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Field Demonstration of Heavy Vehicle Camera/Video Imaging Systems: Final Report

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13. ABSTRACT (Maximum 200 words) To help drivers monitor the road and to reduce blind spots, Camera/Video Imaging Systems (C/VISs) display video from cameras mounted on the truck's exterior to drivers using displays inside the truck cabin. This report investigated drivers' performance with C/VISs in a real-world trucking operation. Twelve commercial drivers' performance with and without a C/VIS was continuously recorded while they each drove for four months. Half of the drivers used a commercially available C/VIS that had a side-view camera on each fender. The other drivers used an advanced C/VIS (A-C/VIS) that had side-view cameras, a rear-view camera, and night-vision capabilities. The results show that when a C/VIS was provided: 1) drivers' involvement in safety-critical events (SCEs) did not change, 2) the probability that drivers looked forward did not change, 3) drivers were more likely to use the C/VIS at night and when making right lane changes, and 4) drivers indicated that the C/VISs helped them become aware of surrounding objects and merge into traffic. In terms of disbenefits, some drivers indicated that glare from the commercially available C/VIS monitors, as positioned to specifications, could be uncomfortable at night. The A-C/VIS's advanced features were highly rated by drivers. The rear-view camera was also used more than the left or right fender cameras.				
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EXECUTIVE SUMMARY

INTRODUCTION

Large blind spots exist along the sides, rear, and front of tractor-trailers (Figure 1) (Federal Motor Carrier Safety Administration, 2006). To help commercial motor vehicle (CMV) drivers monitor the road, and to reduce blind spots, Camera/Video Imaging Systems (C/VISs) use video cameras mounted on the truck and/or trailer to provide a view of the area around the tractor-trailer via monitors inside the truck cabin (Figure 2) (Wierwille, Schaudt, Gupta, Spaulding, & Hanowski, 2008). By providing information not available on the typical mirror configuration, C/VISs can help drivers execute lane changes and backing maneuvers, and provide a countermeasure to blind-spot related crashes.

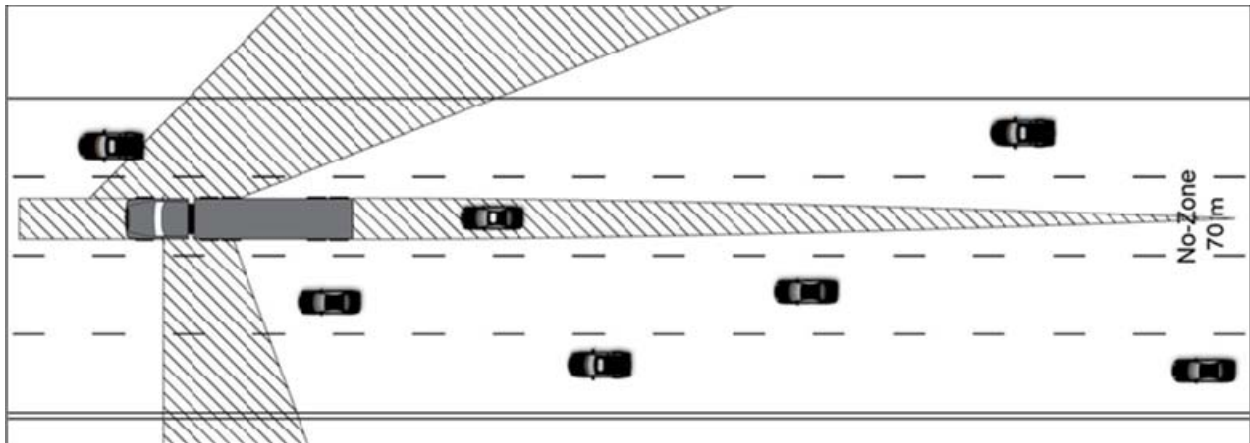


Figure 1. Blind Spots—also Called No-Zone—Around a Tractor-Trailer, Adapted from AAA Public Affairs (2000)



Figure 2. Left: C/VIS Camera Mounted on Trailer; Right: Video Image from C/VIS Camera

PURPOSE

The purpose of this study was to more extensively evaluate the favorable results from previous C/VIS test-track research (Wierwille, Schaudt, Blanco, Alden, & Hanowski, in press; Wierwille, Schaudt, Gupta, et al., 2008; Wierwille, Schaudt, Spaulding, et al., 2008) by investigating the implementation of C/VISs in a real-world trucking operation. This was accomplished by performing a Technology Field Demonstration (TFD), where CMV drivers' performance with and without a C/VIS was unobtrusively recorded using the naturalistic driving study methodology. The focus of the TFD was to determine: (1) the effect of C/VISs on drivers' involvement in safety-critical events (SCEs), (2) the effect of C/VISs on drivers' lane-change performance, and (3) drivers' opinions of C/VISs. The potential disbenefits of C/VISs were concurrently investigated. This document reports the results of all the tasks performed in this project.

BACKGROUND AND PROBLEM SCOPE

Work began by assessing the magnitude of the large-truck crash problem C/VISs stand to address. Analyses of crash databases, including the Large Truck Crash Causation Study (LTCCS) database, were performed and revealed that fatal and severely injurious truck crashes resulting from: 1) improper lane changes, 2) turning across the path of another vehicle, 3) improperly backing the vehicle, and 4) making a blind-spot-related driver error comprised 6.8 percent of the LTCCS database. Furthermore, an analysis of the National Automotive Sampling System/General Estimates System (GES) 2009 data set suggests that improper lane changes, merges, and turning maneuvers account for 20,311 crashes, which is 6.3 percent of all truck crashes. These types of crashes were found to account for 2.0 percent of fatal and incapacitating truck crashes (165 crashes), 6.1 percent of injurious truck crashes (1,426 crashes), and 7.4 percent of non-injurious truck crashes (18,719).

Background information was also obtained to develop an understanding of C/VISs. First, existing C/VIS research was synthesized into a literature review. Interviews with fleet managers were also held to assess their opinions of the C/VISs. A major finding from these interviews was that fleet managers would be willing to invest in a blind spot countermeasure if the return on investment occurred within 2.5 to 3 years. The information gathered from this process was used to inform the design of the TFD and develop a cost-effective, roadworthy C/VIS.

THE ADVANCED-C/VIS

The C/VISs utilized in the earlier test-track studies were excellent for evaluating the C/VIS concept, but were impractical for use in the TFD owing to their large size and moving parts (Wierwille et al., in press). As such, a significant amount of work was performed as part of the current effort to develop a roadworthy and robust C/VIS. The final design was termed the Advanced-C/VIS, or A-C/VIS, because it met the established C/VIS daytime performance specifications (Wierwille, Schaudt, Gupta, et al., 2008), and encompassed the day, night, clear, and inclement weather operational window of the Enhanced-C/VIS, or E-C/VIS (Wierwille et al., in press). The A-C/VIS had the following main elements:

- Three cameras were mounted on the truck: a camera on each fender pointing back along the trailer, and a rear wide-angle look-down camera mounted on the top-center of the back-side of the trailer (Figure 3). The side cameras' field of view (FOV) was 45 degrees, providing coverage and image distortion similar to the fender-mounted mirrors. The rear camera's FOV was 102 degrees and provided coverage of the rear roadway (as far back as 9.7 m as measured from the center of the trailer) as well as the adjacent lanes. The coverage of the road provided by the A-C/VIS is shown in Figure 4.
- Three monitors were mounted inside the cabin: one at the top of the left A-pillar, one at the top-center of the windshield, and one at the top of the right A-pillar (Figure 5).
- The Driver-Vehicle Interface (DVI) was built into the left monitor and allowed all functionality to be accessed with one button press (Figure 6). The functionality included switching between color (day mode) and monochrome (night mode), adjusting the monitor brightness, activating the object detection feature (which traced white lines around objects to enhance the video image), and adjusting the amount of object detection (the driver could select the preferred thickness of the lines).
- Infrared illuminators mounted on the truck and trailer were used by the A-C/VIS to provide night-vision capabilities during night mode (Figure 7).



Figure 3. Placement of A-C/VIS Fender and Trailer Cameras

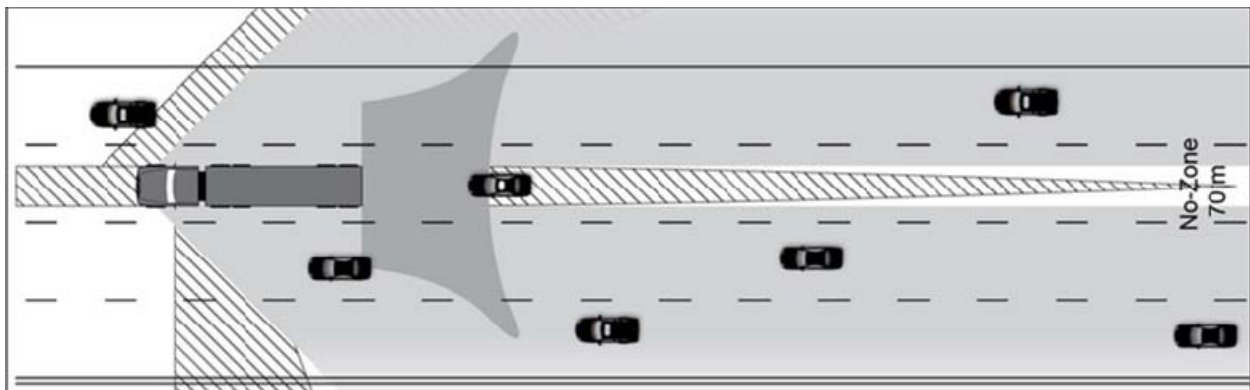


Figure 4. Coverage Provided by A-C/VIS Cameras Shown by Grey Shading. No-Zone Shown by the Diagonal Lines



Figure 5. Placement of A-C/VIS Monitors in Truck Cab



Figure 6. The A-C/VIS DVI Built Into the Left Monitor



Figure 7. Infrared Illuminators Mounted on Truck and Trailer

THE SELECTED COMMERCIALLY AVAILABLE C/VIS

The TFD concurrently aimed to investigate drivers' performance with a commercially available C/VIS. Five C/VISs were reviewed and a trade study identified VTECH USA, LLC's Sidetracker system as ideal for the TFD (V-TECH USA LLC, 2009). VTECH USA provided a specification for installing the Sidetracker system. The main elements of the Sidetracker system were as follows:

- This C/VIS was a cab-only solution, where one camera was mounted on the left fender pointing back along the trailer, and another camera was mounted on the right fender pointing back along the trailer (Figure 8). Each camera's FOV was 88 degrees, which provided wide coverage but also increased image distortion. The coverage provided by the commercially available C/VIS is shown in the grey-shaded area in Figure 9.
- Two monitors were mounted on the dash inside the truck cabin, one on the left side of the steering wheel, and one on the right side of the steering wheel (Figure 10). Figure 11 shows a close-up of the right monitor.
- This C/VIS's settings were selected through an on-screen menu and included the ability to adjust the brightness, contrast, tint, and color of the video image.



Figure 8. Placement of Commercial C/VIS's Cameras on Left and Right Fenders

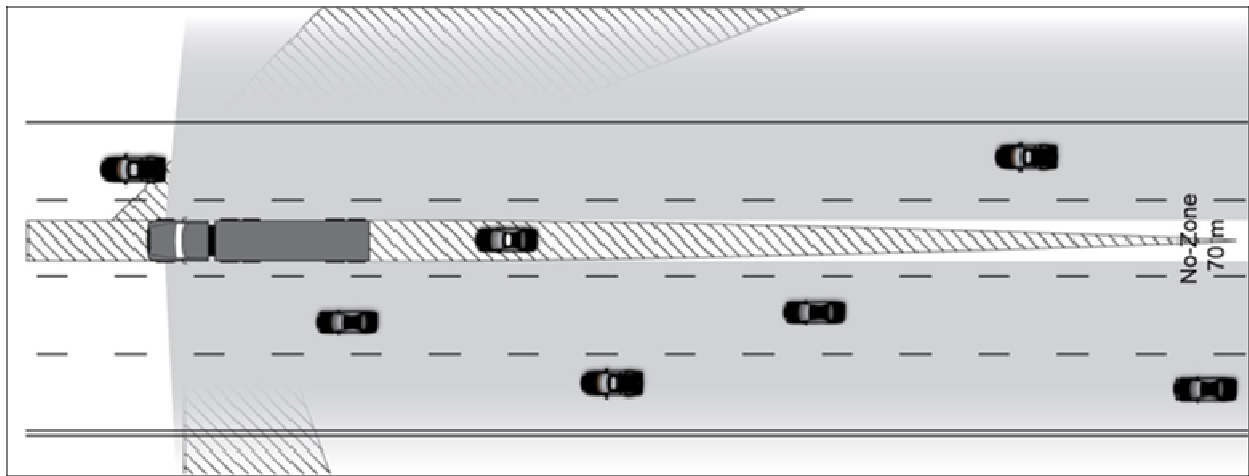


**Figure 9. Coverage Provided by Commercial C/VIS Cameras Shown in the Shaded Area;
No-Zone Shown by the Diagonal Lines**



Figure 10. Placement of Commercial C/VIS's Monitors on Truck Dash



Figure 11. Close-Up of Right Commercial C/VIS Monitor

PRELIMINARY TESTING

Similar to the test-track studies performed with the E-C/VIS (Wierwille et al., in press), static evaluations of the A-C/VIS and the commercially available C/VIS were performed. Here, personnel from the research institution served as participants. Each participant was asked to identify the location and type of object placed around the tractor-trailer. All testing took place at night in an unlit parking lot. The results showed that participants identified the locations of a pedestrian and a stop sign with accuracy that was comparable to the object detection scores obtained by CMV drivers with the E-C/VIS in the test-track studies (Wierwille et al., in press)

(Figure 12). Testing also revealed that the untrained participants correctly identified significantly more objects (i.e., a stop sign, a pedestrian, and a vehicle with its headlights on and off) with the A-C/VIS than they did when using the commercially available C/VIS system in the unlit area. This was predominantly because the A-C/VIS offered a third rear-view as well as night-vision capabilities, while the commercially available C/VIS did not. It should be noted that participants never failed to detect a vehicle with its headlights on with either C/VIS.

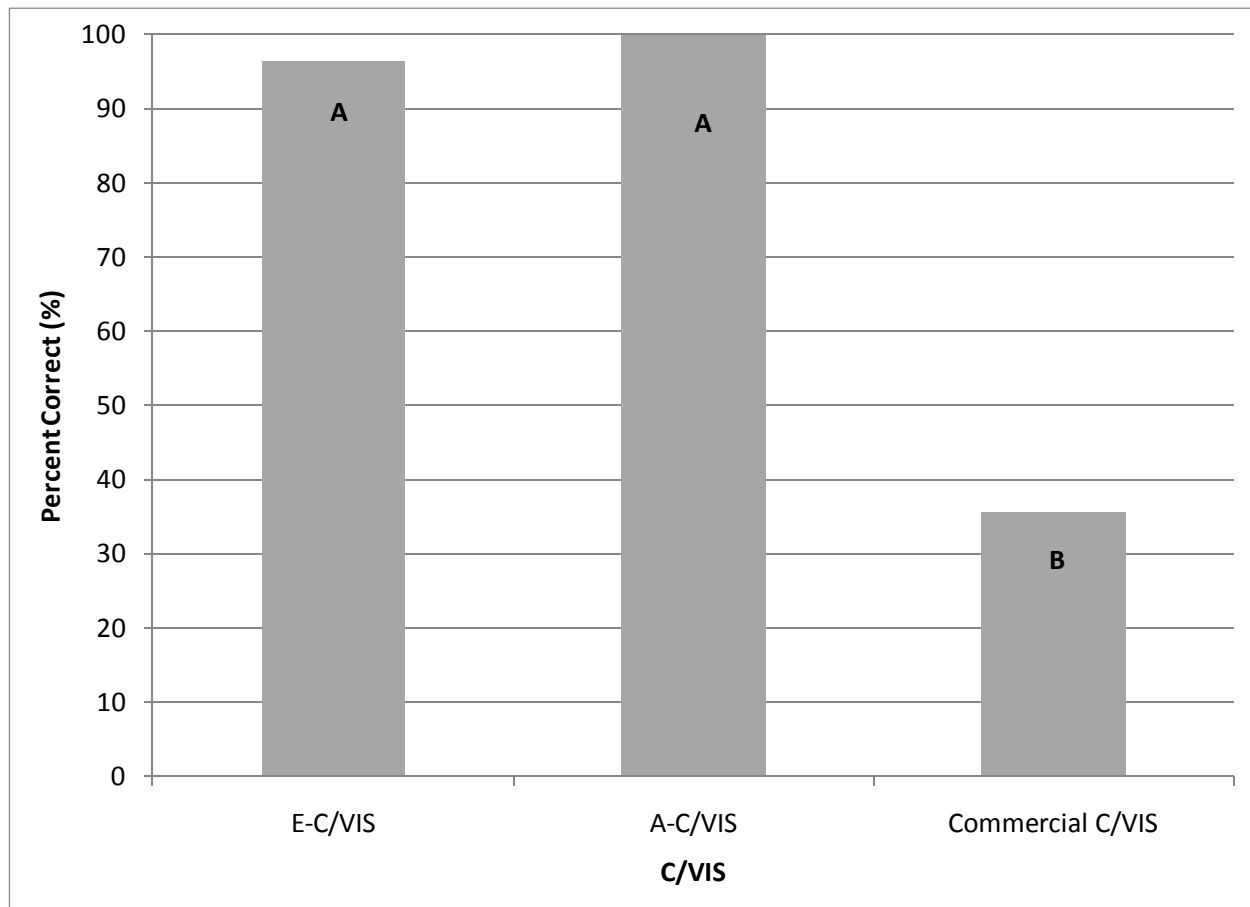


Figure 12. Participants' Object Detection Accuracy for a Pedestrian and a Stop Sign (Different Letters Represent a Statistically Significant Difference)

TECHNOLOGY FIELD DEMONSTRATION METHODS

With the C/VISs selected and an understanding of each system's capabilities, the TFD was initiated. Twelve CMV drivers from Schneider National's Winchester, Virginia operation participated in this research effort. Each driver drove one truck that had either an A-C/VIS or a commercially available C/VIS installed. Schneider National provided six Freightliner C120 tractors that remained permanently coupled to 48-ft trailers over the course of the 12-month data-collection interval (Figure 13). Each driver drove a truck for one month with the C/VIS disabled (comprising the Baseline condition), and three months with the C/VIS enabled (comprising the Test condition) (Figure 14). Video of the roadway and the drivers' face (Figure 15), as well as various vehicle sensor data, were continuously recorded. Drivers completed questionnaires regarding their driving performance and opinions of the C/VISs every two weeks. After

completing their four months with the assigned C/VIS, some drivers volunteered to drive with the other C/VIS for 10 minutes and complete questionnaires regarding their attitudes towards the other system. Some drivers also agreed to perform a 1-month follow-up interview to assess their opinions towards C/VISs.



Figure 13. Freightliner C120 Tractor with 48-ft Trailer

1 Month		3 Months	
Baseline		A-C/VIS - Test	
Baseline		Commercial C/VIS - Test	

Figure 14. Experimental Conditions for the TFD



Figure 15. Eight Camera Images Multiplexed into Two Images

DRIVERS' INVOLVEMENT IN SAFETY-CRITICAL EVENTS

The TFD investigated whether driving performance changed with a C/VIS by analyzing drivers' involvement in Safety-Critical Events (SCEs). Here, it was hypothesized that a C/VIS would allow drivers to make fewer and shorter glances to their mirrors to obtain information about objects not in their forward view. It was therefore expected that C/VISs would allow drivers to spend more time looking forward, become less likely to miss an unfolding conflict, and experience fewer SCEs. However, a reduction in the mean SCE rate was not observed. Drivers' mean SCE rate was 5.2 SCEs per 100 hrs of driving in both the Baseline and Test conditions ($p > 0.05$). Drivers' performance pertaining to the two C/VISs also did not change. The mean SCE rate for drivers of A-C/VIS-equipped trucks was reduced from 5.9 to 5.7 ($p > 0.05$), while the mean SCE rate for drivers of commercial C/VIS-equipped trucks was increased from 4.5 to 4.7 ($p > 0.05$). Drivers' mean SCE rate by fault assignment was also investigated. The mean SCE rate for SCEs in which the driver was at fault did not differ across the four months in the study ($p > 0.05$). It is noteworthy that this finding suggests that drivers' performance did not worsen when using a C/VIS.

A concern with placing visual displays inside a vehicle is that they take drivers' visual attention away from the forward roadway and may increase drivers' crash risk. An earlier study had shown that allocating visual attention to adjust the instrument panel (which is an existing visual

display) increases drivers' crash risk by 1.25 times (Olson, Hanowski, Hickman, & Bocanegra, In Press). Drivers' visual behavior during the 8 s leading up to an SCE was measured by manually reducing video footage of the driver's face on a frame-by-frame basis. Obtrusive eye glance measurement equipment was not used in this study, allowing drivers' natural eye glance patterns to be observed. Four cameras were used to capture video of the driver's face to increase the accuracy of the eye glance reduction. It was found that drivers' mean probability of looking forward did not significantly change when driving with a C/VIS. The drivers' mean probability of looking forward was 0.86 in the Baseline condition and 0.87 in the Test condition ($p > 0.05$). This finding suggests that the C/VISs did not compel drivers to look away from the forward roadway.

DRIVERS' LANE-CHANGE PERFORMANCE

C/VISs are designed to help drivers see objects around their vehicles and execute lane-change maneuvers. Previous test-track research showed that CMV drivers were able to better judge whether there was clearance between the trailer and an adjacent vehicle, as well as better assess the magnitude of this clearance, when provided with a C/VIS (Fitch, Wierwille, Schaudt, & Hanowski, 2008; Wierwille et al., in press; Wierwille, Schaudt, Spaulding, et al., 2008). This research also showed that drivers shifted their visual attention from the west coast/convex mirrors to the C/VISs when the C/VISs were provided. The research also shows that the amount of visual attention allocated to the forward roadway did not change. At the same time, it was also found that the clearance between the tractor trailer and an adjacent vehicle decreased from 6.1 m to 4.2 m when a C/VIS was provided (tests were performed at 40 km/h), presumably because drivers were able to more accurately determine when there was sufficient clearance with the C/VISs (Wierwille, Schaudt, Spaulding, et al., 2008). The TFD analyzed various aspects of drivers' lane-change performance to investigate whether similar changes in driver behavior would be observed when drivers used a C/VIS during their daily employment duties. These aspects of lane-change maneuvers are discussed below.

Clearance to Adjacent Vehicle

Drivers' mean clearance to an adjacent vehicle was not found to significantly change when changing lanes with a C/VIS. The mean clearance to an adjacent vehicle for drivers of A-C/VIS-equipped trucks was 36.91 m in the Baseline condition, and 35.81 m in the Test condition ($p > 0.05$). The mean clearance to an adjacent vehicle for drivers of commercial C/VIS-equipped trucks was 37.86 m in the Baseline condition, and 37.32 m in the Test condition ($p > 0.05$). The data indicate that drivers did not abuse the enhanced visibility offered by the C/VIS by cutting in closer to adjacent vehicles when changing lanes. It is worth noting that the training administered to drivers using the A-C/VIS specifically warned of vehicles being closer than they appeared in the center monitor, and demonstrated how to use the C/VIS when changing lanes (Figure 16). Please note that the red and orange lines shown in Figure 16 were not present on the monitor.

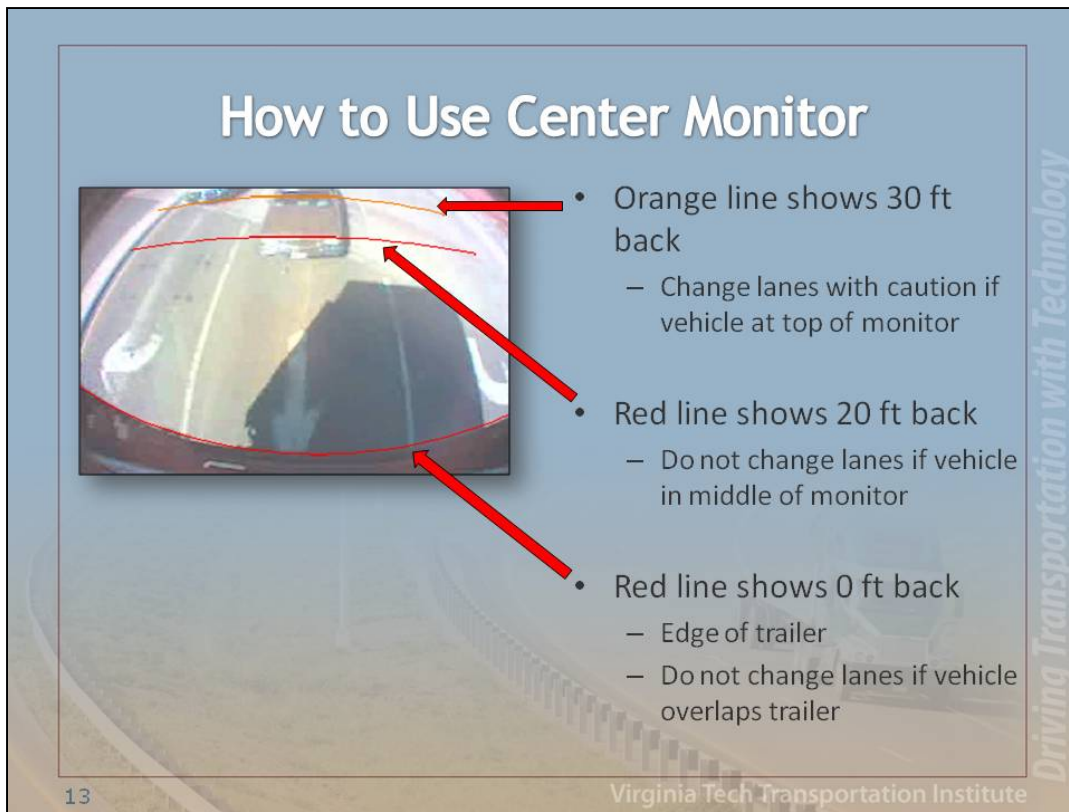


Figure 16. Excerpt from A-C/VIS Training Manual on Proper Use of the Center Monitor

Drivers' mean clearance significantly differed based on lane-change direction ($p < 0.0001$). Drivers' mean clearance to an adjacent vehicle was 53.31 m when making left lane changes, while it was 31.63 m when making right lane changes. The majority of left lane changes arose from drivers initiating a pass of a slow lead vehicle, while the majority of right lane changes were drivers returning to the right lane after passing a lead vehicle. Drivers' clearance data were placed into five clearance categories for left and right lane changes: 1) overlapping, 2) less than 6 m, 3) less than 12 m, 4) less than 18 m, and 5) greater than or equal to 18 m. However, the relative frequency of lane changes in each of these clearance categories was not found to significantly differ when driving with a C/VIS ($p > 0.05$). Overall, the data suggest that drivers did not abuse the enhanced views provided by the C/VISs when making either left or right lane changes.

When making right lane changes, drivers' mean clearance during clear nighttime conditions was found to be significantly longer than their clearance during clear daytime conditions ($p = 0.0117$). However, drivers were not found to change their clearance to an adjacent vehicle when driving with a C/VIS across the environmental conditions ($p > 0.05$).

