpler case is exchanging estimates of position and other GPS-derived variables. The second is sharing lower-level information from GPS that allows for more accurate "differential" corrections by neighboring vehicles, which employs the RTCM v3.0 message. The latter method requires many more bytes to be exchanged, but mitigates the size of the errors that occur when the two vehicles have different satellite sets.
- Receivers for GPS continue to improve.

Possible approaches to resolving these issues, as offered by interviewees

Although the interview did not request suggestions for how to resolve the issues described above, the respondents did offer several thoughts:

- Include tall vehicles in the ongoing CAMP studies of GPS receivers, and development of requirements for those receivers. This will help determine whether there is a unique issue here, and how large of an issue it may represent.
- Some respondents said that dead-reckoning strategies can help receivers determine when a jump in latitude and longitude have occurred that are unrelated to actual vehicle position.

C.5 Aftermarket and Retrofit Safety Devices

This topic addressed vehicles that use the J1939 bus, which is largely class 7 and 8 vehicles. Four of nine respondents felt there was a related issue.

Issues Raised by Respondents

- Aftermarket devices must put DSRC antennas outside the cab, for instance, on the roof or mirrors.
- J1939 is not well populated on all vehicles. The device manufacturer must discover which vehicles have which data signals populated, determine the signal qualities, and customize the aftermarket unit to that vehicle.
- Need a countermeasure to phony signals that a hacker could broadcast onto the J1939, which would be broadcast by an authenticated DSRC system.
- How will the aftermarket device provider know where the antenna(s) should go?

Possible approaches to resolving these issues, as offered by interviewees

- Develop a viable security approach to minimize the effects of a hacker broadcasting false signals onto the J1939 bus.

C.6 Certification and Application-Level Testing

C.6.1 Certification

Seven of 12 (58%) believed that there were commercial vehicle-specific issues with certifications, and 4 more (33%) responded that there may be an issue. Thus only 1 of 12 (8%) felt there would be no issue.

Issues Raised by Respondents

Issues raised by respondents included:

- Three respondents said that there should be vehicle-level certification, in addition to device-level certification. Two other respondents appeared to assume vehicle-level certification.
- For any vehicle-level testing, the commercial vehicle tests need to be tailored to the appropriate vehicle and its configuration, for instance, with various OEM-offered roof fairings, if those may affect DSRC or GPS performance.
- If transmission power is increased around large vehicles, then this attribute needs to be tested.
- Certification at vehicle level depends on antenna configuration and placement. How will this be done with so many different configurations of vehicles and so many different antenna configuration possibilities?

- Aftermarket device certification: how will this be done if the communication performance depends on the vehicle and trailer?
- Commercial vehicles often undergo significant change during life, or even (for vocational vehicles) before the first purchase. Can original certification remain a useful indicator of function?
- Should certification for a commercial vehicle require testing with a high-powered CB radio antenna nearby?

<u>Insights, assumptions, and considerations</u>

The telephone interview resulted in the respondents offering many insights into the issues raised above. These are summarized below.

- A trade group is currently studying certification issues. A few respondents commented that there may be solutions to some of this topic's issues resulting from that.
- Commercial vehicle radios may be variants of light vehicle versions, but with the ability to handle different antenna configurations (including multiple antennas or higher-profile antennas), trailer information, and possibly other differences.

<u>Possible approaches to resolving these issues, as offered by interviewees</u>

Respondents offered a few thoughts:

- Respondents differed on whether antenna placement on commercial vehicles should be "established," or whether only functional performance is needed.

C.6.2 Commercial Vehicles and Application Testing

Six of eight respondents (75%) who were asked about this topic felt there was a related issue. This was a moderately important issue, according to the ratings of the respondents, as reported in Section 3 of the report.

<u>Issues Raised by Respondents</u>

Respondents cited the following possible issues that are unique to commercial vehicles:

- It may be necessary to understand the communication performance degradations due to blockage and multipath effects in common pre-crash situations, and then define a "standard" commercial vehicle and its DSRC configuration. This would be included in test procedures so that V2V devices are exposed to realistic conditions.

<u>Possible approaches to resolving these issues, as offered by interviewees</u>

Although the interview did not request suggestions for how to resolve the issues described above, the respondents did offer several thoughts:

- Testing of application function should be done with a mix of remote vehicle types, no matter which vehicle type hosts the application.
- "At least part of the testing needs to be in the real world traffic environment."
- Tests should include typical values for size, loads, and stopping distances when large vehicles are used.

C.7 Involvement of Commercial Vehicle Industry in Discussions

Twelve of 15 respondents to this question said that more involvement was necessary (80%). A thirteenth respondent had mixed thoughts on this issue, so that 87 percent felt there was, or could be, an issue related to this topic.

<u>Issues Raised by Respondents</u>

- Six respondents said that there was not enough involvement on the technical issues, e.g., the SAE DSRC committee.
- Six respondents said that there needed to be a business case for the industry or the involvement would not come.
- Three respondents mentioned that there were already pressures to meet new regulations, therefore commercial vehicle experts from industry would likely not be available.
- There is fear on two respondents that unless the trucking industry gets involved, the entire connected vehicle effort will not pan out.
- "The trucking community doesn't have the money to look into things that may not come to pass."
- Industry is confused by current outreach efforts, said one respondent. There seem to be unrelated programs at each of the U.S. DOT agencies.

<u>Possible approaches to resolving these issues, as offered by interviewees</u>

- Ideas about forums were offered by respondents including:
    - ATA T&M Council (for fleets);
    - Pairing workshops with meetings such as CVSA (has been a good U.S. DOT strategy, the respondent said);
    - Have forum for fleets: what apps would create a return on investment?
    - SAE commercial vehicle standards committees; and
    - SAE bus and truck meetings.
- Government funding, similar to sponsorship of CAMP, would help the industry afford involvement in standards committees

C.8 Other Issues

All 16 respondents were asked whether there were important issues that had not been covered in the interview. The issues that were suggested, which were not already discussed above, include:

- It was unclear to one respondent why commercial vehicles have to pay for technologies to prevent crashes that s/he said were largely caused by passenger vehicle drivers.
- Technical work is too far ahead of institutional issues, such as data privacy, FOIA, and Sunshine laws, said a respondent.
- Harmonization of standards is a problem. For example 802.11pp is not finalized. Also, the EU standards are not the same as the U.S. standards for DSRC.
- Need to have a separate SAE commercial vehicle standards committee review and negotiate solutions with the current light vehicle-dominated committee.
- One light vehicle respondent was concerned that the trucking industry could kill the connected vehicles programs, if there isn't a widespread view that there was a real bottom-line benefit.
- Consider having a train-truck crash safety application.
- Need to address V2I applications in parallel, in order to woo the industry.
- A return of investment case needs to be made for any penetration.

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