Drivers' Visual Behavior

Drivers did not look at the C/VIS during all of the sampled lane changes. When considering the lane changes in which drivers looked at the monitors at least once, drivers of A-C/VIS-equipped trucks looked at the right monitor in 11 percent of the right lane changes, and at the center

monitor in 20 percent of the right lane changes. Drivers of trucks equipped with the commercially available C/VIS looked at the right monitor in 20 percent of the right lane changes. Additionally, drivers of A-C/VIS-equipped trucks looked at the left monitor in 8 percent of the left lane changes, and at the center monitor in 5 percent of the left lane changes. Drivers of trucks equipped with the commercially available C/VIS looked at the left monitor in 14 percent of the left lane changes.

Lane changes in which drivers looked at least once at the monitors were compared to lane changes in which drivers did not look at the monitors. Drivers were more likely to look at the monitors during clear nighttime conditions compared to all other conditions tested (Odds Ratio = 1.4119, LCL = 1.1055, UCL = 1.8031). This was likely due to the fact that drivers found the C/VIS useful when their visibility was reduced at night. Drivers were more likely to use the monitors during right lane changes compared to left lane changes (Odds Ratio = 1.7322, LCL = 1.26502, UCL = 2.37135). This was likely because drivers find right lane changes harder to execute and demonstrates that C/VISs help to detect objects in the large No-Zone on the right side of the truck. Importantly, drivers that looked at the C/VIS were not found to exhibit different clearances from drivers that did not look at the C/VIS, further indicating that drivers did not abuse the enhanced views.

The C/VISs were not found to divert drivers' visual attention away from the forward roadway when changing lanes; drivers' mean probability of looking forward was 0.66 in both the Baseline and Test conditions. Drivers also did not reduce their probability of looking at the west coast/convex mirrors when changing lanes with a C/VIS ($p > 0.05$). However, drivers of trucks equipped with the commercially available C/VIS looked at the left fender mirror less frequently when making left lane changes with a C/VIS ($p = 0.0099$), and drivers of A-C/VIS-equipped trucks looked at the right fender mirror less frequently when making right lane changes with a C/VIS ($p < 0.0001$). These findings suggest that drivers substituted the visual information provided by the fender mirrors with the visual information provided by the C/VIS.

Eye glances to the C/VIS monitors were relatively quick. When making right lane changes, drivers' mean glance duration at the right monitor was 0.73 s and it was 0.75 s when looking at the center monitor. To compare, drivers' mean glance duration at the right west coast/convex mirror was 1.16 s (1.5 times longer). The data indicate that drivers were able to quickly obtain visual information from the displays.

Unlike the test-track studies, drivers in the TFD generally did not look at the monitors when changing lanes in front of an adjacent vehicle. To compare, the probability that drivers used the C/VIS when making a right lane change in front of a confederate vehicle on the Smart Road was found to be 0.36 (Wierwille, Schaudt, Gupta, et al., 2008), while the mean probability that drivers looked at the monitors in the TFD when making right lane changes in front of an adjacent vehicle was 0.01. It should be noted that the sampled time interval used to determine the eye glance probabilities for both studies was unequal; the TFD used a 15-second sample for each lane change, while the sample used in Wierwille, Schaudt, Gupta, et al. (2008) depended on the point in time the driver initiated the lane change (and was likely shorter). Nevertheless, the C/VIS monitor eye glance probabilities were markedly lower in the TFD. It is possible that drivers only consulted the monitors when there was some uncertainty regarding the location of adjacent vehicles.

The reasons why drivers may have looked at the monitors less in the TFD than in the test-track studies may be as follows:

- The majority of the driving in the TFD was performed on roads with a low traffic density. Drivers may not have used the C/VIS monitors if they felt confident that there were no vehicles in their blind spots. This is supported by the fact that drivers' confidence that they would not hit an adjacent vehicle when merging into traffic was rated high in both the Baseline and Test conditions.
- CMV drivers are professionals. They find new technologies designed to assist them perform the driving task as beneficial, but do not find them essential since they have been operating a tractor-trailer without them for an extended period of time. As a result, their driving habits (e.g., where they look prior to changing lanes) are hard to break. One driver addressed this issue by commenting that perhaps he would have used the monitors more if he had been trained to use them when getting his Commercial Driver's License (CDL).
- Drivers may have used the monitors less often in the TFD because an experimenter was not present in the test vehicle. Drivers brought in for the test-track studies may have focused on the C/VIS in the one-hour time interval more so than when performing their employment duties over the 3-month Test condition.

Lane-Change Execution

Drivers reduced the time taken to cross the lane markings from 2.22 s to 1.96 s when driving with a C/VIS ($p = 0.0078$). Drivers also reduced the time taken to complete a lane change from 8.81 s to 7.91 s when driving with a C/VIS ($p = 0.005$). Although drivers' confidence in not striking an adjacent vehicle during a lane change was rated high in both Baseline and Test conditions, it is believed that the reduction in these time intervals is a reflection of drivers having better situation awareness when driving with a C/VIS. In knowing ahead of time whether there is sufficient clearance to change lanes, drivers no longer need to slowly cross the lane markings out of concern that a vehicle could be hidden in their no-zone.

DRIVERS' RATINGS OF THE DRIVING TASK AND C/VISs

An investigation of drivers' ratings of the driving task revealed the following:

- Drivers indicated that it was easier to merge into traffic with a C/VIS in certain conditions.
 - Drivers of A-C/VIS-equipped trucks indicated that it was easier to merge into traffic during inclement daytime conditions with the C/VIS ($p = 0.0382$).
 - Drivers of trucks equipped with the commercially available C/VIS indicated that it was easier to merge into traffic during clear daytime conditions with the C/VIS ($p = 0.0262$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to identify objects located around their truck during inclement night conditions with the C/VIS ($p = 0.0455$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to determine the approach rate of adjacent vehicles in inclement daytime conditions with the C/VIS ($p = 0.0303$).

Drivers' opinions towards the C/VISs are summarized in Table 1.

Table 1. Summary of Drivers' Opinions towards C/VISs

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Likeability of the C/VIS	• Drivers liked the A-C/VIS, but were neutral regarding the commercial C/VIS	• Drivers indicated that the A-C/VIS was more likable than they expected it to be before the system was turned on ($p = 0.0049$)	• Drivers indicated that the commercial C/VIS was less likable than they expected it to be before the system was turned on ($p = 0.0441$)
How Useful is the C/VIS	• Drivers found the C/VISs to be useful	• Drivers rated the A-C/VIS to be useful. Rear-camera view ranked as more useful than left and right camera views	• Drivers were neutral. Although, right-camera view ranked as more useful than left camera view.
How Irritating is the C/VIS	• Overall, drivers did not find the C/VISs to be irritating. Yet, some drivers did complain about glare from the commercial C/VIS.	• Drivers rated the A-C/VIS to be likeable	• Drivers were neutral. However, some drivers did complain about glare from the commercial C/VIS system.
How Desirable is the C/VIS	• Drivers did not find the C/VISs to be undesirable	• Drivers' desire of the A-C/VIS increased over the course of the study ($p = 0.0068$)	• Drivers' ratings were neutral
Elimination of Blind Spots	• Drivers of A-C/VIS-equipped trucks indicated that the C/VIS helped eliminate blind spots around their truck more so than the drivers of the commercial C/VIS-equipped trucks indicated ($p = 0.0225$)	• Drivers agreed that the A-C/VIS eliminated blind spots, pointing out that the rear-view camera helped them see the area behind their trailer	• Drivers were neutral, pointing out that the C/VIS did not offer any views that were different from the existing fender mirrors
Usefulness of the Object Detection Feature		• Drivers rated the A-C/VIS's object detection feature as useful throughout their time in the study	• N/A

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Glare from Monitors at Night	• Drivers' ratings of the glare from the monitors was dependent on how much the brightness of the monitors could be reduced at night	• Drivers rated the brightness of the A-C/VIS monitors to be comfortable at night. This was because the brightness of the A-C/VIS monitors could be substantially reduced	• Drivers rated the glare from the commercial C/VIS's monitors to be uncomfortable at night. This was because the brightness of the commercial C/VIS's monitors could not be substantially reduced
Degree to which Monitor Glare Reduces Ability to See the Road	• Drivers' ratings were dependent on the degree to which the monitors could be dimmed	• Drivers indicated that the glare from the A-C/VIS monitors slightly reduced their ability to see detail in the road	• Drivers indicated that the glare from the commercial C/VIS's monitors reduced their ability to see detail in the road • One driver indicated that the glare made it difficult to see the lane markings on the road • Drivers reported that they had to turn the monitors off when driving in fog • One driver consistently turned the monitors off at night
Degree to which Monitor Blocks View of Roadway	• Drivers' ratings were dependent on the placement of the monitors	• Drivers indicated that the A-C/VIS monitors, which were mounted on the left and right A-pillars, as well as the top center of the windshield, less than slightly blocked the view of the road	• Drivers indicated that the commercial C/VIS's monitors, which were mounted on the left and right side of the steering wheel on the dash, somewhat blocked their view of the road. This was because the left monitor could block the driver's view of the left fender mirror if the driver was in a certain position

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Effort to Clean Camera Lens	Drivers indicated that the C/VIS cameras were easy to clean	Drivers indicated that the left and right A-C/VIS fender-mounted cameras were very easy to clean. Drivers were not asked to clean the rear camera on the trailer.	Drivers indicated that the left and right fender-mounted cameras of the commercial C/VIS were extremely easy to clean.
Turn Signal Light Diffuser Effectiveness at Reducing Blooming on Monitors		Drivers liked the A-C/VIS turn signal diffusers (i.e., the translucent plastic caps that blocked the turn signal light from reaching the fender cameras) as they substantially reduced the blooming produced on the monitors when the turn signals were activated (Figure 17 and Figure 18).	- Drivers using the commercial C/VIS complained that the turn signals were too bright on the monitors (commercial C/VIS-equipped trucks did not have turn signal diffusers). - Turn signal light diffusers were later installed on commercial C/VIS trucks to reduce discomfort glare.



Figure 17. A-C/VIS Light Diffuser Mounted in Front of Right Turn Signal



Figure 18. Left: A-C/VIS Monitor Image of Turn Signal Activation without Light Diffuser; Right: A-C/VIS Monitor Image of Turn Signal Activation with Light Diffuser

Overall, drivers appreciated being able to use the C/VISs. They indicated that the C/VISs helped them see objects around the tractor-trailer, helped them perform lane-change maneuvers in front of an adjacent vehicle, and made the lane change task easier. Therefore, the CMV driving population should be accepting of C/VISs on their tractor-trailers, provided that the C/VISs:

- do not create new blind spots;
- can be substantially dimmed to avoid glare;
- do not produce large white spots on the monitors when the turn signal lights are activated; and
- ensure that the light reflected off the windshield and windows does not block the drivers' view of the road.

DISBENEFITS OF C/VISs

Observed Disbenefits

Drivers' opinion data revealed the following disbenefits of C/VISs. It should be noted that these disbenefits were identified by drivers that drove trucks equipped with the commercially available C/VIS. Furthermore, the A-C/VIS was purposefully designed to guard against these identified system shortcomings.

Uncomfortable Monitor Glare

During the TFD, drivers indicated that the glare produced from the commercial C/VIS's monitors was too bright and affected their ability to see details in the forward roadway. Drivers had a particularly hard time when driving at night in foggy conditions. The brightness of the C/VIS monitors is a crucial component to its overall usability. This is because if the monitor brightness cannot be substantially dimmed, drivers' vision can be impaired and their ability to perceive objects in the road can degrade. Glare was considered during the development of the A-C/VIS and monitors that could be substantially dimmed were selected as a result. Furthermore, both a training session and manual provided information on how to lower the A-C/VIS monitor brightness. On the other hand, the commercial C/VIS's monitors were tested as they were out of the box. Although a training session and a manual (designed and implemented by the research

team) were used to show drivers how to lower the monitor brightness using both the “brightness” and “contrast” settings, the brightness of the commercial C/VIS’s monitor could not be lowered as much as could the A-C/VIS.

Designers must also consider that the light from the monitors can reflect off the windshield and windows, and block the drivers’ view of the roadway. For example, when mounted on the bottom of the A-pillars, the E-C/VIS prototype’s monitors produced a cross-reflection on the opposite side window that could block the drivers’ view of the west coast mirror. The monitors were relocated to the top of the windshield as a result, moving the cross reflection out of the way. Drivers using the commercially available C/VIS reported that the light reflected off the windshield could block their view of the lane markings and made it difficult to track the direction of the lane. It is believed that this would still occur if the monitors were mounted lower in front of the dash.

Monitors Can Obstruct Drivers’ View of Fender Mirror

The placement of the C/VIS monitors may negatively impact drivers’ opinions of the C/VIS if their position obstructs the drivers’ view of the fender mirror. The A-C/VIS monitors were purposefully positioned at the top of the left and right A-pillars, and top center of the windshield, in order that they would not block the drivers’ view of the road or of the fender mirrors (Figure 19). In fact, the monitors did not occupy any more vertical real estate on the windshield than did the sun visor. On the other hand, the commercial C/VIS’s monitors were installed on the dash on the left and right side of the steering wheel according to a specification sent by VTECH USA, LLC. The monitors came with a stand designed to stick the monitors to the dash. After installing the commercial C/VIS’s monitors on the dash, it was found that the left monitor could block the driver’s view of the left fender mirror if his head was in a certain location (Figure 20). After sending a picture of the installation to VTECH USA, LLC, the manufacturer recommended that the monitors be drilled into the dash so that their position was lower. However, in doing so, elements of the instrument panel, as well as the left window defroster, would be covered (Figure 21). In addition, the vehicle’s dash would be permanently damaged. The Schneider National fleet company manager indicated that he did not want to install the monitors in a fashion that would cover the instrument panel and window defroster. This issue was presented to VTECH USA to determine how they would have installed the monitor had the research team not been involved. The option of fabricating a custom bracket for the Freightliner C-120 trucks was suggested to VTECH USA, LLC, but they indicated that such work would not be possible without permanently damaging the dashboard. As such, the commercial C/VIS’s monitors were installed according to the specification and stand that came with the system.



Figure 19. Placement of A-C/VIS Monitors in Truck Cab



Figure 20. Placement of Commercial C/VIS's Left Monitor, According to VTECH USA, LLC Specification



Figure 21. Potential Placement of Commercial C/VIS's Left Monitor to Avoid Potential Obstruction of Left Fender Mirror; Elements of the Instrument Panel and Window Defroster are Obstructed

Over the course of the TFD, some drivers did indeed indicate that the left monitor could block their view of the left fender mirror if their head was in a certain position. As a result, the left and right monitors of the commercially available C/VIS were folded down during the Baseline condition. The monitors were then flipped up during the Test condition. When leaning to the left, drivers had to look around the monitor in order to use the left fender mirror. Although drivers were still able to use the left fender mirror, their opinions of the monitors may have been negatively affected by this obstruction. It should be noted that drivers indicated that the monitors provided the same view as the fender mirrors did when they were enabled.

When installing a C/VIS, the placement of the monitors should consider the layout of the vehicle's interior. Brackets that allow more flexibility for installing the C/VIS should be provided. If drivers are assigned to specific trucks, their input should be consulted regarding their preferred placement of the monitors. Overall, the findings from the TFD suggest that placing the monitors at the top of the A-pillars and top center of the windshield is the best solution.

Potential Disbenefits

The following disbenefits were not observed during the TFD. However, they are discussed here as potential issues to consider when implementing C/VISs.

C/VIS May Allow Close Lane Changes

In dense traffic conditions, drivers constantly vie for position on the road. It is possible that drivers could misuse the enhanced visibility offered by the C/VISs by cutting in closer to adjacent vehicles when changing lanes. Such a behavior could generate negative reactions from surrounding traffic, such as rapid braking, or lead to crashes if the CMV driver does not fully understand how to perceive gaps with the C/VIS.

Potential for Driver Distraction

It is possible that allocating visual attention to the monitors can increase drivers' crash risk, particularly if the glances to the monitors exceed 2 s in duration. This is because eye glances away from the forward roadway lasting more than 2 s increase crash risk (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Fortunately, drivers' probability of looking forward when driving with a C/VIS was not found to decrease in the TFD. Furthermore, the glances to the monitors were, on average, shorter than 1 s (the longest glance observed was 2.30 s to the A-C/VIS center monitor during a right lane change). Provided that glances to the monitors are short, it is expected that C/VISs will not increase crash risk because information presented on the monitors is relevant to the formulation of spatial awareness. Klauer et al. (2006) found that drivers that looked away from the forward roadway to check their side-view and rear-view mirrors actually had a crash risk less than 1 (i.e., monitoring one's mirrors had a protective effect). It is therefore hypothesized that regular, short eye glances to the monitors will provide a similar benefit to drivers since they will become more aware of their surroundings.

At the same time, there is another concern that selecting C/VIS functions through an on-screen menu can also take drivers' visual attention away from the forward roadway and negatively impact driving performance. C/VISs that demand that drivers navigate deep on-screen menus to adjust features (such as brightness) should only be operated when the vehicle is stationary. It is worth noting that the A-C/VIS's interface was designed to allow drivers to toggle between features with one button press. No on-screen menus were used.

DRIVERS' USE OF THE A-C/VIS'S ADVANCED FEATURES

Rear Wide-Angle Look-Down Camera

The E-C/VIS test-track studies showed that drivers were more likely to use the rear wide-angle look-down monitor relative to the left and right monitors when estimating the clearance to an adjacent confederate vehicle (Wierwille et al., in press). Similarly, the TFD found that drivers were more likely to use the rear wide-angle look-down monitor than the left or right monitors when making right lane changes. This result is interesting as most commercially available C/VISs do not offer a trailer-mounted camera, typically because there are over two trailers for every tractor (American Trucking Associations, 2010) and such an option would increase implementation costs. Nevertheless, the TFD indicates that this view is useful to drivers. Driver ratings support this objective finding. Drivers of A-C/VIS-equipped trucks ranked the center monitor as more useful than the left or right monitors. Drivers also increased their ratings of how much they liked the A-C/VIS over the course of the study ($p = 0.0049$), while drivers' affinity for the commercially available C/VIS did not increase. It is worth noting that trailer-mounted functionality—such as a rear camera and IR lights—that demands drivers make an additional wired connection between the tractor and trailer is not believed to substantially increase driver workload. This is because some drivers who had to disconnect the trailer from their tractor during the TFD indicated that reattaching the C/VIS connection was not bothersome since they already had to make a connection for the trailer lights.

Night Vision Enhancement

The use of trailer-mounted IR lights to illuminate the areas around the tractor-trailer may have supported drivers in maneuvering the tractor-trailer in unlit parking lots and making left and right turns on unlit streets. However, they likely did not assist drivers in perceiving an adjacent vehicle during highway driving at night as the adjacent vehicle's headlights served as the primary cue that a vehicle was present. Although the commercially available C/VIS does not have infrared illumination, drivers could identify that a vehicle was traveling beside the truck if they saw the vehicle's headlights.

Drivers' Use of the Object Detection Feature

Drivers' opinion data indicated that the A-C/VIS's object detection feature was useful and well received. Drivers did not indicate that the feature negatively impacted their driving. The feature was turned on during 43 percent of the lane changes made in the first month of Test mode, but this decreased to 19 percent in the final month of Test mode. Drivers used the feature more when making lane changes during clear daytime conditions compared to when making lane changes during clear nighttime conditions. It should be noted that 55 percent of the 2012 sampled lanes changes were made in clear nighttime conditions, 33 percent were made in clear daytime conditions, 5 percent were made in inclement daytime conditions, and 7 percent were made in inclement nighttime conditions.

CONCLUSIONS

The following conclusions are drawn from the data obtained in the observed conditions:

Impact of C/VISs on Driver Involvement in SCEs

- Drivers' involvement in SCEs did not improve nor worsen when driving with a C/VIS.
- The severity of SCEs experienced did not change when driving with a C/VIS.
- Drivers' visual attention to the forward roadway did not degrade when driving with a C/VIS.

Impact of C/VISs on Driver Lane-Change Performance

- Drivers that looked at the C/VIS changed lanes with the same clearance to an adjacent vehicle as drivers that did not look at the C/VIS.
- Drivers' visual attention to the forward roadway did not degrade when changing lanes with a C/VIS. However, drivers looked at the fender mirrors less frequently when changing lanes with a C/VIS.
- The time taken to cross the lane markings shortened when changing lanes with a C/VIS.
- Drivers were more likely to look at the C/VIS during clear nighttime conditions relative to the other environmental conditions examined. This was because their visibility of the road is reduced at night.
- Drivers were more likely to look at the C/VIS when making right lane changes compared to left lane changes. This was because drivers find right lane changes harder to make because of the large No-Zone on the right side of the truck.

Drivers' Opinions of C/VISs

- Drivers indicated that the A-C/VIS made it easier to merge into traffic during inclement daytime conditions.
- Drivers indicated that the commercially available C/VIS made it easier to merge into traffic during clear daytime conditions.
- Drivers indicated that the A-C/VIS made it easier to identify objects located around their truck during inclement night conditions.
- Drivers indicated that the A-C/VIS made it easier to determine the approach rate of adjacent vehicles in daytime inclement weather.
- Drivers liked the A-C/VIS, but were neutral in rating the commercially available C/VIS's likeability.
- Drivers indicated that the A-C/VIS helped eliminate blind spots around their truck, while drivers of the trucks equipped with the commercially available C/VIS were neutral in this regard.
- Drivers ranked the A-C/VIS's center monitor as more useful than the right or left monitors (although the ranking of the right monitor was a close second). Drivers ranked the commercially available C/VIS's right monitor as more useful than the left monitor.
- Drivers liked the A-C/VIS turn signal diffusers (i.e., the translucent plastic caps that blocked the turn signal light from reaching the fender cameras) as they substantially reduced the blooming produced on the monitors when the turn signals were activated.
- All interviewed drivers indicated that they desired having a C/VIS on their non-C/VIS equipped truck one month after their participation in the study ended.

C/VIS Disbenefits

- Some drivers indicated that the glare from the commercially available C/VIS's monitors is uncomfortable at night and can reduce their ability to see details in the roadway. Drivers found the A-C/VIS monitors' brightness to not be uncomfortable at night probably because A-C/VIS monitors can be substantially dimmed to near darkness.
- Some drivers complained that the turn signals were too bright on the monitors for the commercially available C/VIS as trucks with the commercial C/VIS did not have turn signal light diffusers. Turn signal light diffusers were later installed on these trucks to reduce discomfort glare.
- Some drivers did not like the placement of the left monitor of the commercially available C/VIS as it can obstruct their view of the left fender mirror. Most drivers liked the monitors placed at the top of the left and right A-pillars and the center of the windshield. Iterative user-centered design showed that mounting the monitors in these locations reduces cross-reflection on the windshield and windows, and reduces glare from reflected sunlight. If the monitors cannot be mounted along the top of the windshield, then the driver should be involved in selecting the monitor's placement on the dash.

Concluding Statements

Overall, the TFD demonstrates that C/VISs, both an Advanced C/VIS and a commercially available C/VIS, can benefit drivers by eliminating blind spots, improving drivers' spatial awareness, and easing the execution of lane changes in traffic. Importantly, drivers' involvement in SCEs, their lane-change performance, and their visual attention to the forward roadway were not found to worsen when driving with a C/VIS in the conditions tested. Furthermore, the observed disbenefits, consisting of glare from the commercial C/VIS's monitor and the placement of its left monitor, are resolvable. Because drivers find right lane changes harder to perform than left lane changes, a C/VIS that eliminates the right no-zone will be useful to drivers. Both the commercially available C/VIS and the A-C/VIS did this. However, drivers did find that the A-C/VIS trailer-mounted rear camera helped with lane-change maneuvers, backing maneuvers, turning maneuvers, and maneuvering the tractor-trailer in parking lots. Therefore, there is merit in adopting this advanced feature when implementing a C/VIS in a commercial trucking operation. To conclude, drivers should be widely accepting of this driver-assistance technology, provided that: 1) C/VIS monitors permit coverage of the right no-zone, 2) the monitors can be sufficiently dimmed so as not to generate discomfort glare, 3) they are positioned to avoid new blind spots and cross-reflection in critical locations on the windshield and windows, 4) do not have deep on-screen menus, and 5) diffuse the light emanated from the turn signals.

C/VIS DESIGN GUIDELINES

The following are offered as C/VIS design guidelines:

- Ensure that C/VIS monitors can be substantially dimmed to avoid discomfort glare and to allow drivers to remain dark-adapted when driving at night.
- Position monitors at the top of the left and right A-pillars, and top center of the windshield (if a rear-view is provided), to avoid:
 - Obstructing fender-mounted mirrors
 - Producing cross-reflection on the windshield and side windows
 - Producing glare on the monitors from sunlight during the day
 - Obstructing the driver's view of the adjacent lanes
- If a trailer-mounted C/VIS is used and needs to be connected to the tractor, design the C/VIS cable into the existing trailer light cable. Drivers will then only have one cable to attach. Furthermore, the attachment should provide feedback to drivers when the connection is properly made (e.g., snapping into place, or the alignment of two markings on either side of the connector).
- Deep on-screen menus should not be used for the selection of C/VIS settings. Allow drivers to save settings and toggle between their saved settings with one button press. For instance, the C/VIS should provide a day mode with a high brightness setting, and a night mode with a low brightness setting.
- Attach translucent plastic light diffusers between the turn signal lights and the fender-mounted C/VIS camera's vantage point to reduce blooming on the monitors at night. It

should be noted that the amount of light shined in all other directions by the turn signal light was not reduced by the guards. The side turn signal lights are used to alert adjacent vehicle drivers of the truck's intent to change lanes. The turn signal light diffusers did not prevent the turn signal lights from being seen by adjacent vehicles. The side turn signal lights could also still be seen when directly facing the front of the truck because the plastic guards were translucent. The mandatory turn signal lights positioned on the front of the truck were not guarded and could be clearly seen. Using monitors that can be substantially dimmed also reduces discomfort glare produced from such blooming.

- Ensure that the C/VIS turns on automatically with the ignition. Drivers should not have to turn the C/VIS on after starting the truck.
- Ensure that a training program is developed and used to instruct drivers on how to properly use the C/VIS when implementing them in a commercial trucking operation. For example, ensure that drivers are instructed that objects are closer than they appear in the monitors, particularly for views obtained with cameras with large FOVs (i.e., greater than 55 degrees).

ACRONYMS

A-C/VIS	Advanced Camera/Video Imaging System
AGC	Auto-Gain Control
AI	Analyst Identified
ANOVA	Analysis of Variance
BLC	Backlight Compensation
B/W	Black and white
CBA	Cost-benefit analysis
CDL	Commercial Driver's License
CMOS	Complementary Metal–Oxide–Semiconductor
C/VIS	Camera/Video Imaging System
CMV	Commercial Motor Vehicle
CVSA	Commercial Vehicle Safety Alliance
DART	Data Analysis and Reporting Tool
DAS	Data acquisition system
DDWS FOT	Drowsy Driver Warning System Field Operational Test
DVI	Driver-Vehicle Interface
E-C/VIS	Enhanced Camera/Video Imaging System
EOBR	Electronic On-Board Recorder
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
FOV	Field of View
GES	General Estimates System
GPS	Global Positioning System
HSD	Honestly Significantly Different
IR	Infrared
IRB	Institutional Review Board
IVS	Indirect Visibility System
LA	Longitudinal Acceleration
LCD	Liquid Crystal Display
LTCCS	Large Truck Crash Causation Study
MCMIS	Motor Carrier Management Information System
NHTSA	National Highway Traffic Safety Administration
OTR	Over the Road
PC	Personal computer
POV	Principal other vehicle
ROC	Radius of curvature
ROI	Return on investment
S	Swerve
SBZA	Side blind zone alert
SCE	Safety-Critical Event
SUV	Sport utility vehicle
SV	Subject vehicle

TACT	Ticketing Aggressive Cars and Trucks
TFD	Technology Field Demonstration
TTC	Time-to-collision
U.S. DOT	United States Department of Transportation
V2V	Vehicle to Vehicle
VGA	Vector graphics array
VTI	Virginia Tech Transportation Institute

TABLE OF CONTENTS

EXECUTIVE SUMMARY	ii
CHAPTER 1. INTRODUCTION.....	1
PURPOSE	7
<i>Research Questions.....</i>	<i>8</i>
DOCUMENT OVERVIEW.....	10
CHAPTER 2. BACKGROUND AND PROBLEM SCOPE	12
PROBLEM SCOPE	12
<i>Analysis of the Large Truck Crash Causation Study (LTCCS) Database</i>	<i>14</i>
<i>Analysis of the Most Recent GES Database</i>	<i>20</i>
<i>Problem Scope Summary</i>	<i>22</i>
PREVIOUS RESEARCH.....	23
<i>The No-Zone.....</i>	<i>23</i>
<i>Addressing the No-Zone: Indirect Visibility Systems.....</i>	<i>25</i>
<i>Evaluating Indirect Visibility Systems</i>	<i>50</i>
FLEET SAFETY OFFICIAL INTERVIEWS	55
<i>Method</i>	<i>55</i>
<i>Results</i>	<i>56</i>
<i>Summary</i>	<i>64</i>
CHAPTER 3. THE ADVANCED C/VIS (A-C/VIS)	66
A-C/VIS CAMERAS	66
<i>Camera Settings.....</i>	<i>70</i>
<i>Camera Housing</i>	<i>70</i>
<i>Camera Location</i>	<i>71</i>
A-C/VIS MONITORS.....	73
<i>Monitor Location</i>	<i>73</i>
<i>Monitor Housing.....</i>	<i>75</i>
A-C/VIS DRIVER-VEHICLE INTERFACE (DVI)	76
SUMMARY	78
CHAPTER 4. SELECTION OF COMMERCIALLY AVAILABLE C/VIS.....	79
INTRODUCTION	79
IDENTIFIED COMMERCIALLY AVAILABLE C/VISs	79
<i>Safety Vision®’s Camera System (Product: SV-CLCD-70)</i>	<i>79</i>
<i>V-TECH USA LLC’s Sidetracker System.....</i>	<i>80</i>
<i>Winsted Products’ Dual Camera System Left/Right Side Views (Product: CCH-P70C1TTX2).....</i>	<i>81</i>
<i>Mobile Awareness – Product: VisionStat™ Triple Side View Camera System.....</i>	<i>82</i>
<i>ASA Electronics’ Voyager System</i>	<i>84</i>
<i>Commercially Available C/VIS Trade Study.....</i>	<i>85</i>
SELECTED C/VIS: VTECH USA’S SIDETRACKER SYSTEM	89
<i>Commercial C/VIS’s Cameras.....</i>	<i>89</i>

<i>Commercial C/VIS's Monitors.....</i>	<i>89</i>
CHAPTER 5. PRELIMINARY TESTING	91
INTRODUCTION	91
METHODS	91
<i>Participants.....</i>	<i>91</i>
<i>Test Vehicle.....</i>	<i>91</i>
<i>Apparatus.....</i>	<i>91</i>
<i>Procedure.....</i>	<i>93</i>
<i>Experimental Design.....</i>	<i>97</i>
RESULTS	98
DISCUSSION	103
CONCLUSION	103
CHAPTER 6. TECHNOLOGY FIELD DEMONSTRATION METHODS	105
PARTICIPANTS.....	105
TEST VEHICLES.....	107
<i>A-C/VIS Turn Signal and Side Marker Light Diffusers</i>	<i>107</i>
DATA ACQUISITION SYSTEM	110
PROCEDURE	116
<i>Vehicle Instrumentation</i>	<i>116</i>
<i>Vehicle Data Collection.....</i>	<i>117</i>
<i>Participant Data Collection.....</i>	<i>117</i>
EXPERIMENTAL DESIGN.....	119
<i>Independent Variables</i>	<i>119</i>
<i>Dependent Variables.....</i>	<i>120</i>
DATA REDUCTION	123
<i>Safety-Critical Event Reduction.....</i>	<i>124</i>
<i>Lane-Change Maneuver Reduction</i>	<i>130</i>
<i>Driver Preference Data Reduction</i>	<i>132</i>
CHAPTER 7. RESULTS.....	133
DRIVER INVOLVEMENT IN SAFETY-CRITICAL EVENTS.....	133
<i>Driving Data Statistics.....</i>	<i>133</i>
<i>SCE Classification</i>	<i>133</i>
<i>Analysis of Drivers' Safety-Critical Event Rate</i>	<i>148</i>
<i>Driver Visual Behavior Prior to Safety-Critical Events</i>	<i>155</i>
<i>Lane-Change SCEs</i>	<i>165</i>
<i>Summary</i>	<i>168</i>
DRIVERS' LANE-CHANGE PERFORMANCE	168
<i>Clearance between Tractor-Trailer and Adjacent Vehicle.....</i>	<i>168</i>
<i>Drivers' Visual Behavior when Changing Lanes</i>	<i>188</i>
<i>Elapsed Time from Maneuver Initiation to Crossing Lane Markings</i>	<i>204</i>
<i>Lane-Change Maneuver Duration.....</i>	<i>214</i>
<i>Drivers' Lane Change Performance by C/VIS Use</i>	<i>224</i>
<i>A-C/VIS Drivers' Use of the Object Detection Feature.....</i>	<i>226</i>

<i>Summary</i>	229
DRIVER RATINGS OF DRIVING PERFORMANCE AND C/VISS	230
<i>Drivers' Opinions of C/VISS</i>	230
<i>Drivers' Ratings of the Driving Task</i>	245
<i>Analysis of Driver Comments</i>	257
<i>Drivers' Impressions of the Other C/VIS</i>	259
<i>Summary</i>	261
CHAPTER 8. DISCUSSION	263
IMPACT OF C/VISS ON DRIVER INVOLVEMENT IN SCEs	263
<i>Drivers' Involvement in SCEs</i>	263
<i>Drivers' Visual Behavior Prior to SCEs</i>	263
<i>SCEs Involving Lane Changes</i>	264
<i>Avoidable Tire Strike SCEs</i>	264
IMPACT OF C/VISS ON DRIVER LANE-CHANGE PERFORMANCE.....	264
<i>Clearance to Adjacent Vehicle</i>	265
<i>Drivers' Visual Behavior</i>	266
<i>Lane-Change Execution</i>	269
<i>Evidence of Lane-Change Difficulty</i>	269
<i>Drivers' Use of the Object Detection Feature</i>	270
DRIVER OPINIONS OF C/VISS	270
DISBENEFITS OF C/VISS	274
<i>Observed Disbenefits</i>	274
<i>Potential Disbenefits</i>	277
STUDY LIMITATIONS	277
<i>Number of Drivers</i>	278
<i>Low Traffic Density</i>	278
<i>Eye Glance Analysis Assumes Independence</i>	278
CHAPTER 9. CONCLUSIONS	279
IMPACT OF C/VISS ON DRIVER INVOLVEMENT IN SCEs	280
IMPACT OF C/VISS ON DRIVER LANE-CHANGE PERFORMANCE.....	280
DRIVERS' OPINIONS OF C/VISS	280
C/VIS DISBENEFITS.....	281
CONCLUDING STATEMENTS	281
C/VIS DESIGN GUIDELINES	282
FUTURE RESEARCH.....	283
APPENDIX A. SOLICITATION SCRIPTS	285
APPENDIX B. INTERVIEW SCRIPT	286
APPENDIX C. BRIEFING ON THE C/VIS TECHNOLOGY	287
APPENDIX D. INTERVIEW QUESTIONS	296
APPENDIX E. COMPARISON OF A-C/VIS SPECIFICATIONS TO E-C/VIS SPECIFICATIONS	299

APPENDIX F. C/VIS SPECIFICATIONS.....	307
APPENDIX G. STATIC EVALUATION INFORMED CONSENT FORM.....	329
APPENDIX H. STATIC EVALUATION QUESTIONS	334
APPENDIX I. PRE-STUDY QUESTIONNAIRES	335
APPENDIX J. DRIVING QUESTIONNAIRE	339
APPENDIX K. A-C/VIS TRAINING MANUAL	347
APPENDIX L. COMMERCIAL C/VIS TRAINING MANUAL.....	363
APPENDIX M. A-C/VIS QUESTIONNAIRE	373
APPENDIX N. SIDETRACKER QUESTIONNAIRE.....	378
APPENDIX O. A-C/VIS FINAL MEETING QUESTIONNAIRE	383
APPENDIX P. SIDETRACKER FINAL MEETING QUESTIONNAIRE	391
APPENDIX Q. PARTICIPANT CONTACT FORM.....	399
APPENDIX R. SIDETRACKER QUESTIONNAIRE FOR A-C/VIS DRIVERS AT THE END OF THE STUDY	400
APPENDIX S. A-C/VIS QUESTIONNAIRE FOR SIDETRACKER DRIVERS AT THE END OF THE STUDY.....	406
APPENDIX T. 1-MONTH FOLLOW-UP QUESTIONNAIRE.....	412
APPENDIX U. DRIVER ROUTE, TIME IN TRUCK, AND MILES PER WEEK	413
APPENDIX V. SAFETY-CRITICAL EVENT TRIGGER VALIDATION TRAINING MANUAL.....	425
APPENDIX W. SCE EYE GLANCE REDUCTION PROTOCOL	435
APPENDIX X. SAFETY-CRITICAL EVENT VARIABLES.....	442
APPENDIX Y. LANE CHANGE MANEUVER DATA DIRECTORY	481
APPENDIX Z. LANE CHANGE EYE GLANCE REDUCTION PROTOCOL.....	500
APPENDIX AA. ADDITIONAL ANALYSIS OF DRIVER OPINION DATA.....	509
ACKNOWLEDGEMENTS	521
REFERENCES.....	522

LIST OF FIGURES

FIGURE 1. BLIND SPOTS—ALSO CALLED NO-ZONE—AROUND A TRACTOR-TRAILER, ADAPTED FROM AAA PUBLIC AFFAIRS (2000).....	ii
FIGURE 2. LEFT: C/VIS CAMERA MOUNTED ON TRAILER; RIGHT: VIDEO IMAGE FROM C/VIS CAMERA	ii
FIGURE 3. PLACEMENT OF A-C/VIS FENDER AND TRAILER CAMERAS	iv
FIGURE 4. COVERAGE PROVIDED BY A-C/VIS CAMERAS SHOWN BY GREY SHADING. NO-ZONE SHOWN BY THE DIAGONAL LINES	iv
FIGURE 5. PLACEMENT OF A-C/VIS MONITORS IN TRUCK CAB	v
FIGURE 6. THE A-C/VIS DVI BUILT INTO THE LEFT MONITOR	v
FIGURE 7. INFRARED ILLUMINATORS MOUNTED ON TRUCK AND TRAILER	vi
FIGURE 8. PLACEMENT OF COMMERCIAL C/VIS’S CAMERAS ON LEFT AND RIGHT FENDERS	vii
FIGURE 9. COVERAGE PROVIDED BY COMMERCIAL C/VIS CAMERAS SHOWN IN THE SHADED AREA; NO-ZONE SHOWN BY THE DIAGONAL LINES	vii
FIGURE 10. PLACEMENT OF COMMERCIAL C/VIS’S MONITORS ON TRUCK DASH.....	viii
FIGURE 11. CLOSE-UP OF RIGHT COMMERCIAL C/VIS MONITOR	viii
FIGURE 12. PARTICIPANTS’ OBJECT DETECTION ACCURACY FOR A PEDESTRIAN AND A STOP SIGN (DIFFERENT LETTERS REPRESENT A STATISTICALLY SIGNIFICANT DIFFERENCE).....	ix
FIGURE 13. FREIGHTLINER C120 TRACTOR WITH 48-FT TRAILER	x
FIGURE 14. EXPERIMENTAL CONDITIONS FOR THE TFD	x
FIGURE 15. EIGHT CAMERA IMAGES MULTIPLEXED INTO TWO IMAGES.....	xi
FIGURE 16. EXCERPT FROM A-C/VIS TRAINING MANUAL ON PROPER USE OF THE CENTER MONITOR	xiii
FIGURE 17. A-C/VIS LIGHT DIFFUSER MOUNTED IN FRONT OF RIGHT TURN SIGNAL	xviii
FIGURE 18. LEFT: A-C/VIS MONITOR IMAGE OF TURN SIGNAL ACTIVATION WITHOUT LIGHT DIFFUSER; RIGHT: A-C/VIS MONITOR IMAGE OF TURN SIGNAL ACTIVATION WITH LIGHT DIFFUSER	xix
FIGURE 19. PLACEMENT OF A-C/VIS MONITORS IN TRUCK CAB	xxi
FIGURE 20. PLACEMENT OF COMMERCIAL C/VIS’S LEFT MONITOR, ACCORDING TO VTECH USA, LLC SPECIFICATION	xxi
FIGURE 21. POTENTIAL PLACEMENT OF COMMERCIAL C/VIS’S LEFT MONITOR TO AVOID POTENTIAL OBSTRUCTION OF LEFT FENDER MIRROR; ELEMENTS OF THE INSTRUMENT PANEL AND WINDOW DEFROSTER ARE OBSTRUCTED	xxii
FIGURE 22. PLACEMENT OF COMMERCIAL C/VIS’S CAMERAS ON LEFT FENDER.....	1
FIGURE 23. PLACEMENT OF COMMERCIAL C/VIS’S MONITORS ON TRUCK DASH.....	2
FIGURE 24. PLACEMENT OF E-C/VIS FENDER AND TRAILER CAMERAS, TAKEN FROM WIERWILLE ET AL. (IN PRESS)...	3
FIGURE 25. PLACEMENT OF E-C/VIS MONITORS IN TRUCK CABIN, TAKEN FROM WIERWILLE ET AL. (IN PRESS)	3
FIGURE 26. PLACEMENT OF E-C/VIS INFRARED ILLUMINATORS, TAKEN FROM WIERWILLE ET AL. (IN PRESS).....	4
FIGURE 27. EXAMPLE OF FENDER-MOUNTED E-C/VIS VIEW WITH IMAGE PROCESSING, TAKEN FROM WIERWILLE ET AL. (IN PRESS)	4
FIGURE 28. PLACEMENT OF A-C/VIS FENDER AND TRAILER CAMERAS	5
FIGURE 29. COVERAGE PROVIDED BY A-C/VIS CAMERAS SHOWN BY GREY SHADING. NO-ZONE SHOWN BY THE DIAGONAL LINES	6

FIGURE 30. PLACEMENT OF A-C/VIS MONITORS IN TRUCK CAB	6
FIGURE 31. THE A-C/VIS DVI BUILT INTO THE LEFT MONITOR	7
FIGURE 32. INFRARED ILLUMINATORS MOUNTED ON TRUCK AND TRAILER	7
FIGURE 33. EXPERIMENTAL CONDITIONS FOR THE TFD	8
FIGURE 34. ILLUSTRATION OF THE NO-ZONE, ADAPTED FROM AAA PUBLIC AFFAIRS (2000).....	23
FIGURE 35. REAR OF THE VOLVO TRACTOR CAB SHOWING THE REAR-VIEW C/VIS CAMERA LOCATION, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008)	31
FIGURE 36. MONITOR IN VOLVO TRACTOR FOR REAR-VIEW C/VIS, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008)	31
FIGURE 37. WIDE-ANGLE REAR MULTIPURPOSE LOOK-DOWN CAMERA AT BACK OF TRAILER, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008)	32
FIGURE 38. PETERBILT IN-CAB MONITOR FOR THE WIDE-ANGLE REAR MULTIPURPOSE TRAILER LOOK-DOWN C/VIS, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008).....	32
FIGURE 39. DRIVER-SIDE MONITORS MOUNTED AT THE A-PILLAR; NOTE THE COVERS OVER THE MIRRORS, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008).....	33
FIGURE 40. PASSENGER-SIDE MONITORS MOUNTED AT THE A-PILLAR; NOTE THE COVERS OVER THE MIRRORS, AND ALSO NOTE THAT THE UPPER MONITOR WAS HOODED TO REDUCE GLARE, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008).....	34
FIGURE 41. DRIVER-SIDE CAMERAS AT THE FRONT FENDER; THE ROUND CAMERA IS FOR THE CONVEX MIRROR SURROGATE, AND THE RECTANGULAR CAMERA IS FOR THE WEST COAST MIRROR SURROGATE, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008).....	35
FIGURE 42. PASSENGER-SIDE CAMERAS AT THE FRONT FENDER; THE ROUND CAMERA IS FOR THE CONVEX MIRROR SURROGATE, AND THE RECTANGULAR CAMERA IS FOR THE WEST COAST MIRROR SURROGATE, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008).....	35
FIGURE 43. FIRST GROUP OF CAMERA LOCATIONS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008).....	39
FIGURE 44. SECOND GROUP OF CAMERA LOCATIONS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008)...	40
FIGURE 45. MONITOR LOCATIONS AT THE A-PILLARS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008) ..	40
FIGURE 46. OTHER MONITOR LOCATIONS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008)	41
FIGURE 47. POSITIONS OF THE AUTOMOBILE RELATIVE TO THE TRACTOR-TRAILER FOR THE IMAGE QUALITY AND GLARE DISCRIMINABILITY TESTS; DIMENSIONS ARE IN FEET; 1 FT = 0.305 M, TAKEN FROM SCHAUDT, WIERWILLE, & HANOWSKI (2009)	44
FIGURE 48. PLACEMENT AND ORDER OF OBJECTS USED IN E-C/VIS STATIC TESTING; REPRINTED FROM “ENHANCED CAMERA/VIDEO IMAGING SYSTEMS (E-C/VISS) FOR HEAVY VEHICLES” BY W. W. WIERWILLE, W. A. SCHAUDT, M. BLANCO, A. S. ALDEN, AND R. J. HANOWSKI, 2008, P. 76. NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, REPORT NO.: DTNH22-05-D-01019. REPRINTED WITH PERMISSION	46
FIGURE 49. DAYTIME PHOTOGRAPH OF THE FOUR “OBJECTS” USED IN THE EXPERIMENT; REPRINTED FROM “ENHANCED CAMERA/VIDEO IMAGING SYSTEMS (E-C/VISS) FOR HEAVY VEHICLES” BY W. W. WIERWILLE, W. A. SCHAUDT, M. BLANCO, A. S. ALDEN, AND R. J. HANOWSKI, 2008, P. 82. NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, REPORT NO.: DTNH22-05-D-01019. REPRINTED WITH PERMISSION ...	47
FIGURE 50. DALLMEIER MDF3000A CAMERA. (SOURCE: DALLMEIER-ELECTRONIC.COM, 2010)	66
FIGURE 51. CANDIDATE CAMERAS MOUNTED TO FENDER OF TEST TRUCK	67
FIGURE 52. IR ILLUMINATORS MOUNTED UNDERNEATH TRAILER.....	68
FIGURE 53. TOSHIBA IK-64DNA CAMERA USED IN THE E-C/VIS STUDY	69

FIGURE 54. MULTIPLEXED VIEW OF CANDIDATE CAMERAS.....	70
FIGURE 55. A-C/VIS CAMERA HOUSING DESIGN.....	71
FIGURE 56. COVERAGE OF THE THREE A-C/VIS CAMERAS.....	72
FIGURE 57. A-C/VIS CAMERA HOUSING.....	72
FIGURE 58. THE ACCELEVISION LCD5A AND LCD64A MONITORS WITHOUT MONITOR HOUSINGS.....	73
FIGURE 59. PLACEMENT OF A-C/VIS MONITORS	74
FIGURE 60. CROSS REFLECTION PRODUCED BY A-C/VIS MONITORS ON THE LEFT SIDE WINDOW	75
FIGURE 61. LEFT AND CENTER MONITOR HOUSING FOR A-C/VIS	76
FIGURE 62. VIEW OF DVI ON LEFT MONITOR HOUSING.....	77
FIGURE 63. EXAMPLE IMAGES OF A-C/VIS OBJECT DETECTION FEATURE	77
FIGURE 64. SAFETY VISION® ON-BOARD CAMERA SYSTEM (SOURCE: HTTP://WWW.ELECTRICMOTORSVC.COM/SAFETY/)	80
FIGURE 65. SIDETRACKER SYSTEM MONITORS	81
FIGURE 66. WINSTED PRODUCTS DUAL MONITOR (SOURCE: HTTP://REARVIEWCAMERA.NET/CRV/CRVIS.DLL?MTD=PRODUCTS&PART=CCH-P70C1TTX2)	82
FIGURE 67. WINSTED PRODUCTS CAMERA (SOURCE: HTTP://REARVIEWCAMERA.NET/CRV/CRVIS.DLL?MTD=PRODUCTS&PART=CCH-P70C1TTX2)	82
FIGURE 68. MOBILE AWARENESS SIDE CAMERA (SOURCE: HTTP://WWW.MOBILEAWARENESS.COM/PRODUCT_DETAIL.PHP?PID=137)	83
FIGURE 69. MOBILE AWARENESS REAR CAMERA (SOURCE: HTTP://WWW.MOBILEAWARENESS.COM/PRODUCT_DETAIL.PHP?PID=137)	83
FIGURE 70. MOBILE AWARENESS MONITOR (SOURCE: HTTP://WWW.MOBILEAWARENESS.COM/PRODUCT_DETAIL.PHP?PID=137)	84
FIGURE 71. VOYAGER SIDE CAMERA (SOURCE: HTTP://WWW.ASAELECTRONICS.COM/COMMERCIAL.HTML)	84
FIGURE 72. VOYAGER REAR CAMERA (SOURCE: HTTP://WWW.ASAELECTRONICS.COM/COMMERCIAL.HTML)	85
FIGURE 73. VOYAGER MONITOR (SOURCE: HTTP://WWW.ASAELECTRONICS.COM/COMMERCIAL.HTML)	85
FIGURE 74. COMMERCIAL C/VIS CAMERA AND WEATHERPROOF HOUSING INSTALLATION	89
FIGURE 75. COMMERCIAL C/VIS'S MONITOR INSTALLATION	90
FIGURE 76. MONITOR MOUNTING SPECIFICATION	90
FIGURE 77. DATA ACQUISITION SYSTEM.....	92
FIGURE 78. MULTIPLEX VIEW FROM INTERIOR CAMERAS USED IN THE STATIC TESTS.....	92
FIGURE 79. PARTICIPANT WEARING BLINDFOLD AND HEARING PROTECTION IN THE STATIC TESTS	93
FIGURE 80. OBJECTS USED IN STATIC EVALUATION	94
FIGURE 81. OBJECT POSITION AND A-C/VIS FIELD OF VIEW; NOTE: ALTHOUGH THE A-C/VIS HAS A 45-DEGREE FOV, THERE IS IR ILLUMINATION	96
FIGURE 82. OBJECT LOCATIONS AND COMMERCIAL C/VIS FOV; NOTE: ALTHOUGH THE COMMERCIAL C/VIS HAS A 90-DEGREE FOV, THERE IS NO IR ILLUMINATION	97
FIGURE 83. PARTICIPANTS' OBJECT-DETECTION ACCURACY OF PEDESTRIAN AND STOP SIGN (DIFFERENT LETTERS REPRESENT A STATISTICALLY SIGNIFICANT DIFFERENCE).....	99

FIGURE 84. OBJECT DETECTION SCORES OBTAINED WITH THE A-C/VIS AND COMMERCIAL C/VIS BY OBJECT TYPE	100
FIGURE 85. PARTICIPANTS' OBJECT-DETECTION ACCURACY TO ALL OBJECTS	101
FIGURE 86. PARTICIPANTS' OBJECT RECOGNITION ACCURACY	102
FIGURE 87. CLARITY RATING SCALE.....	103
FIGURE 88. FREIGHTLINER CENTURY 120 TRACTOR WITH 48-FT TRAILER.....	107
FIGURE 89. A-C/VIS LIGHT DIFFUSER MOUNTED IN FRONT OF RIGHT TURN SIGNAL	108
FIGURE 90. LEFT: A-C/VIS MONITOR SHOWING SIDE MARKER LIGHT WITHOUT LIGHT DIFFUSER; RIGHT: A-C/VIS MONITOR SHOWING SIDE MARKER LIGHT WITH LIGHT DIFFUSER	108
FIGURE 91. LEFT: A-C/VIS MONITOR SHOWING SIDE TURN SIGNAL LIGHT WITHOUT LIGHT DIFFUSER; RIGHT: A- C/VIS MONITOR SHOWING SIDE TURN SIGNAL LIGHT WITH LIGHT DIFFUSER.....	109
FIGURE 92. LEFT: COMMERCIAL C/VIS MONITOR SHOWING SIDE MARKER LIGHT WITHOUT LIGHT DIFFUSER; RIGHT: COMMERCIAL C/VIS MONITOR SHOWING SIDE MARKER LIGHT WITH LIGHT DIFFUSER.....	109
FIGURE 93. LEFT: A-C/VIS MONITOR SHOWING SIDE TURN SIGNAL LIGHT WITHOUT LIGHT DIFFUSER; RIGHT: A- C/VIS MONITOR SHOWING SIDE TURN SIGNAL LIGHT WITH LIGHT DIFFUSER.....	110
FIGURE 94. THE DAS UNIT INSTALLED UNDER THE PASSENGER SEAT	111
FIGURE 95. EIGHT A-C/VIS CAMERA IMAGES MULTIPLEXED INTO TWO IMAGES	112
FIGURE 96. EIGHT COMMERCIAL C/VIS CAMERA IMAGES MULTIPLEXED INTO TWO IMAGES.....	113
FIGURE 97. RADAR UNIT MOUNTED ON THE FRONT OF THE TRUCK (LEFT) AND CLOSE VIEW OF RADAR UNIT MOUNTED ON THE FRONT OF THE TRUCK (RIGHT).....	114
FIGURE 98. RADAR UNIT MOUNTED ON THE LEFT AND RIGHT WEST COAST MIRRORS	115
FIGURE 99. EXPERIMENT GROUPS FOR THE TFD.....	119
FIGURE 100. EYE GLANCE LOCATIONS FOR DRIVERS OF A-C/VIS TRUCKS.....	122
FIGURE 101. EYE GLANCE LOCATIONS FOR DRIVERS OF COMMERCIAL C/VIS-EQUIPPED TRUCKS	122
FIGURE 102. SCREEN SHOT OF A PULL-DOWN MENU SHOWING THE PLOTS THAT CAN AID IN DETERMINING THE VALIDITY OF TRIGGERED EVENTS	125
FIGURE 103. EXAMPLE OF A VALIDATED TRIGGER WHERE THE LA WAS OF GREATER MAGNITUDE THAN THE PRE-SET VALUE OF -0.20 G	126
FIGURE 104. EXAMPLE OF A NON-CONFLICT EVENT (WITH A VALID TRIGGER) WHERE THE DRIVER'S SWERVE (QUICK STEERING) WAS 2.49 (TRIGGER SET TO ≥ 2.0).....	127
FIGURE 105. DATA ANALYST VIDEO SET-UP FOR PERFORMING EYE GLANCE REDUCTION IN DART II ON AN A-CVIS DRIVER	129
FIGURE 106. DATA ANALYST VIDEO SET-UP FOR PERFORMING EYE GLANCE REDUCTION IN DART II ON A COMMERCIAL C/VIS DRIVER	130
FIGURE 107. EXAMPLE OF A VALID LANE-CHANGE MANEUVER WHERE THE DRIVER CHANGES FROM THE LEFT TO THE RIGHT LANE WITH A VEHICLE PRESENT IN THE DESTINATION LANE AND VALID REAR RADAR DATA	131
FIGURE 108. EXAMPLE OF THE DATA CHARTS REFERENCED DURING APPLICATION OF THE LANE CHANGE SUMMARY MEASURE DIRECTORY. REFERENCED VIEWS INCLUDE FRONT AND REAR RADAR PARAMETERS, TURN SIGNAL INDICATORS, AND LANE MARKING DISTANCE MEASURES	132
FIGURE 109. SCES BY LIGHTING CONDITION.....	140
FIGURE 110. SCES BY WEATHER CONDITION	141
FIGURE 111. SCES BY ROADWAY SURFACE.....	142

FIGURE 112. SCES BY JUNCTION.....	143
FIGURE 113. SCES BY LEVEL OF SERVICE.....	144
FIGURE 114. SCES BY ROADWAY ALIGNMENT	145
FIGURE 115. SCES BY HOUR OF DAY	146
FIGURE 116. DRIVERS' MEAN SCE RATES BY EXPERIMENTAL CONDITION	148
FIGURE 117. DRIVERS' MEAN SCE RATES BY C/VIS AND EXPERIMENTAL CONDITION	149
FIGURE 118. DRIVERS' MEAN SCE RATES BY MONTH IN STUDY	150
FIGURE 119. DRIVERS' MEAN SCE RATES BY MONTH IN STUDY AND SCE SEVERITY	151
FIGURE 120. DRIVERS' MEAN SCE RATES BY MONTH IN STUDY AND FAULT ASSIGNMENT	152
FIGURE 121. DRIVERS' MEAN SCE RATES BY MONTH IN STUDY AND TYPE OF C/VIS.....	153
FIGURE 122. EACH DRIVER'S MEAN SCE RATE BY MONTH IN STUDY	154
FIGURE 123. EACH DRIVERS' MEAN SCE RATE FOR SCES THAT WERE THEIR FAULT, BY MONTH IN STUDY	155
FIGURE 124. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION IN THE 8 s PRIOR TO EXPERIENCING AN SCE BY EXPERIMENTAL CONDITION.....	157
FIGURE 125. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION IN THE 8 s PRIOR TO EXPERIENCING AN SCE LOCATION BY EXPERIMENTAL CONDITION AND C/VIS.....	158
FIGURE 126. PERCENTAGE OF SCES IN WHICH DRIVERS LOOKED AT LEAST ONCE TO THE RECORDED LOCATIONS BY EXPERIMENTAL CONDITION.....	160
FIGURE 127. PERCENTAGE OF SCES IN WHICH DRIVERS LOOKED AT LEAST ONCE AT THE RECORDED EYE GLANCE LOCATIONS	161
FIGURE 128. MEAN NUMBER OF GLANCES PRIOR TO AN SCE BY EXPERIMENTAL CONDITION.....	162
FIGURE 129. MEAN NUMBER OF GLANCES PRIOR TO AN SCE BY C/VIS AND EXPERIMENTAL CONDITION	163
FIGURE 130. MEAN GLANCE DURATION PRIOR TO AN SCE BY EXPERIMENTAL CONDITION	164
FIGURE 131. MEAN GLANCE DURATION PRIOR TO AN SCE BY C/VIS AND EXPERIMENTAL CONDITION.....	165
FIGURE 132. TWO SAFETY-CRITICAL EVENTS (CRASH-RELEVANT CONFLICT SHOWN ON LEFT, NEAR-CRASH SHOWN ON RIGHT) ARISING FROM A TRAILING VEHICLE PASSING THE SV ON THE RIGHT DURING A RIGHT LANE CHANGE. IT SHOULD BE NOTED THAT THE RIGHT LANE IS SHOWN IN THE BOTTOM LEFT VIDEO QUADRANT	166
FIGURE 133. CRASH-RELEVANT CONFLICTS ARISING FROM AN ADJACENT VEHICLE AND THE SV MOVING INTO A COMMON DESTINATION LANE. IT SHOULD BE NOTED THAT THE LEFT LANE IS SHOWN IN THE BOTTOM LEFT VIDEO QUADRANT	166
FIGURE 134. CRASH-RELEVANT CONFLICT FROM SV MAKING LEFT LANE CHANGE IN FRONT OF APPROACHING ADJACENT VEHICLE.....	167
FIGURE 135. CRASH-RELEVANT CONFLICT ARISING FROM LEAD VEHICLE CHANGING INTO SV'S DESTINATION LANE WHILE SV EXECUTES A LANE CHANGE.....	168
FIGURE 136. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE UPON INITIATING A LANE CHANGE	169
FIGURE 137. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY MONTH IN STUDY	170
FIGURE 138. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY C/VIS AND EXPERIMENTAL CONDITION	171
FIGURE 139. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY C/VIS AND MONTH IN STUDY	172
FIGURE 140. PERCENTAGE OF LANE CHANGES FOR THE CLEARANCE GROUPINGS.....	173

FIGURE 141. PERCENTAGE OF LANE CHANGES FOR THE FIVE CLEARANCE GROUPINGS BY C/VIS AND EXPERIMENTAL CONDITION	174
FIGURE 142. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY LANE-CHANGE DIRECTION.....	175
FIGURE 143. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY C/VIS, EXPERIMENTAL CONDITION, AND LANE-CHANGE DIRECTION	176
FIGURE 144. PERCENTAGE OF LEFT LANE CHANGES PER CLEARANCE CATEGORY	177
FIGURE 145. PERCENTAGE OF LEFT LANE CHANGES FOR THE CLEARANCE GROUPINGS BY C/VIS AND EXPERIMENTAL CONDITION	178
FIGURE 146. PERCENTAGE OF RIGHT LANE CHANGES FOR THE CLEARANCE GROUPINGS.....	179
FIGURE 147. PERCENTAGE OF RIGHT LANE CHANGES FOR THE CLEARANCE GROUPINGS BY C/VIS AND EXPERIMENTAL CONDITION.....	180
FIGURE 148. DRIVERS' MEAN CLEARANCE DURING LEFT LANE CHANGES BY ENVIRONMENTAL CONDITION	181
FIGURE 149. DRIVERS' MEAN CLEARANCE DURING LEFT LANE CHANGES BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	182
FIGURE 150. DRIVERS' MEAN CLEARANCE DURING LEFT LANE CHANGES BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	183
FIGURE 151. DRIVERS' MEAN CLEARANCE DURING RIGHT LANE CHANGES BY ENVIRONMENTAL CONDITION	185
FIGURE 152. DRIVERS' MEAN CLEARANCE DURING RIGHT LANE CHANGES BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	186
FIGURE 153. DRIVERS' MEAN CLEARANCE DURING RIGHT LANE CHANGES BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION	187
FIGURE 154. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION WHEN MAKING A LEFT LANE CHANGE BY EXPERIMENTAL CONDITION.....	189
FIGURE 155. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION WHEN MAKING A LEFT LANE CHANGE BY EXPERIMENTAL CONDITION AND C/VIS	190
FIGURE 156. PERCENTAGE OF LEFT LANE CHANGES IN WHICH DRIVERS LOOKED AT LEAST ONCE TO THE RECORDED LOCATIONS BY EXPERIMENTAL CONDITION	191
FIGURE 157. PERCENTAGE OF LEFT LANE CHANGES IN WHICH DRIVERS LOOKED AT LEAST ONCE AT A GIVEN LOCATION	192
FIGURE 158. MEAN NUMBER OF GLANCES WHEN MAKING A LEFT LANE CHANGE BY EXPERIMENTAL CONDITION..	193
FIGURE 159. MEAN NUMBER OF GLANCES WHEN MAKING A LEFT LANE CHANGE BY C/VIS AND EXPERIMENTAL CONDITION	194
FIGURE 160. MEAN GLANCE DURATION PRIOR TO LEFT LANE CHANGE BY EXPERIMENTAL CONDITION.....	195
FIGURE 161. MEAN GLANCE DURATION WHEN MAKING A LEFT LANE CHANGE BY C/VIS AND EXPERIMENTAL CONDITION	196
FIGURE 162. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION WHEN MAKING A RIGHT LANE CHANGE BY EXPERIMENTAL CONDITION.....	197
FIGURE 163. MEAN PROBABILITY THAT DRIVERS LOOKED IN A LOCATION WHEN MAKING A RIGHT LANE CHANGE BY EXPERIMENTAL CONDITION AND C/VIS	198
FIGURE 164. PERCENTAGE OF RIGHT LANE CHANGES IN WHICH DRIVERS LOOKED AT LEAST ONCE TO THE RECORDED LOCATIONS BY EXPERIMENTAL CONDITION	199
FIGURE 165. PERCENTAGE OF RIGHT LANE CHANGES IN WHICH DRIVERS LOOKED AT LEAST ONCE AT A GIVEN LOCATION	200

FIGURE 166. MEAN NUMBER OF GLANCES WHEN MAKING A RIGHT LANE CHANGE BY EXPERIMENTAL CONDITION	201
FIGURE 167. MEAN NUMBER OF GLANCES WHEN MAKING A RIGHT LANE CHANGE BY C/VIS AND EXPERIMENTAL CONDITION	202
FIGURE 168. MEAN GLANCE DURATION WHEN MAKING RIGHT LANE CHANGES BY EXPERIMENTAL CONDITION.....	203
FIGURE 169. MEAN GLANCE DURATION WHEN MAKING RIGHT LANE CHANGES BY C/VIS AND EXPERIMENTAL CONDITION	204
FIGURE 170. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY EXPERIMENTAL CONDITION	205
FIGURE 171. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY MONTH IN STUDY	206
FIGURE 172. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY C/VIS AND EXPERIMENTAL CONDITION	207
FIGURE 173. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY C/VIS AND MONTH IN STUDY	208
FIGURE 174. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY LANE-CHANGE DIRECTION.....	209
FIGURE 175. DRIVERS' MEAN TIMES TO CROSS LANE MARKINGS BY C/VIS, EXPERIMENTAL CONDITION, AND LANE- CHANGE DIRECTION	210
FIGURE 176. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY ENVIRONMENTAL CONDITION	211
FIGURE 177. DRIVERS' MEAN TIMES TO CROSS LANE MARKINGS BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	212
FIGURE 178. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	213
FIGURE 179. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY EXPERIMENTAL CONDITION	215
FIGURE 180. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY MONTH IN STUDY	216
FIGURE 181. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY C/VIS AND EXPERIMENTAL CONDITION	217
FIGURE 182. MEAN TIME TO COMPLETE A LANE CHANGE BY C/VIS AND MONTH IN STUDY	218
FIGURE 183. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY LANE-CHANGE DIRECTION.....	219
FIGURE 184. DRIVERS' MEAN TIMES TO COMPLETE A LANE CHANGE BY C/VIS, EXPERIMENTAL CONDITION, AND LANE-CHANGE DIRECTION	220
FIGURE 185. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY ENVIRONMENTAL CONDITION	221
FIGURE 186. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	222
FIGURE 187. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	223
FIGURE 188. PERCENTAGE OF TIME FROM SAMPLED LANE CHANGES THAT THE OBJECT DETECTION FEATURE WAS TURNED ON	227
FIGURE 189. MEAN OBJECT DETECTION LEVEL WHEN THE OBJECT DETECTION FEATURE WAS TURNED ON	228
FIGURE 190. PERCENTAGE OF LANE CHANGES WITH OBJECT DETECTION FEATURE TURNED ON.....	229
FIGURE 191. COMPARISON OF MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, "HOW MUCH DO YOU LIKE THE IDEA OF HAVING A CAMERA/VIDEO IMAGING SYSTEM (C/VIS) ON YOUR TRUCK?"	232
FIGURE 192. COMPARISON OF MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, "I THINK THE C/VIS IS USEFUL."	233
FIGURE 193. COMPARISON OF MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, "I THINK THE C/VIS IS IRRITATING."	235

FIGURE 194. COMPARISON OF MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS DESIRABLE.”	236
FIGURE 195. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “HOW MUCH DO YOU AGREE WITH THE STATEMENT, ‘THIS C/VIS ELIMINATES THE BLIND SPOTS AROUND MY TRUCK?’”	237
FIGURE 196. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “HOW MUCH DO YOU AGREE WITH THE STATEMENT, ‘THIS C/VIS IS EASY TO USE?’”	238
FIGURE 197. COMPARISON OF MEAN DRIVER RATING IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “HOW MUCH DO YOU AGREE WITH THE STATEMENT, ‘THE OBJECT DETECTION FEATURE IS USEFUL?’”	239
FIGURE 198. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “HOW UNCOMFORTABLE IS THE GLARE FROM THE MONITORS WHEN YOU ARE DRIVING AT NIGHT LOOKING FORWARD DOWN THE ROAD?”	240
FIGURE 199. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “BY HOW MUCH DOES THE LIGHTING FROM THE MONITORS REDUCE YOUR ABILITY TO SEE DETAILS IN THE ROAD AHEAD OF YOU (FOR EXAMPLE, ABILITY TO READ THE LICENSE PLATE CHARACTERS)?”	241
FIGURE 200. COMPARISON OF THE COMMERCIALLY AVAILABLE C/VIS DRIVERS’ HEIGHTS AND THEIR MEDIAN RATINGS IN RESPONSE TO THE QUESTION, “BY HOW MUCH DOES THE LIGHTING FROM THE MONITORS REDUCE YOUR ABILITY TO SEE DETAILS IN THE ROAD AHEAD OF YOU (FOR EXAMPLE, ABILITY TO READ THE LICENSE PLATE CHARACTERS)?”	242
FIGURE 201. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “HOW MUCH DOES THE MONITOR BLOCK YOUR VIEW OF THE ROAD?”	243
FIGURE 202. COMPARISON OF THE COMMERCIALLY AVAILABLE C/VIS DRIVERS’ HEIGHTS AND THEIR MEDIAN RATINGS IN RESPONSE TO THE QUESTION, “HOW MUCH DOES THE MONITOR BLOCK YOUR VIEW OF THE ROAD?”	244
FIGURE 203. COMPARISON OF MEAN DRIVER RATINGS IN RESPONSE TO THE QUESTION, “HOW EASY IS IT TO CLEAN THE CAMERA LENS?”	245
FIGURE 204. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, “HOW DIFFICULT IS IT TO BE AWARE OF OBJECTS LOCATED IN THE AREA AROUND YOUR TRUCK AND TRAILER WHILE DRIVING?”	246
FIGURE 205. COMPARISON OF A-C/VIS DRIVERS’ MEAN RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “DURING THE NIGHT AND WHEN THERE IS INCLEMENT WEATHER, HOW DIFFICULT IS IT TO BE AWARE OF OBJECTS LOCATED IN THE AREA AROUND YOUR TRUCK WHILE DRIVING?” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	247
FIGURE 206. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, “HOW DIFFICULT IS IT TO DETERMINE WHETHER THERE IS CLEARANCE BETWEEN THE BACK EDGE OF THE TRAILER AND THE FRONT OF A VEHICLE TRAVELING BESIDE THE TRUCK?”	248
FIGURE 207. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, “HOW DIFFICULT IS IT TO TELL WHAT KIND OF VEHICLE IS TRAVELING IN THE LANE BESIDE ME?”	249
FIGURE 208. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, “HOW DIFFICULT IS IT TO TELL HOW FAST A VEHICLE IN THE LANE BESIDE ME IS APPROACHING ME?”	250
FIGURE 209. COMPARISON OF A-C/VIS DRIVERS’ MEAN RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “DURING THE DAY AND WHEN THERE IS INCLEMENT WEATHER, HOW DIFFICULT IS IT TO TELL HOW FAST A VEHICLE IN THE LANE BESIDE ME IS APPROACHING ME?” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	251
FIGURE 210. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, “HOW DIFFICULT IS IT TO MERGE INTO TRAFFIC?”	252

FIGURE 211. COMPARISON OF A-C/VIS DRIVERS' MEAN RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, "DURING THE DAY AND WHEN THERE IS INCLEMENT WEATHER, HOW DIFFICULT IS IT TO MERGE INTO TRAFFIC?" (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	253
FIGURE 212. COMPARISON OF THE COMMERCIALLY AVAILABLE C/VIS DRIVERS' MEAN RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, "DURING THE DAY, HOW DIFFICULT IS IT TO MERGE INTO TRAFFIC?" (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES).....	254
FIGURE 213. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, "HOW CONFIDENT ARE YOU THAT YOU WILL NOT HIT AN ADJACENT VEHICLE WHEN MERGING INTO TRAFFIC?"	255
FIGURE 214. COMPARISON OF DRIVER RESPONSES TO THE QUESTION, "HOW DIFFICULT IS IT TO BACK UP TO AN OBJECT?"	256
FIGURE 215. FIGURE OF LANE-CHANGE DIRECTION	257
FIGURE 216. FREQUENCY OF DRIVERS' COMMENTS IN THE TEST CONDITION REGARDING THEIR FAVORITE FEATURES OF THE C/VIS.....	257
FIGURE 217. FREQUENCY OF DRIVERS' COMMENTS IN THE TEST CONDITION REGARDING THEIR LEAST FAVORITE FEATURES OF THE C/VIS	258
FIGURE 218. FREQUENCY OF DRIVERS' ADDITIONAL COMMENTS IN THE TEST CONDITION REGARDING THE C/VIS.	259
FIGURE 219. EXCERPT FROM A-C/VIS TRAINING MANUAL ON PROPER USE OF THE CENTER MONITOR	266
FIGURE 220. PLACEMENT OF A-C/VIS MONITORS IN TRUCK CAB	275
FIGURE 221. PLACEMENT OF COMMERCIAL C/VIS'S LEFT MONITOR ACCORDING TO VTECH USA, LLC SPECIFICATION.....	276
FIGURE 222. POTENTIAL PLACEMENT OF COMMERCIAL C/VIS'S LEFT MONITOR TO AVOID POTENTIAL OBSTRUCTION OF LEFT FENDER MIRROR; ELEMENTS OF THE INSTRUMENT PANEL AND WINDOW DEFROSTER ARE OBSTRUCTED	276
FIGURE 223. MAP OF DRIVER 1'S NIGHTLY ROUTE.....	413
FIGURE 224. MAP OF DRIVER 3'S NIGHTLY ROUTE.....	414
FIGURE 225. MAP OF DRIVER 4'S NIGHTLY ROUTE.....	415
FIGURE 226. MAP OF DRIVER 5'S NIGHTLY ROUTE.....	416
FIGURE 227. MAP OF DRIVER 13'S NIGHTLY ROUTE.....	417
FIGURE 228. MAP OF DRIVER 15'S NIGHTLY ROUTE.....	418
FIGURE 229. MAP OF DRIVER 7'S NIGHTLY ROUTE.....	419
FIGURE 230. MAP OF DRIVER 8'S NIGHTLY ROUTE.....	420
FIGURE 231. MAP OF DRIVER 9'S NIGHTLY ROUTE.....	421
FIGURE 232. MAP OF DRIVER 10'S NIGHTLY ROUTE.....	422
FIGURE 233. MAP OF DRIVER 12'S NIGHTLY ROUTE.....	423
FIGURE 234. MAP OF DRIVER 14'S NIGHTLY ROUTE.....	424
FIGURE 235. EXAMPLE OF A VIEW SETUP IN DART	426
FIGURE 236. TRIGGER CHART SHOWING AN UNVALIDATED TRIGGER.....	427
FIGURE 237. TRIGGER CHART SHOWING AN UNVALIDATED TRIGGER AND AN EPOCH.....	428
FIGURE 238. VALID LONGITUDINAL ACCELERATION TRIGGER (LA)	429
FIGURE 239. INVALID LONGITUDINAL ACCELERATION TRIGGER (LA)	429
FIGURE 240. VALID SWERVE TRIGGER (SWERVE).....	430

FIGURE 241. INVALID SWERVE TRIGGER (SWERVE).....	430
FIGURE 242. VALID TIME-TO-COLLISION (TTC) TRIGGER.....	431
FIGURE 243. INVALID TIME-TO-COLLISION (TTC) TRIGGER.....	432
FIGURE 244. “NO VIDEO” EXAMPLE	433
FIGURE 245. DRAG TRIGGER STRAIGHT DOWN TO VALIDATE	433
FIGURE 246. YELLOW EVENT MARKER AND EVENT ID	434
FIGURE 247. INVALIDATE TRIGGER.....	434
FIGURE 248. ILLUSTRATION OF TRUCK INTERIOR.....	441
FIGURE 249. COMPARISON OF A-C/VIS AND THE COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS PLEASANT.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	510
FIGURE 250. COMPARISON OF A-C/VIS AND THE COMMERCIALLY AVAILABLE C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS GOOD.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	511
FIGURE 251. COMPARISON OF A-C/VIS AND THE COMMERCIALLY AVAILABLE C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS NICE.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES).....	512
FIGURE 252. COMPARISON OF A-C/VIS AND THE COMMERCIALLY AVAILABLE C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS EFFECTIVE.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	513
FIGURE 253. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS ASSISTING.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	514
FIGURE 254. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 1, MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE STATEMENT, “I THINK THE C/VIS IS SLEEP-INDUCING.” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	515
FIGURE 255. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “HOW DOES YOUR DRIVING PERFORMANCE WITH A C/VIS COMPARE TO YOUR DRIVING PERFORMANCE WITHOUT A C/VIS?” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES).....	516
FIGURE 256. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “HOW MUCH DO YOU AGREE WITH THE STATEMENT, ‘I WOULD LIKE TO HAVE THIS C/VIS IN MY TRUCK?’” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	517
FIGURE 257. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “HOW MUCH DO YOU AGREE WITH THE STATEMENT, ‘I KNOW HOW TO USE ALL THE FEATURES THE SYSTEM OFFERS?’” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES).....	518
FIGURE 258. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “WHEN IT'S CLEAR OUTSIDE, HOW OFTEN DOES THE CAMERA LENS GET DIRTY TO THE POINT WHERE IT AFFECTS THE VIEW OF THE ROAD?” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES).....	519
FIGURE 259. COMPARISON OF A-C/VIS AND COMMERCIAL C/VIS MEAN DRIVER RATINGS IN MONTH 2, MONTH 3, AND MONTH 4 IN RESPONSE TO THE QUESTION, “WHEN IT'S RAINING, HOW OFTEN DOES THE CAMERA LENS GET DIRTY TO THE POINT WHERE IT AFFECTS THE VIEW OF THE ROAD?” (D = NUMBER OF DRIVERS; R = NUMBER OF RESPONSES)	520

LIST OF TABLES

TABLE 1. SUMMARY OF DRIVERS' OPINIONS TOWARDS C/VISs	xvi
TABLE 2. CRASHES IN 1999 THAT INVOLVED TRUCKS MAKING LANE CHANGES INTO ANOTHER VEHICLE TRAVELING STRAIGHT, ADAPTED FROM SEN ET AL. (2003)	13
TABLE 3. FREQUENCY AND PERCENT OF ACCIDENT CATEGORY IN LTCCS	15
TABLE 4. CRASH CODE FREQUENCY AND PERCENT OF TOTAL	16
TABLE 5. C/VIS-RELEVANT CRASH CODES EXAMINED WITHIN THE LTCCS	18
TABLE 6. FREQUENCY AND PERCENTAGE OF BLIND SPOT RELATION IN CRASHES	19
TABLE 7. CRASH CODE FREQUENCY AND PERCENT OF ALL CRASHES BY BLIND SPOT INVOLVEMENT	19
TABLE 8. TRUCK CRASHES IN 2009 GES DATA SET	20
TABLE 9. CRASHES IN WHICH TRUCK WAS THE STRIKING VEHICLE IN 2009 GES DATA SET	21
TABLE 10. STRIKING TRUCK CRASHES BY PRE-CRASH MANEUVER	22
TABLE 11. CONFIGURATION SUMMARY OF CONCEPTS (EARLY VERSION). TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008)	28
TABLE 12. MONITOR IMAGE SIZES USED IN THE FORMAL ON-ROAD TESTS, TAKEN FROM WIERWILLE, SCHAUDT, SPAULDING, ET AL. (2008)	31
TABLE 13. REVISED FINAL CONFIGURATION SUMMARY LISTING OF CONCEPTS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008)	39
TABLE 14. MONITOR IMAGE SIZES USED IN THE SPECIFICATIONS, TAKEN FROM WIERWILLE, SCHAUDT, GUPTA, ET AL. (2008)	41
TABLE 15. DRIVERS AND POWER UNITS WITHIN FLEETS	56
TABLE 16. SUMMARY OF C/VIS FEATURES	85
TABLE 17. WEIGHTINGS USED IN C/VIS TRADE STUDY	86
TABLE 18. TRADE STUDY WEIGHTED SCORES FOR EACH C/VIS	88
TABLE 19. ORDER OF TRIALS	95
TABLE 20. PARTICIPANT DEMOGRAPHICS	106
TABLE 21. PARTICIPANT EXPERIENCE LEVELS AND DRIVING CHARACTERISTICS	106
TABLE 22. TRIGGERS AND TRIGGER VALUES USED TO IDENTIFY CRITICAL INCIDENTS	124
TABLE 23. DESCRIPTION OF EACH EVENT TYPE	128
TABLE 24. SCE PRE-CRASH EVENT CATEGORIES	134
TABLE 25. SCE PRE-CRASH EVENT BY SEVERITY	135
TABLE 26. SCE PRE-CRASH EVENT BY SEVERITY AND TRIGGER LOGIC	137
TABLE 27. SCE SEVERITY BY HOUR OF OCCURRENCE	147
TABLE 28. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY C/VIS AND MONTH IN STUDY	172
TABLE 29. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY LANE-CHANGE DIRECTION	175
TABLE 30. DRIVERS' MEAN CLEARANCE TO AN ADJACENT VEHICLE BY C/VIS, EXPERIMENTAL CONDITION, AND LANE-CHANGE DIRECTION	176
TABLE 31. DISTRIBUTION OF SAMPLED LEFT LANE CHANGES BY ENVIRONMENTAL CONDITION	180

TABLE 32. DRIVERS' CLEARANCE DURING LEFT LANE CHANGES BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	182
TABLE 33. DRIVERS' MEAN CLEARANCE DURING LEFT LANE CHANGES BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	184
TABLE 34. DISTRIBUTION OF SAMPLED RIGHT LANE CHANGES BY ENVIRONMENTAL CONDITION	184
TABLE 35. DRIVERS' CLEARANCE DURING RIGHT LANE CHANGES BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION.....	186
TABLE 36. DRIVERS' MEAN CLEARANCE DURING RIGHT LANE CHANGES BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	188
TABLE 37. DRIVERS' MEAN TIME TO CROSS LANE MARKINGS BY C/VIS AND MONTH IN STUDY	208
TABLE 38. DRIVERS' MEAN TIMES TO CROSS LANE MARKINGS BY ENVIRONMENTAL AND EXPERIMENTAL CONDITIONS.....	212
TABLE 39. DRIVERS' MEAN TIMES TO CROSS LANE MARKINGS BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	214
TABLE 40. DRIVERS' MEAN TIME TO COMPLETE A LANE CHANGE BY DIRECTION, C/VIS AND EXPERIMENTAL CONDITION	220
TABLE 41. DRIVERS' TIME TO COMPLETE A LANE CHANGE BY EXPERIMENTAL CONDITION AND ENVIRONMENTAL CONDITION	222
TABLE 42. DRIVERS' TIME TO COMPLETE A LANE CHANGE BY C/VIS, EXPERIMENTAL CONDITION, AND ENVIRONMENTAL CONDITION.....	224
TABLE 43. PERCENTAGE OF LANE CHANGES DRIVERS LOOKED AT MONITORS BY ENVIRONMENTAL CONDITION	225
TABLE 44. PERCENTAGE OF LANE CHANGES DRIVERS LOOKED AT MONITORS BY LANE CHANGE DIRECTION	225
TABLE 45. PERCENTAGE OF LANE CHANGES DRIVERS LOOKED AT MONITORS BY CLEARANCE GROUPING	226
TABLE 46. SUMMARY OF DRIVERS COMPLETING COMPARISON TASK AND FOLLOW-UP INTERVIEW	260
TABLE 47. SUMMARY OF DRIVERS' OPINIONS TOWARDS C/VISS	271
TABLE 48. SAFETY VISION® ON-BOARD CAMERA SYSTEM	312
TABLE 49. V-TECH USA'S SIDETRACKER SYSTEM	315
TABLE 50. WINSTED PRODUCTS DUAL CAMERA SYSTEM	318
TABLE 51. MOBILE AWARENESS VISIONSTAT™ CAMERA SYSTEM	321
TABLE 52. ASA ELECTRONICS' VOYAGER SYSTEM.....	325
TABLE 53. TRIGGER TYPES	427
TABLE 54. EYE GLANCE LOCATION DEFINITIONS AND CODES.....	439
TABLE 55. BUSES	444
TABLE 56. STRAIGHT TRUCKS.....	445
TABLE 57. TRACTOR-TRAILER TRUCKS	446
TABLE 58. EMERGENCY VEHICLES.....	447
TABLE 59. DESCRIPTION OF THE ACCIDENT TYPES (THIERIEZ, RADJA, & TOTH, 2002)	461
TABLE 60. INCIDENT TYPE TABLE (HANOWSKI, OLSON, HICKMAN, & DINGUS, 2006; HANOWSKI, PEREZ, & DINGUS, 2005; HANOWSKI, WIERWILLE, GARNES, & DINGUS, 2000; HICKMAN ET AL., IN PRESS).....	463

CHAPTER 1. INTRODUCTION

Contrary to popular belief, truck drivers do not have better visibility of the road due to their higher seating position. Large blind spots exist along the sides, rear, and front of their vehicles (Federal Motor Carrier Safety Administration, 2006). For instance, the blind spot located behind a tractor-trailer extends up to 61 m (Indiana University of Pennsylvania in cooperation with the American Association of Motor Vehicle Administrators and the Federal Motor Carrier Safety Administration, 2004) .

Camera/Video Imaging Systems (C/VISs) use video cameras mounted on the truck and/or trailer to show drivers the area around the tractor-trailer on monitors inside the truck cabin. C/VISs help drivers execute lane changes and provide a countermeasure to blind-spot-related crashes by allowing drivers to see objects not ordinarily visible with a typical mirror configuration. C/VISs are expected to help reduce the number of crashes resulting from improper tractor-trailer lane changes/merges, turning maneuvers, and backing maneuvers. An analysis presented in this report estimates these categories to account for 225 fatalities (7.2 percent of fatal large-truck crashes recorded in 2009) and 26,280 non-fatal crashes (9 percent of the large-truck crashes recorded in 2009 that resulted in injury or property damage). C/VISs may also reduce the number of frontal crashes if they allow drivers to spend less time determining the location of surrounding vehicles and more time looking at the forward roadway. C/VISs may also make it easier to merge into traffic, particularly at nighttime and in inclement weather, thus reducing commercial vehicle operator workload and stress.

Commercially available C/VISs exist and have been installed on some truck fleets in the United States. For example, U.S. Xpress reportedly has a C/VIS called Sidetracker installed on 8,000 trucks in their fleet (V-TECH USA LLC, 2009). The Sidetracker system is a cab-only solution that uses cameras mounted on the truck's fenders (Figure 22) to show drivers the area beside the truck on monitors mounted on the dash (Figure 23).



Figure 22. Placement of Commercial C/VIS's Cameras on Left Fender



Figure 23. Placement of Commercial C/VIS's Monitors on Truck Dash

With the realization of the potential safety benefit that C/VISs stand to provide, both the National Highway Traffic Safety Administration (NHTSA) and the Federal Motor Carrier Safety Administration (FMCSA) began collaboratively funding studies to investigate C/VISs for commercial motor vehicles (CMVs) so that the potential safety benefits could be maximized. The current U.S. Department of Transportation (DOT)-funded C/VIS research program, which the study reported here is part of, consisted of the following earlier project phases: 1) developing a static testing method for assessing the quality of indirect visibility on heavy trucks (Jenness, Llaneras, & Huey, 2008), 2) developing a performance specification for daytime C/VISs on heavy vehicles (Wierwille, Schaudt, Gupta, et al., 2008), and 3) enhancing C/VISs to provide all-around visibility to drivers during nighttime and inclement weather conditions (Wierwille et al., in press). In the third phase, the Enhanced C/VIS (E-C/VIS) that was prototyped was markedly different from existing commercially available C/VISs in that, in addition to the two fender-mounted cameras, it used a wide-angle look-down camera on the trailer to generate a bird's-eye-view of the area behind the trailer (Figure 24). The oversized cameras used were selected based on their high image quality and were not intended to be suitable for robust fleet operation. The E-C/VIS monitors were positioned inside the truck cab along the A-Pillars and top center of the windshield (Figure 25). To provide additional visibility at night, the E-C/VIS cameras used a retractable infrared (IR) filter that enabled them to become sensitive to IR light emitted from IR illuminators mounted along the trailer (Figure 26). Lastly, the E-C/VIS had an image-processing feature that could improve vehicle conspicuity by tracing white lines around objects displayed on the monitors (Figure 27).



Figure 24. Placement of E-C/VIS Fender and Trailer Cameras, Taken from Wierwille et al. (in press)



Figure 25. Placement of E-C/VIS Monitors in Truck Cabin, Taken from Wierwille et al. (in press)



Figure 26. Placement of E-C/VIS Infrared Illuminators, Taken from Wierwille et al. (in press)



Figure 27. Example of Fender-mounted E-C/VIS View with Image Processing, Taken from Wierwille et al. (in press)

Although some of these features have recently progressed into the commercial marketplace (such as the limited use of IR light), many commercial C/VISs remain cab-only solutions and do not include a trailer-mounted camera due to the cost of such an implementation. A common concern is that, in many operations, trailers do not remain permanently coupled to a tractor (American Trucking Associations, 2010). Nevertheless, the on-road testing performed by Wierwille et al. (in press) revealed that the rear wide-angle look-down view was favored and regularly used by drivers during test-track testing, demonstrating that the rear camera was an essential C/VIS component.

The E-C/VIS prototype utilized in the earlier test-track studies was excellent for evaluating the C/VIS concept, but was impractical for use in the Technology Field Demonstration (TFD) owing, in part, to its large size and moving parts. A roadworthy version of the E-C/VIS, termed the Advanced C/VIS (A-C/VIS) was therefore developed in the current study. The A-C/VIS was designed to leverage the E-C/VIS's features, while also being compact and capable of operating under substantial vibration. Furthermore, the A-C/VIS possessed features that improved upon the E-C/VIS's design. These features included alternate monitor locations, dimmable displays, translucent turn signal light diffusers, and an optimized Driver-Vehicle Interface (DVI). The A-C/VIS's main elements are summarized below:

- Three cameras were mounted on the truck: a camera on each fender pointing back along the trailer, and a rear wide-angle look-down camera mounted on the top-center of the back-side of the trailer (Figure 28). The coverage provided by the A-C/VIS cameras is shown by the grey shaded area in Figure 29.
- Three monitors were mounted inside the cabin: one at the top of the left A-pillar, one at the top-center of the windshield, and one at the top of the right A-pillar (Figure 30).
- The DVI was built into the left monitor and allowed all functionality to be accessed with one button press (Figure 31). The functionality included switching between color (day mode) and monochrome (night mode), adjusting the monitor brightness, activating the object detection feature (which traced white lines around objects using augmented reality), and adjusting the amount of object detection (the driver could select the preferred thickness of the lines).
- IR illuminators mounted on the truck and trailer were used by the A-C/VIS to provide night-vision capabilities during night mode (Figure 32).



Figure 28. Placement of A-C/VIS Fender and Trailer Cameras

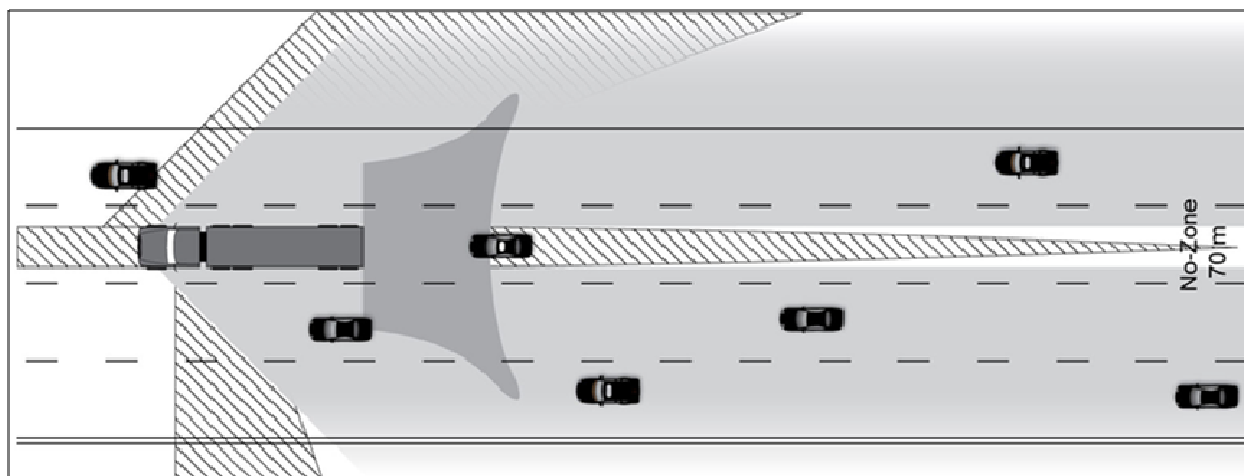


Figure 29. Coverage Provided by A-C/VIS Cameras Shown by Grey Shading. No-Zone Shown by the Diagonal Lines

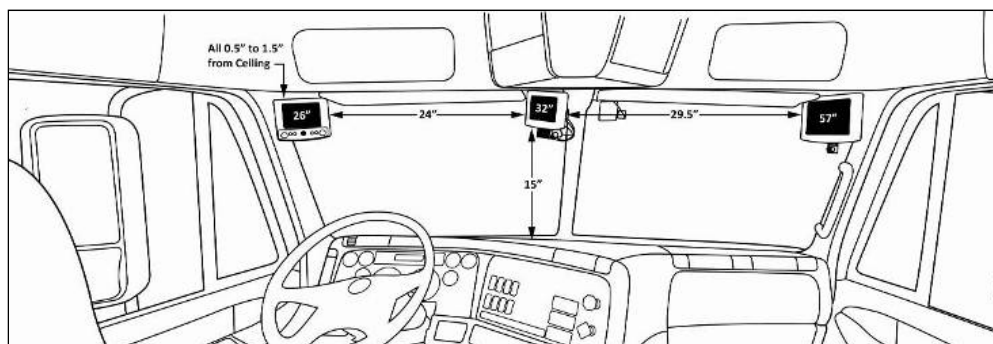


Figure 30. Placement of A-C/VIS Monitors in Truck Cab



Figure 31. The A-C/VIS DVI Built Into the Left Monitor



Figure 32. Infrared Illuminators Mounted on Truck and Trailer

PURPOSE

The purpose of this study was to more extensively evaluate the favorable results from previous C/VIS test-track research (Wierwille et al., in press; Wierwille, Schaudt, Gupta, et al., 2008; Wierwille, Schaudt, Spaulding, et al., 2008) by investigating the implementation of C/VISs in a real-world operation. This was accomplished by performing a TFD, where drivers' performance with and without a C/VIS was unobtrusively recorded using the naturalistic driving study methodology (Blanco et al., in press; Hanowski et al., 2008). The focus of the TFD was to determine: 1) the effect of C/VISs on drivers' involvement in Safety-Critical Events (SCEs), 2)

the effect of C/VISs on drivers' lane-change performance, and 3) drivers' opinions of C/VISs. Through these analyses, the potential disadvantages of C/VISs were concurrently investigated. The results from this study are expected to support the U.S. DOT in identifying the implications of providing C/VISs to CMV drivers.

Two C/VISs were included in the TFD: 1) The A-C/VIS, which was included to investigate the effects of the advanced features (i.e., a rearview camera, night vision capability, and the object detection feature) on drivers' performance, and 2) a commercially available C/VIS, which was selected in order to investigate the effect of a readily available commercial C/VIS on drivers' performance. The A-C/VIS and the commercially available C/VIS were installed on six tractor-trailers that were provided by Schneider National; three trucks possessed the A-C/VIS and three trucks possessed the commercial C/VIS. Twelve CMV drivers drove one truck each; six participants drove A-C/VIS-equipped trucks, while the other six drove trucks equipped with the commercially available C/VIS. The trucks were driven one month without the C/VIS (Baseline condition) and three months with the C/VIS (Test condition) (Figure 33). The TFD primarily compared driver performance between Baseline and Test conditions; however, the study also explored the disparity in drivers' performance across C/VISs. Such comparisons provide insight on whether the third camera, night vision, and object detection features benefit drivers' performance more than a cab-only solution C/VIS. The research questions posed to assess CMV drivers' performance with, and attitudes towards, C/VISs are listed below.

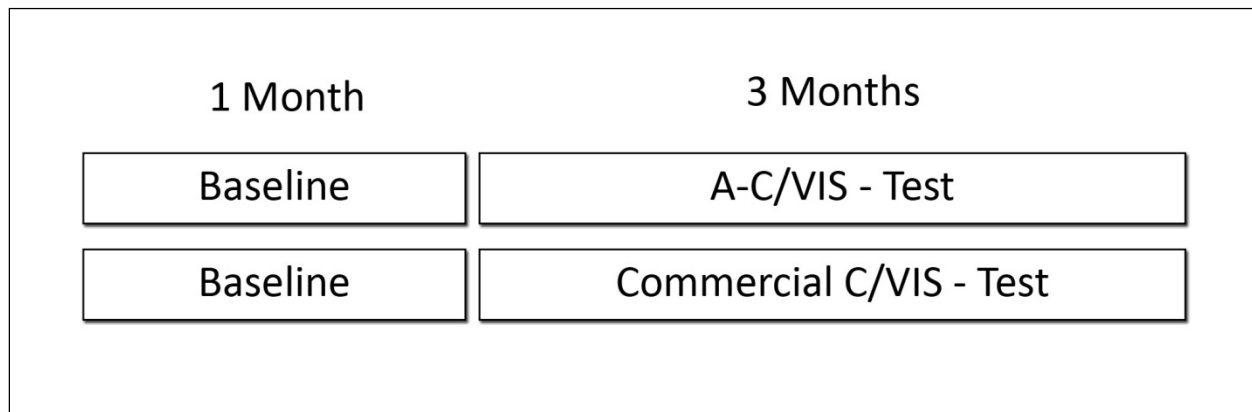


Figure 33. Experimental Conditions for the TFD

Research Questions

The research questions posed at the onset of the TFD are grouped according to the three main objectives: 1) to determine the effect of C/VISs on drivers' involvement in SCEs, 2) to determine the effect of C/VISs on drivers' lane-change performance, and 3) to determine drivers' opinions of C/VISs. In answering these research questions, the potential disbenefits of C/VISs were concurrently investigated.

Involvement in Safety-Critical Events

The following research questions were posed to determine whether drivers' SCE rate diminished when driving with a C/VIS.

1. Overall, are drivers involved in fewer SCEs when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 1.1 With respect to each C/VIS tested (i.e., the A-C/VIS and the commercially available C/VIS), are drivers involved in fewer SCEs when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 1.2 Are drivers involved in fewer SCEs when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

The following research questions were posed to determine whether drivers' visual behavior prior to SCEs changed when driving with a C/VIS.

2. Overall, do drivers' eye glance patterns before the occurrence of SCEs differ when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 2.1 With respect to each C/VIS tested, do drivers' eye glance patterns before the occurrence of SCEs differ when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 2.2 Do drivers' eye glance patterns before the occurrence of SCEs differ when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

Lane-Change Behavior

The following research questions were posed to investigate whether the distance between the tractor-trailer and an adjacent vehicle when changing lanes differed when driving with a C/VIS.

3. Overall, does the amount of clearance between the trailer and an adjacent vehicle differ when drivers make lane changes when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 3.1 With respect to each C/VIS tested, does the amount of clearance between the trailer and an adjacent vehicle differ when drivers make lane changes when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 3.2 Does the amount of clearance between the trailer and an adjacent vehicle differ when drivers make lane changes when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

The following research questions were posed to investigate whether the frequency of close lane changes to an adjacent vehicle changed when driving with a C/VIS.

4. Overall, are the number of lane changes made in which an adjacent vehicle is close fewer when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
- 4.1 With respect to each C/VIS tested, are the number of lane changes made in which an adjacent vehicle is close fewer when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?

- 4.2 Are the number of lane changes made in which an adjacent vehicle is close fewer when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

The following research questions were posed to investigate whether the time taken to change lanes differed when driving with a C/VIS.

5. Overall, do drivers take longer to execute lane-change maneuvers when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
 - 5.1 With respect to each C/VIS tested, do drivers take longer to execute lane-change maneuvers when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
 - 5.2 Do drivers take longer to execute lane-change maneuvers when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

The following research questions were posed to investigate whether drivers' visual behavior prior to changing lanes changed when driving with a C/VIS.

6. Overall, do drivers' eye glance patterns when changing lanes differ when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
 - 6.1 With respect to each C/VIS tested, do drivers' eye glance patterns when changing lanes differ when a C/VIS is available compared to when a C/VIS is not available (within-subject comparison)?
 - 6.2 Do drivers' eye glance patterns when changing lanes differ when an A-C/VIS is available compared to when the commercial C/VIS is available (between-subjects comparison)?

Driver Preferences

Bi-weekly meetings with drivers were held to measure their perceptions of their driving performance and preferences towards the C/VISs. The following research questions were posed to investigate whether these opinions changed when driving with a C/VIS.

7. Overall, do drivers' attitudes towards the C/VISs change once a C/VIS is available? Note: drivers' attitudes were investigated across multiple dimensions using questionnaires. Dimensions included driving task difficulty, C/VIS utility, C/VIS annoyance, and C/VIS ease of use.
 - 7.1 With respect to each C/VIS tested, do drivers' attitudes towards the C/VISs change once a C/VIS is available?
 - 7.2 Do drivers' attitudes towards the A-CVIS differ from drivers' attitudes towards the commercially available C/VIS (between-subjects comparison)?

DOCUMENT OVERVIEW

This report is structured as follows. Chapter 1 introduced the concept of a C/VIS, and presented the objectives of the TFD as well as the specific research questions posed to investigate driver performance with C/VISs. Chapter 2 presents background information, including a definition of the problem scope derived from an analysis of the Large Truck Crash Causation Study (LTCCS)

database, a review of relevant literature, and the results from fleet manager interviews regarding the value of C/VISs. Chapter 3 details the components of the A-C/VIS, while Chapter 4 provides a review of commercially available C/VISs and how the commercial C/VIS was selected by way of a trade study. Chapter 5 presents results of a static object detection task based on Jenness et al. (2008) and Wierwille et al. (in press). Chapter 6 presents the methods used to perform the TFD, which include an explanation of the experimental design, data collection process, and data reduction process. Results of drivers' involvement in SCEs, lane-change performance, and subjective preference opinions are presented in Chapter 7. The findings are discussed in Chapter 8, while Chapter 9 presents conclusions based on the key findings, identifies the study limitations, and suggests future C/VIS research.

CHAPTER 2. BACKGROUND AND PROBLEM SCOPE

This chapter presents background information relevant to C/VISs. It begins by defining the problem scope for C/VISs by analyzing the Large Truck Crash Causation Study and other crash reporting databases. A review of the literature relevant to C/VISs and their evaluation is then presented. The chapter concludes with a presentation of the findings from interviews held with trucking industry fleet managers regarding their thoughts on C/VISs and the barriers to their implementation.

PROBLEM SCOPE

The 2006 Large Truck Crash Facts report, which annually synthesizes crash data from the Fatality Analysis Reporting System (FARS), the General Estimates System (GES), and the Motor Carrier Management Information System (MCMIS), indicates that in 2006 there were approximately 368,000 police-reported crashes involving large trucks. Approximately 1 percent of these crashes resulted in at least one fatality (Federal Motor Carrier Safety Administration, 2008). An examination of these 4,695 fatal large-truck crashes revealed that the following percentage of crashes might be addressable by a C/VIS. One percent (45 fatalities) of these crashes occurred due to drivers making improper lane changes, 1 percent (45 fatalities) occurred due to the drivers' vision being obscured by weather, and 0.4 percent (17 fatalities) occurred when the driver started or reversed the truck improperly (Federal Motor Carrier Safety Administration, 2008). Overall, these crash categories comprise 2.4 percent of the 4,695 fatal large truck crashes, in which there were 107 fatalities.

Sen, Smith and Najm (2003) investigated both light- and heavy-vehicle lane-change crashes in the United States based on data from the 1999 National Automotive Sampling System/GES crash database. In the Sen et al. (2003) analysis, lane-change crashes were defined as two-vehicle crashes occurring when one vehicle encroached into the path of another vehicle which was initially on a parallel travel path with the first vehicle. This definition included several different maneuvers: lane changes, merges, passes, drifts, turns, and leaving or entering a parking position. Additionally, the Sen et al. analysis included all major categories of crashes: fatal, injury, and property-damage crashes. The study found that approximately 539,000 two-vehicle lane-change crashes occurred in the United States in 1999. This constitutes about 9 percent of the 6.3 million crashes in the 1999 GES. These lane-change crashes are further decomposed into seven categories: 1) typical lane changes, 2) turning at intersection, 3) drifting, 4) passing combined with turning, 5) passing, 6) leaving parked position, and 7) merging. Of primary importance to the current study is the percentage of crashes (in each category) in which a large truck was the vehicle performing the lane change. The information extracted from the results of Sen et al. (2003) indicate the number of large-truck lane-change crashes that might be prevented by C/VISs (Table 2). Please note that the "drifting" crash category was not included in this count since a C/VIS is not likely to assist drivers in avoiding these types of crashes.

Table 2. Crashes in 1999 that Involved Trucks Making Lane Changes into Another Vehicle Traveling Straight, Adapted from Sen et al. (2003)

Scenario Name	Number of Lane-Change Crashes (All Vehicles)		Type of Vehicle Struck by Truck Making Lane Change						Number of Truck Lane-Change Crashes
			Light Vehicle	Truck	Bus	Emergency Vehicle	Other Vehicle	Percentage of all Lane Change Crashes	
“Typical” lane changes	207,000	43.4%	10.2%	0.8%	0.0%	0.0%	0.2%	11.2%	23,184
Turning at intersection	89,000	18.7%	10.1%	0.0%	0.0%	0.0%	0.2%	10.3%	9,167
Other and unknown	64,000	13.4%	N/A	N/A	N/A	N/A	N/A	N/A	0
Passing combined with turning	46,000	9.6%	1.6%	0.0%	0.0%	0.0%	0.1%	1.8%	828
Passing	27,000	5.7%	5.3%	0.2%	0.0%	0.0%	2.2%	7.8%	2,106
Leaving parked position	25,000	5.2%	1.7%	0.0%	1.3%	0.0%	0.0%	3.0%	750
Merging	19,000	4.0%	12.9%	1.3%	0.0%	0.0%	0.0%	14.1%	2,679
Total	477,000		7.4% (n = 35,146)	(n = 1,957)	0.1% (n = 325)	0.0% (n = 0)	0.3% (n = 1,232)	8.1%	38,714

N/A – not applicable

0.4%

These data indicate that large trucks were involved in 38,714 crashes as a result of making lane changes into other vehicles that were traveling on a parallel path. This comprises approximately 8 percent of the total number of lane-change crashes recorded across all vehicle types in the 1999 GES. The majority of the large truck lane-change crashes (35,146 crashes, or 91 percent) involved large trucks performing lane changes into light vehicles. It is noteworthy that crashes resulting from a truck sideswiping another heavy vehicle occurred less frequently. Because the GES shows that there were 453,000 police-reported crashes involving large trucks in 1999, it can be said that the 38,714 large truck lane-change crashes comprise 9 percent of total number of police-reported large-truck crashes.

Kostyniuk, Streff, and Zakrajsek (2002) examined the 1995 to 1998 FARS database to examine differences in car-car and car-truck crashes. Specifically, the interactions preceding a crash were examined. A total of 35,244 fatal car-car and 10,732 fatal car-truck crashes were analyzed. Kostyniuk et al. found that fatal crashes involving improper lane changes were more likely to occur in car-truck crashes than in car-car crashes. However, they also found that fatal car-truck crashes involving improper lane changes accounted for 2.2 percent of the observed fatal car-truck crashes.

Analysis of the Large Truck Crash Causation Study (LTCCS) Database

In 2007, FMCSA and NHTSA completed the LTCCS. The purpose of the study was to examine the reasons for serious crashes involving large trucks. A nationally representative sample of injurious and fatal crashes was collected from the 120,000 large-truck crashes that occurred between April 2001 and December 2003. The sample consisted of 963 crashes, which involved 1,123 large trucks and 959 motor vehicles that were not large trucks. The 963 large-truck crashes resulted in 249 fatalities and 1,654 injuries. Crash scene data were collected at 24 sites across 17 states. Data were collected on up to 1,000 dimensions, including the condition of the truck driver and the other drivers involved before the crash, the drivers' behavior during the crash, the condition of the trucks and other vehicles, roadway factors, and weather conditions.

The LTCCS database was analyzed to determine the number of crashes a C/VIS may help prevent. *C/VIS-relevant* crashes were defined as crashes that may have been avoided had the driver received information pertaining to objects located in the blind spots. The following crash scenarios were considered:

- Two vehicles going in the same direction. Large truck performs lane change into other vehicle's lane.
- Two vehicles going in the same direction. Large truck merges onto highway and strikes other vehicle.
- Large truck turns across another vehicle's path that is traveling in the same direction.
- Large truck backs into other vehicle/pedestrian.

Regrettably, the following scenarios could not be considered in the analysis due to LTCCS data coding limitations:

- Two vehicles going in the same direction. Large truck performs lane change, causing other vehicle to veer off road

- Rear-end crashes that arise from drivers failing to perceive a stopping, or decelerating, lead vehicle because they are checking their mirrors in preparation to change lanes.

It is important to note that the LTCCS data set only sampled severely injurious and fatal crashes. The estimates produced from the LTCCS data analysis are therefore conservative (Hedlund & Blower, 2006).

Sideswipe, Turn Across Path, and Backing LTCCS Crashes

Table 3 presents the frequency and percent of each Accident Category recorded in the LTCCS (all non-zero weighted cases are included). Accident Category is a categorization of the configuration of collisions. Here, a collision is defined as the first harmful event in a crash involving a vehicle and an object, resulting in property damage or human injury. This operational definition of an object is lenient and includes vehicles, people, animals, fixed objects, roadway surface, and the ground strikes (including impacting the ground due to sudden deceleration in soft soil). The operational definition of collision specifically excludes roadway departures with no damage or injury. The exact assignment of this variable was made by the individual case reviewer based on available information (e.g., police reports, interviews, inspections).

Table 3. Frequency and Percent of Accident Category in LTCCS

Accident Category	Frequency	Percent
Miscellaneous	280	24.9
Rear-End	274	24.4
Same Trafficway Same Direction - Sideswipe/Angle	121	10.8
Right Roadside Departure	89	7.9
Straight Paths	69	6.1
Left Roadside Departure	69	6.1
Turn Across Path	58	5.2
Same Trafficway Opposite Directions - Sideswipe/Angle	42	3.7
Turn Into Path	42	3.7
Head-On	36	3.2
Single Driver - Forward Impact	36	3.2
Same Trafficway Opposite Directions - Forward Impact	4	0.4
Same Trafficway Same Direction - Forward Impact	3	0.3
Total	1,123	100.0

It can be seen from the table above that sideswipes occurring in the same travel direction were the third most common accident category (10.8%, or 121 fatal crashes).

The CrashCode variable provides additional detail on the Accident Category variable. The frequency and percent of all crash codes with an observed frequency of at least one crash is provided in Table 4.

Table 4. Crash Code Frequency and Percent of Total

Crash Code and Description	Frequency	Percent
00 - No Impact	14	1.2
01 - Right Roadside Departure - Drive off Road	49	4.4
02 - Right Roadside Departure - Control/Traction Loss	34	3.0
03 - Right Roadside Departure - Avoid Collision w/ Vehicle, Pedestrian, Animal	5	0.4
05 - Specifics Unknown	1	0.1
06 - Left Roadside Departure - Drive off Road	26	2.3
07 - Left Roadside Departure - Control/Traction Loss	39	3.5
08 - Left Roadside Departure - Avoid Collision w/ Vehicle, Pedestrian, Animal	3	0.3
10 - Specifics Unknown	1	0.1
11 - Forward Impact - Parked Vehicle	2	0.2
12 - Forward Impact - Stationary Object	1	0.1
13 - Forward Impact - Pedestrian/Animal	28	2.5
14 - End Departure	1	0.1
15 - Forward Impact - Specifics Other	4	0.4
20 - Rear-End - Stopped	64	5.7
21 - Rear-End - Stopped, Straight	42	3.7
22 - Rear-End - Stopped Left	3	0.3
24 - Rear-End - Slower	37	3.3
25 - Slower, Going Straight	54	4.8
26 - Rear-End - Slower Going Left	1	0.1
27 - Rear-End - Slower Going Right	1	0.1
28 - Rear-End - Decelerating (Slower)	40	3.6
29 - Rear-End - Decelerating (Slower) Going Straight	19	1.7
31 - Rear-End - Decelerating (Slower) Going Right	2	0.2
32 - Rear-End - Specifics Other	11	1.0
42 - Forward Impact - Specifics Other	2	0.2
43 - Forward Impact - Specifics Unknown	1	0.1
44 - Sideswipe/Angle - Straight Ahead on Left	4	0.4
45 - Sideswipe/Angle - Straight Ahead on Left/Right	46	4.1
46 - Sideswipe/Angle - Changing Lanes to the Right	25	2.2
47 - Sideswipe/Angle - Changing Lanes to the Left	25	2.2
48 - Sideswipe/Angle - Specifics Other	21	1.9
50 - Head-On - Lateral Move (Left/Right)	9	0.8
51 - Head-On - Lateral Move (Going Straight)	24	2.1
52 - Head-On - Specifics Other	3	0.3
62 - Forward Impact - Specifics Other	4	0.4
64 - Sideswipe/Angle - Lateral Move (Left/Right)	6	0.5
65 - Sideswipe/Angle - Lateral Move (Going Straight)	30	2.7
66 - Sideswipe/Angle - Specifics Other	6	0.5

68 - Turn Across Path - Initial Opposite Directions (Left/Right)	14	1.2
69 - Turn Across Path - Initial Opposite Directions (Going Straight)	20	1.8
70 - Turn Across Path - Initial Same Directions (Turning Right)	9	0.8
71 - Turn Across Path - Initial Same Directions (Going Straight)	3	0.3
72 - Turn Across Path - Initial Same Directions (Turning Left)	5	0.4
73 - Turn Across Path - Initial Same Directions (Going Straight)	6	0.5
74 - Turn Across Path - Specifics Other	1	0.1
76 - Turn Into Same Direction (Turning Left)	4	0.4
77 - Turn Into Same Direction (Going Straight)	1	0.1
78 - Turn Into Same Direction (Turning Right)	2	0.2
79 - Turn Into Same Direction (Going Straight)	3	0.3
80 - Turn Into Opposite Directions (Turning Right)	3	0.3
81 - Turn Into Opposite Directions (Going Straight)	1	0.1
82 - Turn Into Opposite Directions (Turning Left)	6	0.5
83 - Turn Into Opposite Directions (Going Straight)	21	1.9
84 - Turn Into Path - Specifics Other	1	0.1
86 - Straight Paths - Striking from the Right	20	1.8
87 - Straight Paths - Striking on the Right	11	1.0
88 - Straight Paths - Striking from the Left	19	1.7
89 - Straight Paths - Striking on the Left	17	1.5
90 - Straight Paths - Specifics Other	2	0.2
92 - Backing Etc. - Backing Vehicle	7	0.6
98 - Backing Etc. - Other Crash Type	259	23.1
Total	1,123	100.0

From the total of 93 crash codes available in the database, 6 were identified as indicating *C/VIS-relevant* crashes (Table 5); that is, crashes that potentially could have been mitigated with a C/VIS. The first four crash codes describe a heavy vehicle changing lanes into, or turning across the path of, an object. Related crash codes, such as codes 44 (Sideswipe/Angle - Straight Ahead on Left), 45 (Sideswipe/Angle - Straight Ahead on Left/Right), 71 (Turn Across Path - Initial Same Directions [Going Straight]), and 73 (Turn Across Path - Initial Same Directions [Going Straight]) were excluded because they are believed to describe situations in which a heavy vehicle was traveling straight and was struck by another vehicle (potentially a light vehicle) making a lateral maneuver (unfortunately, operational definitions of the crash codes were not provided in the LTCCS manual). Here, a C/VIS would not likely have assisted the struck vehicle drivers in avoiding these types of crashes. The fifth crash code describes heavy vehicles that backed into an object. Table 5 sums the first five crash codes and estimates that a C/VIS could be expected to help prevent 6 percent of all fatal and severely injurious crashes. A more liberal estimate is also provided by considering crash code 64 (Sideswipe/Angle - Lateral Move [Left/Right]). Although this crash code is believed to describe heavy vehicles drifting out of their lanes (a maneuver that a C/VIS is likely not able to help prevent), a review of the crash descriptions revealed that some “Sideswipe/Angle - Changing Lane” crashes were erroneously coded as “Sideswipe/Angle - Lateral Move” crashes. Therefore, a liberal estimate that includes

“Sideswipe/Angle - Lateral Move” crashes is provided in case such miscoding is pervasive. It should be noted that crash code 65 (Sideswipe/Angle - Lateral Move [Going Straight]) is not considered since this is believed to describe cases in which a heavy vehicle is struck by another vehicle drifting out of its lane.

Table 5. C/VIS-Relevant Crash Codes Examined within the LTCCS

Crash Code and Description	Frequency	Percent
46 - Sideswipe/Angle - Changing Lanes to the Right	25	2.2
47 - Sideswipe/Angle - Changing Lanes to the Left	25	2.2
70 - Turn Across Path - Initial Same Directions (Turning Right)	9	0.8
72 - Turn Across Path - Initial Same Directions (Turning Left)	5	0.4
92 - Backing Etc. - Backing Vehicle	7	0.6
Total (conservative estimate)	71	6.3
64 - Sideswipe/Angle - Lateral Move (Left/Right)	6	0.5
Total (all variables)	77	6.8

Sideswipe/Angle crashes were the largest crash type observed, with a total of 50 crashes comprising 4.4 percent of crashes in the LTCCS. These collisions involved a large truck sideswiping another vehicle on the left or right while both vehicles were traveling in the same direction. There did not appear to be a difference in crash contribution from the lane-change direction; both changing lanes to the left and right had an equal number of observed crashes. Turn Across Path variables revealed 14 (1.2 percent) of the 1,123 total crashes involved large trucks turning across the path of another vehicle that was travelling in the same direction. Nine of these crashes involved a right turning maneuver (0.8 percent) and the other five crashes involved a left turning move (0.4 percent). Backing crashes comprised a total of seven crashes from the 1,123 total (0.6 percent). Combining all crash types together, these crash categories make up 6.3 percent of all crashes in the LTCCS. When the more lenient categories of sideswipes following lateral moves were included, only six additional crashes were added, bringing the total percent of all LTCCS crashes to 6.8 percent.

Blind Spot LTCCS Crashes

The “Blind Spot” variable is an attribute in the LTCCS database that specifies whether blind spots due to the vehicle’s mirror system were related to the crash. The variable is researcher-determined and can be used to establish links between the vehicle’s mirror system and crash causation. A query for the number of blind-spot-related crashes was performed. It was found that 1.6 percent of crashes (18 total) were related to the mirror blind spots. The frequency and percent for blind spot categorization is provided in Table 6.

Table 6. Frequency and Percentage of Blind Spot Relation in Crashes

Category	Frequency	Percent
Blind Spot Related	18	1.6
Not Blind Spot Related	1,042	92.8
Not Inspected	20	1.8
Unknown	43	3.8
Total	1,123	100.0

These 18 blind-spot-related crashes were further examined by crash code (using the “Crash Code” variable). The most common crash code for blind-spot-involved crashes was “46 - Sideswipe/Angle - Changing Lanes to the Right.” These were 5 of the 18 crashes, comprising 0.4 percent of all crashes in the LTCCS. The “47 - Sideswipe/Angle - Changing Lanes to the Left” crash code contributed one crash (0.1 percent). Backing crashes (both types had 2 instances each) comprised 4 of the 18 crashes, with a combined 0.4 percent of crashes. This cross tabulation is presented in Table 7.

Table 7. Crash Code Frequency and Percent of All Crashes by Blind Spot Involvement

Crash Code and Description	Blind Spot Related <i>n</i> (%)	Not Blind Spot Related <i>n</i> (%)	Not Inspected <i>n</i> (%)	Unknown <i>n</i> (%)	Total <i>n</i> (%)
02 - Right Roadside Departure - Control/Traction Loss	1 (0.1)	33 (2.9)	0 (0.0)	0 (0.0)	34 (3.0)
13 - Forward Impact - Pedestrian/Animal	1 (0.1)	25 (2.2)	1 (0.1)	1 (0.1)	28 (2.5)
28 - Rear-End - Decelerating (Slower)	1 (0.1)	39 (3.5)	0 (0.0)	0 (0.0)	40 (3.6)
45 - Sideswipe/Angle - Straight Ahead on Left/Right	2 (0.2)	44 (3.9)	0 (0.0)	0 (0.0)	46 (4.1)
46 - Sideswipe/Angle - Changing Lanes to the Right	5 (0.4)	15 (1.3)	2 (0.2)	3 (0.3)	25 (2.2)
47 - Sideswipe/Angle - Changing Lanes to the Left	1 (0.1)	21 (1.9)	2 (0.2)	1 (0.1)	25 (2.2)
48 - Sideswipe/Angle - Specifics Other	1 (0.1)	19 (1.7)	0 (0.0)	1 (0.1)	21 (1.9)
82 - Turn Into Opposite Directions (Turning Left)	1 (0.1)	5 (0.4)	0 (0.0)	0 (0.0)	6 (0.5)
89 - Straight Paths - Striking on the Left	1 (0.1)	15 (1.3)	1 (0.1)	0 (0.0)	17 (1.5)
92 - Backing Etc. - Backing Vehicle	2 (0.2)	5 (0.4)	0 (0.0)	0 (0.0)	7 (0.6)
98 - Backing Etc. - Other Crash Type	2 (0.2)	240 (21.4)	10 (0.9)	7 (0.6)	259 (23.1)
Total	18 (1.6)	1,042 (41.1)	20 (1.4)	43 (1.2)	1,123 (45.2)

Eight of the 18 blind-spot-related crashes are independent of the crashes reported in Table 8. It is unclear whether a C/VIS would have prevented these blind-spot-related crashes.

Analysis of the Most Recent GES Database

The literature review and data analyses presented thus far in the problem scope section were performed at the onset of this study in 2008. However, there was an interest in revisiting the crash data upon completing the entire study. An analysis of the National Automotive Sampling System/GES 2009 data set was performed at the end of 2010 by the research team. It was found that 17.5 percent of the 321,289 truck crashes where both vehicles were travelling in the same direction were classified as sideswipes. This percentage includes crashes where the truck sideswiped another vehicle (i.e., cases where the truck was the striking vehicle), crashes where the truck was sideswiped by another vehicle (i.e., cases where the truck was struck), and cases where vehicle role is indeterminable.

Table 8. Truck Crashes in 2009 GES Data Set

Manner of Collision	Fatal Injury	Incapacitating Injury	Non-Incapacitating Injury	Injury, Unknown Severity	Possible Injury	Unknown if Injured	No Injury	No Persons Involved in Crash	Total	Percent
Not Collision with Motor Vehicle in Transport	341	2,315	4,505	410	3,571	2,356	65,289	43	78,832	24.5
Rear-End	527	2,577	6,781	445	12,245	5	58,637	162	81,378	25.3
Head-On	765	897	1,024	36	824	5	3,254	0	6,804	2.1
Rear-to-Rear	0	5	5	5	0	0	113	0	129	0.0
Angle	987	2,957	6,268	487	8,131	383	65,494	0	84,706	26.4
Sideswipe, same direction	108	766	1,729	49	2,629	19	51,012	0	56,313	17.5
Sideswipe, opposite direction	162	81	883	5	1,773	0	9,320	0	12,224	3.8
Unknown	0	0	41	0	138	0	724	0	903	0.3
Total	2,890	9,598	21,236	1,438	29,311	2,768	253,843	205	321,289	100

Similar to how the previously described analysis of the LTCCS database excluded cases where the truck was struck (because it was assumed that a C/VIS would not prevent such a collision), only crashes where the truck was the striking vehicle were of interest. Table 9 presents the sampled truck crashes in which the truck was the striking vehicle. A total of 15.1 percent of these crashes (28,600 crashes) involved a truck sideswiping another vehicle travelling in the same direction.

Table 9. Crashes in which Truck was the Striking Vehicle in 2009 GES Data Set

Manner of Collision	Fatal Injury	Incapacitating Injury	Non-Incapacitating Injury	Injury, Unknown Severity	Possible Injury	Unknown if Injured	No Injury	No Persons Involved in Crash	Total	Percent
Not Collision with Motor Vehicle in Transport	302	1,208	2,512	410	1,662	2,356	51,584	41	60,076	31.7
Rear-End	177	966	2,571	206	6,835	0	33,489	162	44,406	23.4
Head-On	765	883	816	36	543	5	2,640	0	5,687	3.0
Rear-to-Rear	0	0	0	5	0	0	89	0	94	0.1
Angle	583	1,342	3,022	284	4,049	71	34,057	0	43,408	22.9
Sideswipe, same direction	27	309	671	14	1,663	19	25,898	0	28,600	15.1
Sideswipe, opposite direction	162	59	141	5	1,380	0	5,403	0	7,151	3.8
Unknown	0	0	17	0	9	0	344	0	370	0.2
Total	2,015	4,766	9,751	960	16,141	2,451	153,504	203	189,792	100.0

In classifying these 28,600 sideswipe crashes by their pre-crash maneuver, it was found that 46.2 percent occurred from the truck changing lanes, 10.7 percent occurred from the truck turning right, 4.6 percent occurred from the truck passing a vehicle, 3.6 percent occurred from the truck turning left, 3.1 percent occurred from the truck starting in its lane, 2.6 percent occurred from the truck merging into traffic, 0.1 percent occurred from making a U-turn, and 0.1 percent occurred from leaving a parking position (Table 10). These categories comprise 70.8 percent of the striking truck crashes in which the truck sideswiped an adjacent vehicle (20,311 crashes). A C/VIS would be expected to help prevent these 20,311 crashes. These 20,311 crashes are 6.3 percent of the 321,289 truck crashes in the 2009 GES database. A total of 165 of these crashes (0.05 percent) were fatal or incapacitating, 1,426 of these crashes (0.44 percent) were injurious, and 18,719 of these crashes (5.8 percent) did not result in injury. Please note that the 6,914 crashes in Table 10 that involved the truck going straight may reflect drivers sideswiping a vehicle because they departed their lane while distracted or drowsy.

Table 10. Striking Truck Crashes by Pre-Crash Maneuver

Movement Prior to Critical Event	Fatal Injury	Incapacitating Injury	Non-Incapacitating Injury	Injury, Unknown Severity	Possible Injury	Unknown if Injured	No Injury	Total	Percent
Changing lanes	10	155	380	9	702	0	11,958	13,215	46.2
Going Straight	17	147	188	4	657	19	5,882	6,914	24.2
Turning right	0	0	45	0	147	0	2,873	3,065	10.7
Passing or overtaking another vehicle	0	0	9	0	41	0	1,255	1,305	4.6
Turning left	0	0	13	0	36	0	992	1,040	3.6
Starting in traffic lane	0	0	0	0	0	0	878	878	3.1
Merging	0	0	0	0	10	0	741	751	2.6
Negotiating a curve	0	6	19	0	12	0	358	396	1.4
Unknown	0	0	17	0	13	0	308	338	1.2
Decelerating in traffic lane	0	0	0	0	10	0	322	332	1.2
Other	0	0	0	0	0	0	309	309	1.1
Making a U-turn	0	0	0	0	28	0	8	36	0.1
Leaving a parking position	0	0	0	0	5	0	16	21	0.1
Total	27	309	671	14	1,663	19	25,898	28,600	100.0

Problem Scope Summary

Data from multiple sources were examined to assess the size of *C/VIS relevant* crashes. The Large Truck Crash Facts report (Federal Motor Carrier Safety Administration, 2008) indicates that approximately 2.4 percent of 4,695 fatal large-truck crashes were due to the truck driver making an improper lane change or backing improperly. Sen et al. (2003) suggest that approximately 9 percent of police-reported large-truck crashes were lane-change-related. Kostyniuk, Streff, and Zakrajsek (2002) reported that improper or erratic lane changes account for 2.2 percent of fatal large-truck crashes. Furthermore, an examination of the LTCCS database suggests that improper lane changes, turning across the path of another vehicle, improperly backing the vehicle, and making a blind-spot-related driver error accounted for 6.8 percent of sampled fatal and severely injurious large-truck crashes. Finally, an analysis of the 2009 GES data set suggests that improper lane changes, merges, and turning maneuvers account for 20,311 crashes, which is 6.3 percent of all truck crashes. These types of crashes were found to account for 2.0 percent of fatal and incapacitating truck crashes [165 crashes], 6.1 percent of injurious truck crashes [1,426 crashes], and 7.4 percent of non-injurious truck crashes [18,719].

At the same time, it is worth considering that an adjacent-vehicle driver may be more likely to avoid an improper lane change made by a large truck by departing the roadway instead of allowing his vehicle to be struck. As such, the magnitude of the *C/VIS* problem may cover a portion of the crashes categorized as single-vehicle road departures. It is also worth considering that the information provided by *C/VIS*s may allow drivers to reduce the number, or duration, of glances to the mirrors, and allow drivers to look forward more often. Such a change in behavior may lead to a reduction in rear-end crashes because drivers may be more likely to see an unfolding conflict in the forward roadway. In summary, providing drivers with more information

regarding the location of surrounding vehicles may prevent the occurrence of the above crash types and have a beneficial effect on transportation safety.

PREVIOUS RESEARCH

The No-Zone

The “no-zone ” refers to the four blind spots in which truck drivers are unable to see cars (AAA Public Affairs, 2000; Indiana University of Pennsylvania in cooperation with the American Association of Motor Vehicle Administrators and the Federal Motor Carrier Safety Administration, 2004) and is significant because it represents the danger areas around trucks where crashes are most likely to occur. Additionally, the no-zone represents a misunderstanding on the part of motorists. Many motorists assume that the truck driver is able to see more of the road because of the truck’s size and higher driving position. However, trucks actually have much larger blind spots than do passenger cars (Indiana University of Pennsylvania in cooperation with the American Association of Motor Vehicle Administrators and the Federal Motor Carrier Safety Administration, 2004).

The no-zone blind spots are: 1) the front blind spot which is 10-20 feet in front of the cab (for truck cabs with no hood [i.e., cab-overs] the front no-zone is up to 10 feet), 2) the rear no-zone which extends 200 feet behind the truck, and 3) the truck’s side zones which start behind the cab and extend back 20-40 feet. Figure 34 illustrates the location of the no-zones. As illustrated, trucks have a larger blind spot on the right side of the cab than the left. The right side blind spot extends up the side of the truck and increases in size as it moves out further from the side of the truck (Indiana University of Pennsylvania in cooperation with the American Association of Motor Vehicle Administrators and the Federal Motor Carrier Safety Administration, 2004).

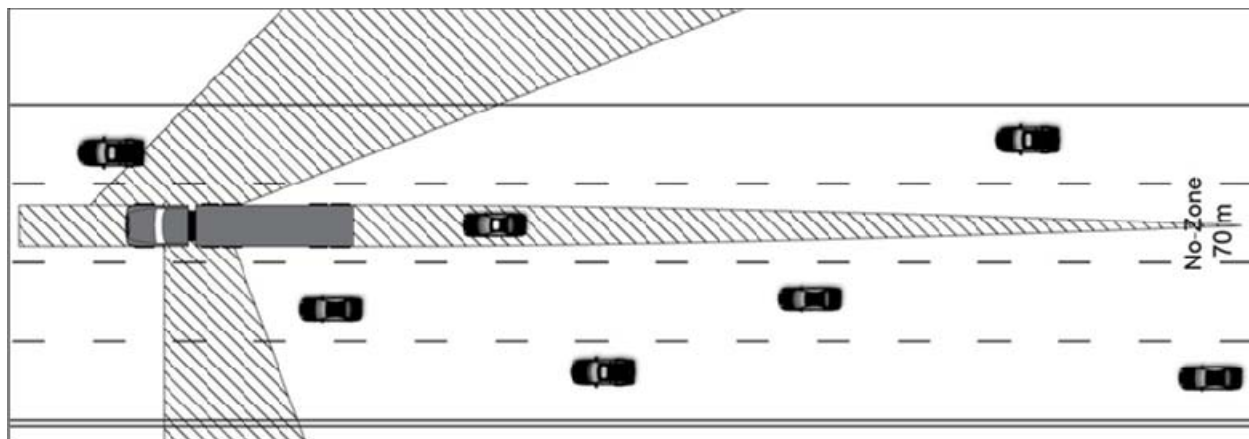


Figure 34. Illustration of the No-Zone, Adapted from AAA Public Affairs (2000)

Because of the dangers associated with the no-zone, several projects that seek to educate passenger vehicle drivers and professional truck drivers have been developed. For example, in 1994, FMCSA introduced the “No-Zone,” or “Share the Road Safely” Program. The goal of this program was to educate motorists about how to safely share the road with trucks and buses, which would increase awareness of the no-zone and reduce deaths, injuries, and property damage resulting from no-zone crashes. The Share the Road Safely web site provides information and

resources for car drivers, truck and bus drivers, motorcyclists, bicyclists, pedestrians, and mature drivers (Federal Motor Carrier Safety Administration, 2009). An example of the no-zone outreach effort is the No-Zone Campaign Truck and Bus Decal Program. Through public-private collaboration, carriers with a “satisfactory” safety rating place no-zone graphics on the sides and rear of their truck trailers and buses. The decals depict the no-zone blind spots along with campaign slogans and logos of participating partners.

The Commercial Vehicle Safety Alliance (CVSA), working with FMCSA, state, provincial, and local law enforcement, and the CMV industry, launched “Operation Safe Driver” in an effort to reduce the number of deaths in crashes involving passenger vehicles and CMVs. The goal of the program is to educate both passenger and commercial vehicle drivers about unsafe and aggressive driving practices and improve driver behavior and performance. The “Operation Safe Driver” program, which began in 2007 and is conducted each October, takes place throughout the United States, Canada, and Mexico. This safety initiative includes many educational outreach efforts, training courses focused on teen driver interactions, webinars, and the Ticketing Aggressive Cars and Trucks (TACT) enforcement operation (Commercial Vehicle Safety Alliance, 2009).

Also, the American Trucking Associations’ “Share the Road” program, which is sponsored by Mack Trucks, Inc. and Michelin North America Inc., serves to educate passenger-vehicle drivers how to share the road safely with large trucks and other heavy vehicles (American Trucking Associations, 2009). The “Share the Road” program works with highway safety partners, state trucking associations, the FMCSA, and industry partners including Pre-Pass, Freight Wing, and General Electric. Million-mile accident-free professional truck drivers deliver safety tips to the public with the goal of reaching as many people as possible and changing driving behavior in order to save lives. This program has been in existence for 20 years and continues to hold media and community events across the United States.

Further, the American Trucking Associations established America’s Road Team in 1986. This outreach organization, sponsored by Volvo Trucks North America, is comprised of a team of professional truck drivers who exhibit superior driving skills and maintain exemplary, incident-free safety and driving records. The mission statement of this group is “Safety is our Driving Concern” and the program is designed to spread the word about truck safety to all motorists and pedestrians. America’s Road Team travels throughout the United States to schools, truck stops, and truck rodeos as well as radio and television events (American Trucking Associations, 2010).

Additionally, AAA produced a nationwide campaign designed to educate drivers about ways to reduce crashes involving cars and trucks. This safety program originally began in June, 2000, to target the increased travel during the summer months, and was re-launched again in 2002 in conjunction with the release of the AAA Foundation for Traffic Safety study results. AAA notes that, each year, more than 5,000 people are killed and 140,000 are injured on the nation’s highways (AAA Public Affairs, 2000). The *Share with Care: Sharing the Road Safely* brochure provides both passenger car and commercial vehicle operators with advice on how to share the road safely.”

Addressing the No-Zone: Indirect Visibility Systems

Indirect Visibility Systems (IVS) are systems that help operators see areas that cannot be viewed directly. The typical mirror system, aspheric mirrors, and C/VISs are all forms of IVSs. Although various types of mirrors, such as fender-mounted convex mirrors, have been used to help drivers see the no-zone (Jenness et al., 2008), there are certain locations, such as the area behind a tractor-trailer, that cannot be viewed with mirrors. C/VISs can be used to provide such vantage points to drivers.

Previous C/VIS research has been conducted under the NHTSA Indirect Viewing Technology program. Earlier research phases included: 1) the development of a static testing method for assessing the quality of indirect visibility on heavy trucks (Jenness et al., 2008), 2) development of a performance specification for C/VISs on heavy vehicles (Wierwille, Schaudt, Gupta, et al., 2008), and 3) enhancing indirect viewing technology to provide an all-around and all-weather vision enhancement to drivers (Wierwille et al., in press). Collectively, these three research phases generated significant new knowledge about the performance of current heavy-truck mirror systems and unified many of the previous findings of the historical research in this field of study. A review of this research is provided below.

Development of a Static Testing Method for Assessing Indirect Visibility

Jenness et al. (2008) established a safe, repeatable procedure for measuring functional Field-of-View (FOV) for IVSs on heavy trucks. To accomplish this task, baseline behavioral performance measures for truck drivers using conventional mirrors were determined. The baseline measures resembled aspects of common driving tasks and were performed in a way that imposed minimal risk on participants and experimenters. Jenness et al. (2008) used 32 professional truck drivers, half of whom were aged 25 to 35, and half were aged 50 to 61. Measures were obtained through the use of a stationary class 8 tractor with attached semi-trailer. Using the available mirrors, drivers were asked to identify a mid-size passenger car, minivan, motorcycle, or pedestrian target positioned around the truck. In order to provide a visually cluttered and challenging environment, distracter targets were located in fixed positions around the tractor-trailer. These distracter targets remained in fixed locations throughout the study and all had a similar size (46 cm x 46 cm), shape (i.e., square), and color (i.e., green). They ranged in height from 91 to 137 cm, which represented the span of a car's hood (i.e., 91 cm) and roof line (i.e., 137 cm).

A mixed factorial design with three within-subject factors and one between-subjects factor (i.e., a 4x4x14x2 split-plot design) was used to assess the quality and quantity of truck mirror systems' FOV under static conditions. The independent variables included:

- Within-Subject Factors:
 1. Mirror configurations, four levels;
 2. Target type, four levels;
 3. Target location, 14 levels; and
- Between-Subjects Factor:
 1. Age (25-35 years and 50-61 years).

The within-subject variables of the factorial design yielded 224 unique test conditions (4x4x14) which were distributed across two sets of eight participants, each of whom completed approximately 28 trials (not including the benchmark trials and trials with no targets) (i.e., 8 participants x 28 trials for a total of 224 unique test conditions). Four commonly used mirror configurations were examined:

1. Flat (west coast) mirror set alone (only the two flat mirrors, on both sides of truck). This configuration satisfied Federal Motor Vehicle Safety Standard (FMVSS) No. 111 S8.1 for heavy trucks.
2. Baseline Condition - Combination of a flat mirror plus a convex mirror on both sides of the truck. This is a very common configuration used on heavy trucks.
 - a. Benchmark Trials (convex mirror alone): The study also included some benchmark trials with the convex mirror set alone (only the two cab-mounted convex mirrors mounted just below the flat mirrors on both sides of the truck).
3. Flat mirrors, convex mirrors, plus lookdown mirror: A look-down mirror mounted above the passenger side window was used in addition to the mirrors used in the baseline condition.
4. Flat mirrors, convex mirrors, plus fender-mounted mirrors: Two additional convex mirrors were mounted to the front fenders of the truck in addition to the mirrors used in the baseline condition.

Jenness et al. (2008) placed targets in one of the predefined locations around the tractor-trailer and the targets were presented in similar locations on the left and right sides of the truck. The specific target locations were selected to correspond to drivers' FOV associated with the different individual mirrors, as mapped from inside the Peterbilt truck cab (Wierwille, Spaulding, & Hanowski, 2004). With the exception of the two forward-most locations, all four targets were presented at each target location on different trials. The exact positions of the forward-most locations were dependent upon the target in use. Researchers placed the large targets (i.e. the car and the minivan) so that the front of each vehicle was at 2 feet (i.e., slightly forward of the truck bumper), while the small targets (i.e., the pedestrian and motorcycle) were positioned so that the front of the target was at 8 feet (i.e., behind the truck bumper). These distances were used so that the rear of the large targets would be close to the position of the rear of the two smaller targets. The data from the 2 feet and 8 feet target locations were pooled for all analyses.

Jenness et al. (2008) used the following dependent variables:

1. Response Time: Total time required for visual search and identification of the target, terminated by participant pressing a button.
2. Target Identification Accuracy: Accuracy in identifying the type of target (car, minivan, pedestrian, motorcycle, no object). Expressed as percentages of target detections as well as correct identifications, missed detections, and misidentifications. For trials with no target present, possible outcomes were false positives and correct rejections.
3. Target Location Accuracy: Error in estimating the true position of the target (when present). Expressed as an error score relative to the actual position of the target measured as a distance in feet. Also, accuracy in identification of the target's lane was measured.

4. Confidence in Target Type: Level of confidence rated on a 7 point scale (1= just a guess, 7 = extremely certain).
5. Confidence in Target Location: Level of confidence rated on a 7 point scale (1= just a guess, 7 = extremely certain).

Researchers used an occluded-view procedure that restricted drivers' visual search to 2-second glances and a touch-screen map of the testing area which was used by participants to indicate the position of detected targets relative to the truck. The experiments were conducted during July and August, during daylight hours (i.e., 8 a.m. to 5 p.m.) while the sun was at various angles overhead. Additionally, the weather conditions were noted. Experimental sessions were not conducted when visibility was reduced by conditions such as rain or fog. Researchers tested each participant individually over the course of a 2.5-hour session.

Obtained Findings

Jenness et al. (2008) found that, for both the flat and convex mirror configurations, the target locations reported by drivers were closer to the truck cab than were the actual target locations, especially for distant targets, and for targets viewed directly near the front of the truck. Target detection was determined to be dependent on mirror configuration, target type, and target location. Additionally, response times were determined to be dependent on mirror configurations, target type, target location, participant's age group, and the interaction between these factors.

Development of Heavy-vehicle C/VIS Performance Specifications

Wierwille, Schaudt, Spaulding, et al. (2008) note that improved technology can be used in heavy vehicles to provide views to drivers that were previously unavailable ("enhancements"), and to take the place of certain mirrors ("surrogates"). The enhancement applications are those which reduce blind spots or allow better views around the vehicle, while surrogate applications are intended to replace essential mirrors. Both NHTSA and FMCSA collaboratively contracted the Virginia Tech Transportation Institute (VTTI) to investigate the utility of C/VIS enhancements and surrogates for heavy-vehicle drivers. Wierwille, Schaudt, Spaulding, et al. (2008) devised and tested a variety of concepts for the use of C/VISs as applied to heavy vehicles; primarily tractor-trailers, but potentially other heavy vehicles as well. Performance specifications for using C/VISs in heavy vehicles were created based on a combination of analyses including driver needs and human factors, current and future video technology, systems analyses, focus groups, preliminary tests, and formal on-road tests (Wierwille, Schaudt, Gupta, et al., 2008). A summary of this research is provided below.

C/VIS Focus-Group

A focus group containing 10 paid volunteer participants, 9 men and 1 woman, was conducted (Wierwille, Schaudt, Spaulding, et al., 2008). Participants in the focus group each held a Commercial Driver's License (CDL) and had at least three years of recent heavy-vehicle driving experience. The focus group was used to obtain driver opinions of the C/VIS concepts and to determine if the participants had additional C/VIS concepts that they would like to have considered. Participants were asked to envision a vehicle in which each C/VIS concept was implemented separately (i.e., one at a time or in pairs such as right and left side) and to evaluate

how well they believed the application would work. Participants completed rating and ranking scales for each concept. For the surrogates, drivers completed scales for Receptiveness and Adaptability. For the enhancements, they filled out scales for Receptiveness, Adaptability, Safety Benefit, and Usefulness. Additionally, participants ranked all of the concepts from most to least desirable. Analysis of the rankings was completed using a Friedman nonparametric two-way analysis of variance (ANOVA) using the data with $k = 15$ (the number of concepts) and $N = 10$ (the number of drivers). Wierwille, Schaudt, Gupta, et al. (2008) obtained results that were significant ($\chi^2 = 31.6$, $p = 0.01$). The findings showed that drivers significantly preferred the Right-side wide-angle blind-spot enhancement; however, the preference was relatively broad. Using the feedback from the focus group, a list of 13 C/VIS concepts were developed and are presented as Table 11.

Table 11. Configuration Summary of Concepts (Early Version). Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

Rank	Description
1	Right-side wide-angle blind-spot enhancement
2	Left- and right-side trailer-view enhancements
3	Left merge/re-merge enhancement
4	Convex left- and right-side mirror surrogates
5	Right merge/re-merge enhancement
6	Front blind-spot enhancement
7	Left and right west coast/flat mirror surrogates
8	Trailer rear-view enhancement
9	Left-side blind-spot enhancement (camera same as 2L)
10	Trailer rear look-down enhancement
11	Trailer rear wide-angle multipurpose look-down enhancement
12	Tractor rear backing/bobtailing enhancement
13	Trailer rear multi-camera enhancement

Preliminary C/VIS On-Road Tests

Wierwille, Schaudt, Spaulding, et al. (2008) developed preliminary and formal on-road experimental plans. The results of the preliminary tests were used to develop the final C/VIS configurations used during the formal tests. The preliminary road tests steps were as follows (Wierwille, Schaudt, Gupta, et al., 2008):

1. Select concepts typical of the entire set of concepts for preliminary testing in order to obtain enough information so that generalizations could be made to all of the concepts appearing in the preliminary specifications;
2. Find and order appropriate video equipment, and design all support hardware, such as power conditioning, bracketing, and wire interconnection;
3. Install the various C/VISs, conduct tests, and perform any necessary early redesigns;
4. Develop groupings for tests so drivers could complete their tasks in approximately one hour and other concepts could be installed with minimal interference;
5. Devise road tests for each concept;

6. Select VTTI test drivers, perform the road tests with an emphasis on usability procedures, use several replications of maneuvers to aid drivers in making assessments, and query drivers using a standard questionnaire and obtain their general impressions and comments;
7. Analyze/report the results, and make recommendations for changes in the preliminary specifications.

The preliminary tests were completed using four VTTI employees with current CDLs. Three total drivers completed all the tests. The tests consisted of five test groupings that tested 11 concepts. The first two test groupings were performed with the 1994 Peterbilt tractor uncoupled, while the later three were performed using a 14.6 m trailer. Tests were completed on the Virginia Smart Road and VTTI's large asphalt pad. Results of the preliminary tests suggested that the concepts were generally successful in providing useful driving information to the drivers. Based upon the preliminary tests, they determined that several improvements should be made. Recommendations for improvement were grouped based on system aspect and include the following:

- **General recommendations:** when possible, use color video; avoid the use of the front header to mount monitors; ensure that FOVs are only as wide as necessary; maintain relatively slow camera automatic gain controls; consider the ambient glare when determining placement and shading of monitors.
- **West coast mirror surrogates:** use size 3 monitors; consider the effects of angular vibration and consider using better mounts or electronic image stabilization; properly determine the correct angle of view through a comparison with a traditionally mounted west coast mirror; the video chain should be high resolution and include accurate daytime color renditions; monitors should include a horizontal reference line that designates the projection of the end of the trailer on a flat surface.
- **Tractor rear backing/Bobtailing enhancement:** the lens horizontal FOV should be set at 70°; camera locations should be moved down to the rear of the cab to ensure better coverage; size 1 monitors should be used for the center dash location, but an alternative (similar to the center mirror in a light vehicle) should be used for the upper center windshield mount.
- **Convex mirror surrogates:** size 2 monitors should be used at the A-pillar locations.
- **Front blind-spot enhancement:** the camera should be aimed so that the front bumper and part of the grill appears in the right edge of the scene.
- **Right-side wide-angle blind-spot enhancement:** the horizontal FOV should be 80° to 90°; size 2 monitors should be used for the center dash location, or, space permitting, at the right A-pillar location.
- **Trailer rear-view enhancement:** the FOV should be approximately 70°; the camera location should be relocated further down on the trailer so that it is closer to the centerline of the trailer (i.e., approximately 2.4m above the pavement level); size 1 monitors should be placed on the center dash (although alternatives, such as placing the monitor at the top center of the windshield could be used).
- **Side Trailer-View Enhancements:** these enhancements should be deleted as they were not effective or necessary.

- **Trailer rear multi-camera enhancement:** Camera 3 should be replaced with a left-side merge/re-merge camera and camera 4 should be replaced with the right-side merge/re-merge camera; the horizontal FOV for camera 1 should be changed to 60° while the trailer rear-view enhancements for camera 2 should be approximately 70°.
- **Trailer rear look-down enhancement:** the horizontal FOV of the camera should be changed to 60°; the bottom edge of the monitor scene should feature the lower horizontal edge of the trailer in a contrasting color.
- **Trailer rear wide-angle multipurpose look-down enhancement:** increase camera's horizontal FOV to 102°; the bottom edge of the monitor scene should feature the lower horizontal edge of the trailer in a contrasting color.
- **Merge/Re-merge enhancements:** the camera horizontal FOV should be increased to 55°; a size 2 monitor should be located at the front end of the side header, which side of the header should correspond with the side of the enhancement (i.e., right-side header for right-side enhancements).
- **Combination of west coast mirror surrogates and convex mirror surrogates:** only if the convex mirror surrogate is implemented should the west coast mirror surrogate be implemented; however, the convex mirror surrogate could be implemented without the implementation of the west coast mirror surrogate.

Formal C/VIS On-Road Tests

The on-road tests were performed using 24 naïve licensed heavy-vehicle drivers who were divided into three groups of eight drivers. Tests were completed on the Virginia Smart Road and VTTI's large asphalt pad. Wierwille, Schaudt, Spaulding, et al. (2008) had each group of drivers perform tasks with two C/VIS concepts as follows.

Group 1: The tractor backing/bobtailing rear-view enhancement and the trailer wide-angle rear multipurpose look-down enhancement. Group 1 consisted of the Volvo tractor operated in the uncoupled mode. The C/VIS camera was placed behind the cab at a height of 3.05 m above the road surface (Figure 35). It was aimed so that the top edge of the FOV was slightly above the horizon, and the lower edge included the rear wheels of the tractor. The camera had a horizontal FOV of 70°. The monitor (Size 2, Table 12) was placed at the top center of the windshield (Figure 36).



Figure 35. Rear of the Volvo Tractor Cab Showing the Rear-View C/VIS Camera Location, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)



Figure 36. Monitor in Volvo Tractor for Rear-View C/VIS, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

Table 12. Monitor Image Sizes Used in the Formal On-Road Tests, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

Size Designation	Height	Width	Diagonal
Size 1	8.35 cm 3.29 in	11.3 cm 4.45 in	14.05 cm 5.53 in
Size 2	9.6 cm 3.78 in	12.9 cm 5.08 in	16.1 cm 6.33 in
Size 3	12.8 cm 5.04 in	17 cm 6.69 in	21.3 cm 8.38 in

Group 2: The left and right merge/re-merge enhancements and the trailer rear look-down enhancement. Group 2 used a multipurpose enhancement that was similarly tested using the Peterbilt tractor with trailer. The C/VIS camera was placed at the top center rear of the trailer and

had a camera horizontal FOV of 102° (Figure 37). The lower edge of view in the image included the rear bumper of the trailer so that drivers could judge distance relative to the rear bumper (Figure 38). The monitor was placed at the upper edge of the tractor windshield (with overlap above the windshield) and was Size 2 (Table 12). Although image re-mapping in the display was considered potentially beneficial, these tests were run without image re-mapping. Note that image re-mapping would be desirable because the wide-angle lens caused distortions in the FOV. In particular, the roadway lines appeared curved without image re-mapping (Figure 38). The idea was that if the tests showed the C/VIS to be capable of satisfactory performance, then specifications would not need to require image re-mapping (Wierwille, Schaudt, Spaulding, et al., 2008).



Figure 37. Wide-Angle Rear Multipurpose Look-Down Camera at Back of Trailer, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)



Figure 38. Peterbilt In-Cab Monitor for the Wide-Angle Rear Multipurpose Trailer Look-Down C/VIS, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

Group 3: The left and right convex mirror surrogates and these same surrogates combined with the left and right west coast mirror surrogates. The Group 3 tests consisted of the use of surrogates. Under Group 3A, the convex mirrors were replaced with surrogates. The cameras were placed on the outer edges of the front fenders and had a 45° FOV. The monitors were Size 2 (Table 12) and were located at the A-pillars. Under Group 3B, the west coast mirror surrogates were added to the convex mirror surrogates. Since the recommendation is likely to be made that the west coast surrogates should not be used by themselves, it was the combination that had to be tested. For Group 3B, the convex mirror surrogates were the same as in Group 3A. The west coast surrogates also used cameras mounted at the outer edges of the front fenders (there were two cameras on each fender). Image size was matched to that provided by the actual west coast mirrors by adjustment of the zoom lenses. Monitors for the west coast surrogates were Size 3 (Table 12) and were mounted at the A-pillars. It was necessary to stack the two monitors (for the convex and the west coast surrogates) at the A-pillars. Figure 39 and Figure 40 show the stacked monitors mounted in front of the A-pillars. This location was decided upon because it minimized blind spots.



Figure 39. Driver-Side Monitors Mounted at the A-pillar; Note the Covers Over the Mirrors, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)



Figure 40. Passenger-Side Monitors Mounted at the A-pillar; Note the Covers Over the Mirrors, and also Note that the Upper Monitor was Hooded to Reduce Glare, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

The Size 3 monitors (for the west coast mirror surrogates) (Table 12) each had a horizontal line on them corresponding to a vertical plane projected downward from the rear surface of the trailer (onto a flat roadway). This horizontal line indicated the rear end of the trailer (on a flat roadway), so that drivers could better judge distances relative to the rear end of the trailer. The camera aim was carefully calibrated prior to data gathering runs to ensure that the horizontal line indicated the end of the trailer on a flat roadway. A conventional video system does not provide stereographic presentation; consequently, distances may be more difficult to judge with video. It was deemed desirable to include the horizontal line in the video presentation as a means of helping the driver judge distances in the most critical situations. Note also that such a line is not a function of driver eye height or other aspects of driver viewing position. It is only a function of camera aim and camera FOV, both of which were carefully calibrated prior to data gathering.

Figure 41 shows the camera locations on the driver-side front fender, and Figure 42 shows the camera location on the passenger-side front fender. The round cameras are the convex mirror surrogate cameras and the rectangular cameras are the west coast mirror surrogate cameras. The convex mirror cameras had a 45° FOV. The west coast mirror surrogate cameras had FOVs creating the same image size in width as the corresponding mirrors themselves, when viewed from the driver's position (Wierwille, Schaudt, Spaulding, et al., 2008).



Figure 41. Driver-Side Cameras at the Front Fender; the Round Camera is for the Convex Mirror Surrogate, and the Rectangular Camera is for the West Coast Mirror Surrogate, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)



Figure 42. Passenger-Side Cameras at the Front Fender; the Round Camera is for the Convex Mirror Surrogate, and the Rectangular Camera is for the West Coast Mirror Surrogate, Taken from Wierwille, Schaudt, Spaulding, et al. (2008)

In all cases, drivers were asked to perform tests which served as a baseline for comparison. For enhancements (Group 1 and Group 2), the baseline was the tractor or tractor-trailer without enhancements. For surrogates (Group 3), drivers experienced normal-mirror and the corresponding mirror-surrogate C/VISs. Drivers were asked to provide opinion data for both the baseline and the C/VIS configurations. Opinion data were used to gauge receptiveness of drivers to the C/VISs. Drivers were asked to complete highway driving tasks, which included two major subtasks which were performed in a highway setting on the Virginia Smart Road. The first subtask was a Clearance/Overlap Test during which drivers were asked to determine whether an

adjacent confederate automobile was clear of the rear of the trailer and then asked to provide an estimate in feet of the amount of clearance or overlap. Eye glance data for the clearance/overlap subtask were analyzed for the time interval starting with completion of clearance/overlap instruction by the experimenter and ending when the driver provided the estimate of distance. Glance data were analyzed based on driver age as well as side.

The second subtask required the driver of the tractor-trailer to merge in front of the confederate automobile, which was maintaining a constant speed. This task measured differences and variations in merging distances. Group 1 drivers were also asked to observe the confederate automobile directly behind the tractor in the bobtailing mode and moving away. When instructed, the driver was asked to provide an estimate of distance to the confederate automobile. Glance probabilities were calculated for the interval during which the pass/merge maneuver was performed. Specifically, the interval began when the automobile (confederate) driver moved to the center of the trailer and matched speed to the tractor-trailer. It was at this point that the experimenter in the tractor-trailer instructed the driver to increase speed and merge in front of the automobile. The interval ended when the tractor-trailer driver began the lateral maneuver to merge in front of the automobile. Again, glance data were analyzed based on driver age as well as side.

Drivers practiced each subtask which was then repeated for data gathering. Drivers were also asked to complete the low-speed backing subtasks of parking, loading-dock backing, and S-curve backing. For groups 1 and 2, the independent variables were 2 (age groups, between) by 2 (C/VIS conditions: present versus absent, within), with four drivers in each age group. For group 3, the independent variables were 2 (age groups, between) by 3 (C/VIS conditions: absent versus convex C/VIS versus combined C/VIS, within), with four drivers in each age group. Where appropriate, Wierwille, Schaudt, Spaulding, et al. (2008) used the following dependent variables:

- Highway Driving Variables
 - Percent correctness of answers to the clearance/overlap queries
 - Absolute error of clearance/overlap distance estimates
 - Glance location probabilities for the clearance/overlap subtask
 - Mean cut-in distance in the passing/merging maneuvers
 - Glance location probabilities for the passing/merging maneuvers
 - Individual ratings of difficulty in determining clearance or overlap in the clearance/overlap subtask (baseline and C/VIS)
 - Individual ratings of difficulty in estimating distance in the clearance/overlap subtask (baseline and C/VIS)
 - Individual ratings of usefulness, learning time, receptiveness, and blind-spot reduction after completing the clearance overlap and passing/merging subtasks (C/VIS only)
- Backing and Parking Variables
 - Time to complete parking subtask
 - Parking subtask final position relative to the parked vehicle

- o Glance location probabilities for the parking task¹
- o Time to complete the loading dock (or backing to cones) maneuver
- o Loading dock (or cone barrier) distance in final position
- o Glance location probabilities for the loading dock (cone barrier) maneuver
- o S-curve backing subtask completion time
- o S-curve number of direction reversals
- o Number of barrels struck in the S-curve subtask
- o Glance location probabilities for the S-curve subtask
- o Individual ratings of difficulty for the parking subtask (baseline and C/VIS)
- o Individual ratings of difficulty for the loading dock (cone barrier) backing subtask (baseline and C/VIS)
- o Individual ratings of difficulty for the S-curve subtask (baseline and C/VIS)
- o Individual ratings of usefulness, learning time, receptiveness, and blind-spot reduction for the backing subtasks (C/VIS only)

Formal C/VIS On-Road Test Results

The merge/re-merge enhancements were intended to help the driver determine whether or not there was clearance of a vehicle in the adjacent lane near the back of the trailer. Formal tests indicated a marked improvement with this C/VIS. Wierwille, Schaudt, Spaulding, et al. (2008) found that clearance/overlap estimates were 100 percent correct and errors in distance of clearance or overlap were drastically reduced. Additionally, for the passing/merging subtask, cut-in distances were reduced by 50 percent. The glance analyses indicated that the drivers heavily used the enhancements, with visual attention taken from the side mirrors. In sum, the results indicated that the merge/re-merge enhancements made the driver's task easier and more accurate, and opinion ratings suggested a high level of driver acceptance.

The trailer rear look-down enhancement consisted of a camera at the top rear center of the trailer. For the parking and loading dock backing tasks the results showed that drivers significantly improved their performance with this C/VIS. The enhancement was not helpful in the S-curve task, an expected result. The glance analysis indicated that drivers used the C/VIS close to 50 percent of the visual resource time. Drivers expressed a strong level of acceptance by the drivers.

The tractor-only backing/bobtailing enhancement was intended to serve as the equivalent of an interior rearview mirror for a tractor and was intended to be used for both on-road and backing tasks. Wierwille, Schaudt, Spaulding, et al. (2008) found no significant improvements for the clearance/overlap tasks or the cut-in task when this C/VIS was used on just the tractor. For the backing subtask, only the loading dock backing task showed significant improvement with this C/VIS. For both the driving and parking tasks, drivers indicated general receptiveness to this C/VIS.

¹ Glance location probability was defined as the number of samples in which the eyes were fixated at the given location divided by the total number of samples in which the eyes were fixated. This measure indicates the degree to which the driver fixates on a given location. Note that the sum of all glance location probabilities should be equal to 1.

The trailer wide-angle rear multipurpose look-down enhancement results indicated that drivers were 100 percent accurate in determining clearance/overlap. For the passing/merging task drivers shortened their cut-in distance by 30 percent compared with baseline. Glance analyses indicated that drivers used the C/VIS for more than 50 percent of their total glance time for the clearance/overlap task and 31 percent of total glance time for the cut-in task. For the backing subtask, the C/VIS resulted in improvements for the backing and loading dock subtasks. Glance behavior was 37 percent and 33 percent for the backing and loading dock tasks. Drivers' opinions of the C/VIS were positive.

The convex mirror surrogates were found to provide little difference in results for the highway driving subtasks. Glance patterns indicated that the drivers relied on the surrogates very little. Results were similar for the parking subtasks with task completion times essentially the same for the convex C/VISs and baseline.

The combination of convex and flat (west coast) mirror surrogates found that the C/VIS resulted in a small reduction in mean absolute error, as compared with baseline, for the clearance/overlap distance estimation subtask, but a 26 percent increase in mean cut-in distance. Glance analyses showed that the C/VISs were used exactly the same as baseline, 68 percent of available visual resource time for the clearance/overlap subtask and 62 percent of available resource time for the passing/merging subtask. For the backing subtasks, completion times were significantly longer for the backing and loading dock subtasks. Glance analyses determined that for the backing subtasks drivers relied almost exclusively on the mirrors in baseline and on C/VISs in the combined C/VISs condition.

Development of C/VIS Specifications

Based on focus group driver preferences, as well as preliminary and formal test results, Wierwille, Schaudt, Gupta, et al. (2008) developed a revised final summary listing of configurations (Table 13) and camera and monitor locations were developed (Figure 43 through Figure 46). Note that the monitors in Figure 45 and Figure 46 were angled toward the driver so that the screens were nearly perpendicular to the driver's line of sight. Additionally, Wierwille, Schaudt, Gupta, et al. (2008) suggest that no monitor should have a deviation of more than 20° from being perpendicular to the driver's nominal line of sight. The suggested monitor sizes are presented in Table 14. Wierwille, Schaudt, Gupta, et al. (2008) caution that careful consideration should be taken if monitors are reduced in size by more than 5 percent.

Table 13. Revised Final Configuration Summary Listing of Concepts, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

C/VIS	Camera Location	Monitor Location
Right-side wide-angle blind-spot enhancement	B	H or I
Left- and right merge/re-merge enhancements	D and E	E and F
Trailer rear-view enhancement	H	G
Convex left- and right-side mirror surrogates	C and B	A and C
Front blind-spot enhancement	A	H or I
Left- and right "combined" mirror surrogates	C and B	A, B, C, and D
Left-side blind-spot enhancement	C	B
Trailer rear look-down enhancement	G	G
Trailer rear wide-angle multipurpose look-down enhancement	G	G
Tractor rear backing/bobtailing enhancement	F	G
Trailer rear multi-camera enhancement (revised)	D, E, and G	E, F, and G

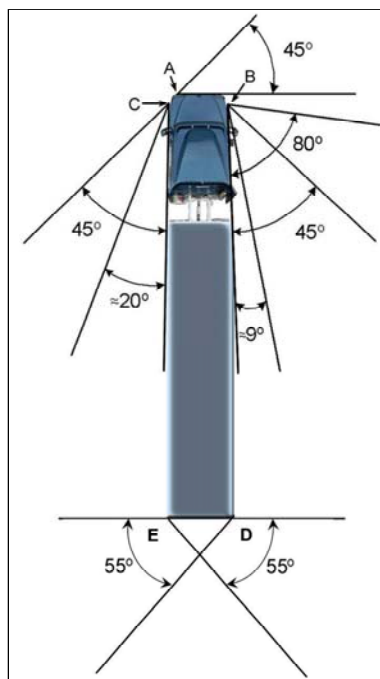


Figure 43. First Group of Camera Locations, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

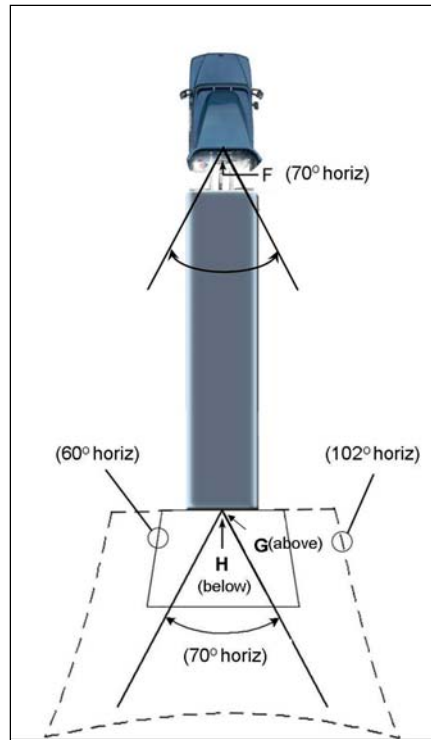


Figure 44. Second Group of Camera Locations, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

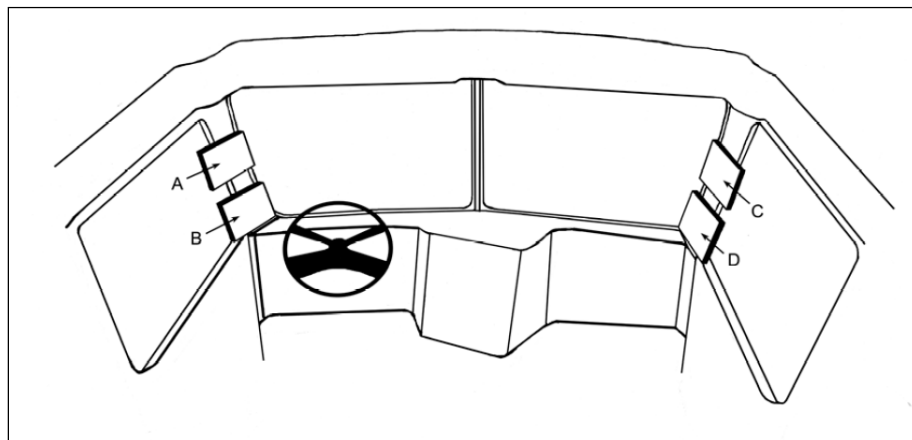


Figure 45. Monitor Locations at the A-pillars, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

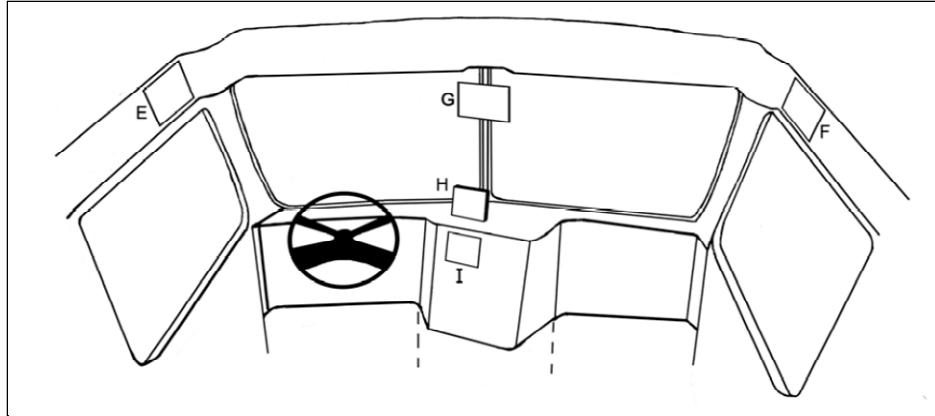


Figure 46. Other Monitor Locations, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

Table 14. Monitor Image Sizes Used in the Specifications, Taken from Wierwille, Schaudt, Gupta, et al. (2008)

Size Designation	Height	Width	Diagonal
Size 1	8.35 cm 3.29 in	11.3 cm 4.45 in	14.05 cm 5.53 in
Size 2	9.6 cm 3.78 in	12.9 cm 5.08 in	16.1 cm 6.33 in
Size 3	12.8 cm 5.04 in	17 cm 6.69 in	21.3 cm 8.38 in

Additional details for surrogate and enhancement concepts are presented by Wierwille, Schaudt, Gupta, et al. (2008). Details include discussions of the following:

- Application
- Purpose
- Special Notes
- Camera Location, Angle of Coverage, Aim Direction, and Focus Range
- Monitor Location and Approximate Size
- Image Presentation
- Activation/Deactivation
- Backup
- Horizontal Delineator or Distance Aid
- Vibration Isolation
- Detailed Justification and Specifications in Regard to Camera Placement, Camera FOV, Monitor Placement, and Monitor FOV
- Coordination (for enhancements)
- System Operating Temperature Range; Exposure Temperature Range
- Exterior Illumination Operating Range
- Cab Interior Illumination Operating Range
- Monitor Luminance/Contrast Adjustment
- Monitor Luminance Fluctuation
- System Minimum Image Resolution
- System Refresh Rate
- System Maximum Image Delay
- System Persistence
- System Reliability
- Vibration and Shock Immunity
- Response to Activation
- Image Aspect Ratio

Development of an All-Around/All-Weather Enhanced C/VIS (E-C/VIS)

With specifications set for how C/VISs should be designed for daytime use, the next step was to enhance the C/VISs' operational window. An E-C/VIS was designed to provide simultaneous coverage of the sides and rear of a heavy vehicle with an operating envelope that included daytime and nighttime conditions, as well as clear and inclement weather conditions. It was designed to improve drivers' situational awareness, with a specific objective of reducing sideswipe crashes when heavy vehicles merge or change lanes. It should be noted that the E-C/VIS was intended to supplement the current side mirrors—not replace them. The E-C/VIS design was also limited to use technology that could be developed at a reasonable cost in order to be adopted by commercial carriers. The methods used to develop the E-C/VIS, as well as the results obtained from its evaluation, are described below. Details pertaining to these methods and results can be found in Wierwille et al. (in press).

Static Tests

During the E-C/VIS research effort, work began with testing of one-of-a-kind components in a darkened laboratory. Numerous visible and IR illumination sources, cameras, and filters were examined, with the objective of video chain development operating over the entire lighting envelope. The tests included an object vehicle or target, so that images could be compared.

Eventually, a single camera and two different illumination sources were selected as viable finalists. A second camera had some usable capabilities, but was lacking in that it was only monochrome and did not possess sufficient sensitivity in subdued light. Many camera filters were tried, but none improved the video image. The selected "first place" camera, the Toshiba IK-64DNA camera, had daytime color capability and nighttime monochrome (black and white [B/W]) capability, and it was sensitive at night to both visible and near-IR radiation illumination. One of the illumination source finalists was visible and the other was near-IR. This testing produced a wealth of information economically.

Once the components had been selected, outdoor stationary tests were performed. A major outdoor "simulator" was developed which included a tractor-trailer equipped with multiple units of the visible and IR illuminators. A Toshiba IK-64DNA camera was housed in a waterproof enclosure and was mounted at the passenger-side front fender. The corresponding monitor was placed in the cab in a position at the passenger-side A-pillar. The remainder of the facility produced wind at up to 117 km/h as well as rain. The rain system was composed of the wind generation system with 10 nozzles, three overhead towers, two mist generation nozzles, and all support systems for storing and pumping the water, including hoses and connections. This system allowed testing of highway rain conditions, but with the heavy vehicle and surrounding vehicles standing still. This made testing possible without having to drive the heavy vehicle and without having to generate rain artificially using multiple rain towers over long stretches of roadway.

Because the outdoor facility took a good deal of time to construct, parallel efforts were carried out regarding image processing and experiment design for use of the stationary outdoor facility. The image processing routines allowed the "outlining" of targets or objects. This processing was incorporated in the outdoor stationary test setup, but required use of a monitor with vector graphics array (VGA) input, so that delays in presenting the video image would be short. Once

the facility was ready, testing took place using VTTI employees as research participants. All of the participants experienced and evaluated all combinations of conditions. The combinations included daytime color and nighttime B/W combined with clear and rainy conditions. Also included were a variety of target vehicle positions (Figure 47). For the nighttime/visible illumination conditions, the participants also rated the discomfort glare and loss of discriminability when viewed from the target vehicle position (that is, outside the heavy vehicle).

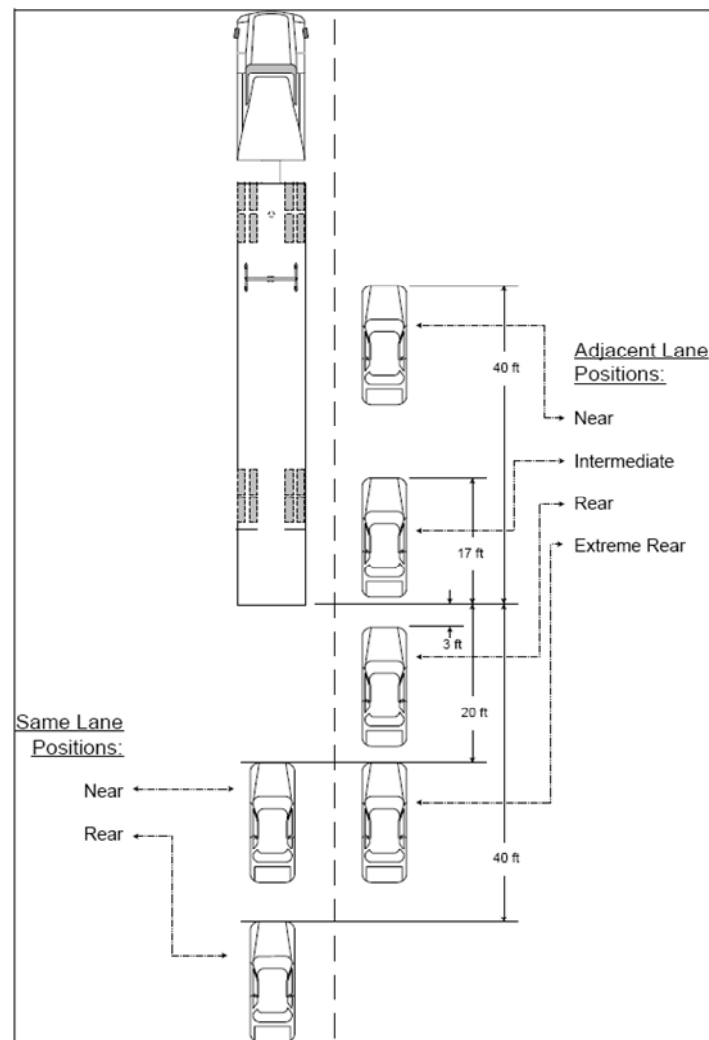


Figure 47. Positions of the Automobile Relative to the Tractor-Trailer for the Image Quality and Glare Discriminability Tests; Dimensions are in feet; 1 FT = 0.305 M, Taken from Schaudt, Wierwille, & Hanowski (2009)

Results demonstrated that all ratings provided by the participants were satisfactory or better. Glare from the visible illumination was found to be well within an acceptable level. However, results showed that the IR illuminators had slightly better ratings and, of course, produced no glare. Therefore, the IR illuminators were considered to be the better choice. The image processing seemed to work well. A few problem areas were uncovered, and solutions were suggested for them.

Results of the outdoor stationary tests were used to finalize the E-C/VIS. Cameras contained in weatherproof housings were mounted on the right and left fenders of the test vehicle. A third wide-angle multipurpose look-down camera was mounted at the top rear of the trailer. Monitors positioned on the left and right A-pillars displayed the video captured from the left and right fender cameras, respectively. A monitor mounted at the top center of the windshield displayed the video captured by the rear camera. It was anticipated that heavy-vehicle drivers in an equipped tractor-trailer would be able to use the E-C/VIS to assess "where" object vehicles in adjacent lanes were relative to the trailer. In addition, the driver of the heavy vehicle would be able to assess the situation directly behind the trailer or cargo box. Consequently, heavy-vehicle drivers would be able to determine clearance or overlap with much greater accuracy. They would be able to do this by a combination of looks to the rear monitor, the side monitor, and the mirrors. This approach was intended to make it possible to avoid or at least reduce sideswipe crashes. In addition, the drivers would have greatly improved coverage of blind spots along the sides and to the rear with the full E-C/VIS.

With the final system established, static testing was performed with Commercial Motor Vehicle drivers to evaluate their object detection and identification performance with the E-C/VIS, and to allow them to become familiar with the system prior to performing the dynamics tests described in the next section. The static tests were performed in a large blacktopped area at the research institution using a variation of the paradigm developed by Jenness, Llaneras, and Huey (2005) under subcontract in the original C/VIS project. Eight male drivers, who had at least two years of professional truck driving experience and a visual acuity of 20/30 or better, were recruited from a volunteer database maintained by the research institution. A tractor-trailer was equipped with the three-channel E-C/VIS. In addition to the three camera views, the E-C/VIS provided drivers with night vision capabilities by having eight IR LED illuminators mounted around the tractor-trailer. The E-C/VIS also allowed drivers to augment the video image by tracing white lines around objects detected in the scene. The algorithms used to run this augmented display were run on three laptop computers mounted inside the test vehicle. In order to record drivers' performance with the E-C/VIS, two cameras and two microphones were added to the tractor-trailer.

Participants were asked to sit in the driver seat of a parked, equipped tractor-trailer and were instructed to look down while wearing noise-cancelling headphones (to prohibit hearing experimenters maneuvering objects outside the tractor-trailer). Once an object was maneuvered to the desired location, the experimenter commanded the participant to look up and search for the object located around the truck. If the object was located, the participant was asked to identify the object and to provide an approximate location. If the object was not located, the participant was asked to say "undetectable." In a counterbalanced fashion, participants performed this task 15 times with the conventional mirror system (Baseline), and again 15 times while using the mirrors and the E-C/VIS (Test). The objects and location of objects shown in both conditions were identical, but were presented using a two pseudo-random order. In other words, the order in which the objects were present in the Baseline condition was different than the order in which the objects were presented in the Test condition. Using a pseudo-random order allowed the experimenters to change the order so that the participant was unable to predict which object would be presented next and where the object would be located. Since participants were shown each object twice, a within-subject comparison could be made between each participant's response in the Baseline condition and the Test condition and as a function of object/location.

Figure 48 below illustrates the placement and order of the objects shown to participants. Four different objects were used in this task (Figure 49): an orange construction barrier with two horizontal reflective stripes (represented by a circle in the figure), a pedestrian (represented by a small circle surrounded by an ellipse), a yellow adult tricycle (represented by a pair of handlebars and rectangle connected by a line), and a stop sign placed on a pole (represented by an X inside a hexagon). The number to the left of each object in the figure represents the order in which the objects were shown to each participant.

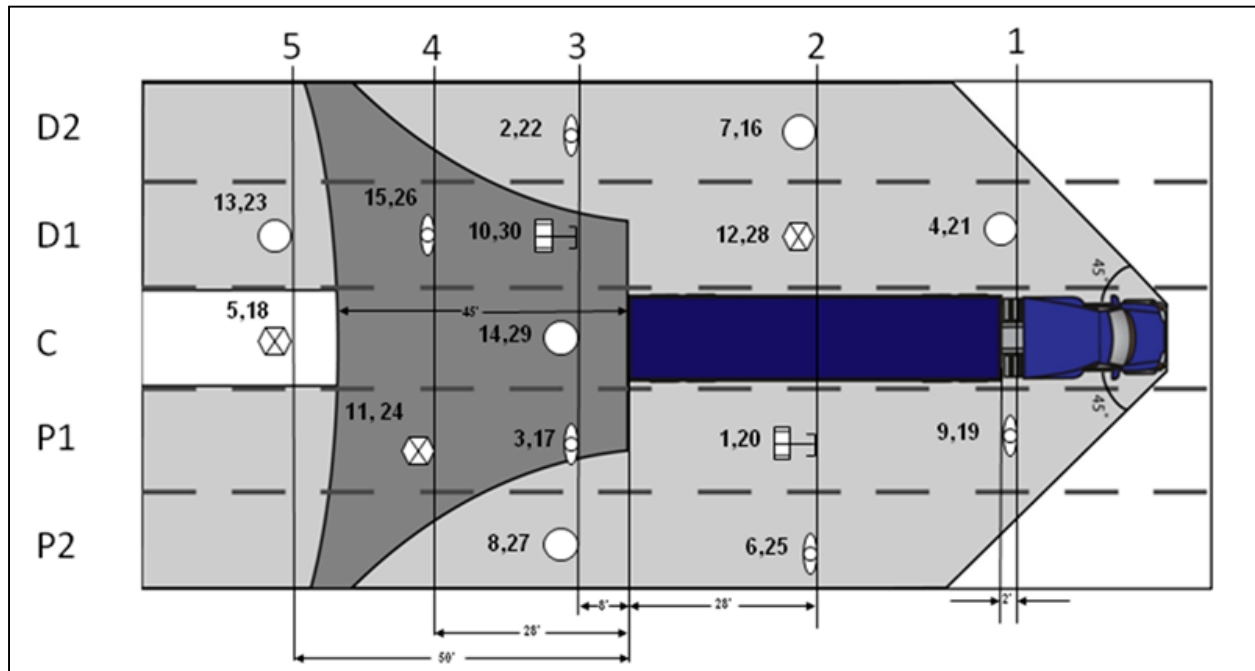


Figure 48. Placement and Order of Objects Used in E-C/VIS Static Testing; Reprinted from “Enhanced Camera/Video Imaging Systems (E-C/VISs) for Heavy Vehicles” by W. W. Wierwille, W. A. Schaudt, M. Blanco, A. S. Alden, and R. J. Hanowski, 2008, p. 76. National Highway Traffic Safety Administration, Report No.: DTNH22-05-D-01019. Reprinted with Permission



Figure 49. Daytime Photograph of the Four “Objects” Used in the Experiment; Reprinted from “Enhanced Camera/Video Imaging Systems (E-C/VISs) for Heavy Vehicles” by W. Wierwille, W. A. Schaudt, M. Blanco, A. S. Alden, and R. J. Hanowski, 2008, p. 82. National Highway Traffic Safety Administration, Report No.: DTNH22-05-D-01019. Reprinted with Permission

Schaudt et al. (2009) found participants were able to locate objects more accurately with the E-C/VIS compared to the Baseline condition ($\chi^2(1) = 22.5, p < 0.0001$). Specifically, participants accurately located objects 96 percent of the time with the E-C/VIS compared to 72 percent of the time in Baseline. Furthermore, participants were able to locate and identify objects more accurately with the E-C/VIS compared to Baseline ($\chi^2(1) = 15.0, p = 0.0001$). Participants accurately located and identified objects 91 percent of the time with the E-C/VIS compared to 70 percent of the time in Baseline. Schaudt et al. also examined the participants’ responses times and found participants responded faster with the E-C/VIS compared to Baseline.

Dynamic Tests

In addition to the static tests described above, dynamic tests were performed on the E-C/VIS at night and in inclement weather using the Virginia Smart Road test facility. The Smart Road is an instrumented roadway closed to the public and used strictly for research and development. Here, both baseline (mirrors only) and E-C/VIS (mirrors plus enhanced video) conditions were examined under nighttime and artificial lighting conditions. Both rainy and clear conditions were also examined. Rain was generated using more than 70 rain-producing towers. Class A CDL drivers drove a heavy vehicle and determined the position of an adjacent vehicle. Drivers indicated whether there was longitudinal clearance or longitudinal overlap in feet, and how much overlap there was in terms of distance. Clearance/overlap was then scored as correct or incorrect and amount of clearance or overlap in feet was scored in terms of the amount of error. Researchers tracked the clearance/overlap determination, absolute error in the clearance/overlap estimate, the amount of time required to determine clearance/overlap added to the amount of

time required to estimate distance, and eye glance probability to specific locations. It was found that drivers took advantage of the E-C/VIS when locating the adjacent vehicle, which resulted in less absolute error in estimating distance. However, there was an overestimation of the amount of clearance and an underestimation of the amount of overlap. These results were consistent with the use of convex mirrors in which an overestimation of distance was also found. Overall, the results show that the extended range of the E-C/VIS is quite useful and should reduce sideswipe crashes, increase the situation awareness of heavy-vehicle drivers, and also meet with their acceptance. Minor problems remained with the developed system; mainly that the monitors could not be adequately dimmed and that the light reflected from them created a cross-reflection on the side windows that interfered with the drivers' view of the west coast mirrors. These problems were solved, however, in the development of the A-C/VIS for the TFD.

Mirror Research Relevant to C/VISs

According to research conducted by Liberty Mutual, 29 percent of roadway construction vehicle crashes occur in three different scenarios: side-swiping, backing, and pulling forward from a parking place (Money, 2000, May). These accidents are often the result of inadequately placed or poorly aimed mirrors. When selecting mirrors, manufacturers and drivers should use a system of both flat and convex mirrors. Flat mirrors provide narrow reflected vision width and very long (the entire extent of the driver's line of sight) reflected vision length, both of which are undistorted FOVs. Convex mirrors present a wider FOV, but the image is somewhat distorted (minified), even more so as the radius of curvature (ROC) of the mirror decreases in size. When slightly overlapped, these two types of mirrors produce a viewing environment that includes objects next to and around the truck, as well as ones that are to the rear of the truck or in the distance. However, even with a two-mirror system, blind areas around the front of the truck still exist. This report (2000, May) suggests that a fender-mounted mirror be placed on the truck, especially on the right side, in order to reduce blind spots as much as possible. Before doing this, the driver or manufacturer should consider the configuration and dimensions of all of the windows present in the cab in addition to the position of the driver's seat. This will ensure that the mirrors are not blocked by any of the structural parts of the truck; if they are, the seat could be repositioned in order to remedy the problem.

Technologies such as non-planar rearview mirror systems attempt to deliver a wider FOV for drivers (Platzer, 1995). Non-planar mirrors are those with either a constant ROC (such as a convex mirror) or those with a ROC that decreases across the horizontal width of the mirror (such as an aspheric mirror). Planar rearview mirrors, consisting of a flat surface (providing an infinite ROC), provide a more limited FOV while providing a non-minified image which appears to support driver estimations of distance and approach speeds. The increases in FOV provided by convex and aspheric mirrors are accompanied by minification in the image which may offset any benefits in blind-spot coverage. However, efforts to provide drivers' vision within their blind spots is of great importance, as most lane-change collisions occur without other explanatory factors such as weather or unusual road hazards (Eberhard, Luebkekmann, Moffa, & Young, 1994) and may be considered to be failures of the driver to detect adjacent traffic.

As much non-planar mirror research has been performed with light vehicles, examining the body of literature from this field may yield important information for the problem of increasing the FOV around heavy trucks. Insufficient FOV is a likely causal factor in a number of light-vehicle

collisions (Mortimer, 1971). Non-planar mirrors have the potential to increase the FOV provided to the driver, reduce blind spots around the vehicle, and have a palliative effect on the number of mirror-related collisions that occur. Potential problems and safety concerns with non-planar mirrors include a number of factors related to driver judgment. Due to the convexity of non-planar mirrors, both aspheric and convex mirrors present the driver with a minified image (images that are smaller in proportion than the real object). However, to gain an increased FOV, mirror convexity (and, thus, the minification produced by the mirror) must be increased. This leads to an image which drivers may have difficulty in perceiving and interpreting. Exterior rearview mirrors (mirrors mounted on the front fender or doors of the vehicle) augment the information provided to the driver through the interior rearview mirror (which is affixed to the dashboard or windshield of the vehicle).

Wierwille, Schaudt, Gupta, et al. (2008) performed a series of on-road experiments examining light-vehicle driver performance with different types of mirrors. Wierwille et al. had drivers perform passing maneuvers, maneuvers that required the driver-participant to merge in-between two vehicles, and gap acceptance tasks (using a button press to mark the last safe gap the driver-participant would accept) on a closed test track. The driver-side rearview mirrors examined included planar, convex (2000 and 1400 mm ROC), aspheric (1400 mm ROC with a 73 percent spherically convex inner portion, and 2000 mm ROC with a 66-percent spherically convex inner portion), and two elongated (one flat and one 1400 mm ROC convex) mirrors. There was a significant effect for the type of mirror on cut-in distances for both the passing and merging maneuvers. Generally, as the ROC of the mirror was increased, drivers allowed for more conservative (safe) cut-in distances. The elongated planar mirror produced the greatest average cut-in distance (approximately 23 m), while the planar and 2000 mm ROC aspheric mirrors produced almost identical cut-in distances (approximately 22 m). There were no significant differences between the planar and the 1400 or 2000 mm ROC aspheric mirrors used in the study for cut-in distance. All mirrors produced cut-in distances within 2.35 m of each other. No significant effect of mirror type was found on the last safe gap drivers would accept in the gap acceptance task.

A study by De Vos (2000) examined planar, spherically convex (1400 mm ROC), and aspheric mirrors (1400 and 2000 mm ROC; both of approximately 75 percent spherical inboard and 25 percent aspheric outboard sections) in a gap acceptance task. Participants using the experimental mirrors drove on a closed test track while a vehicle approached from the rear in the left lane and marked the smallest point with an acceptable gap for a lane-change maneuver into the adjacent lane. Next, each participant-driver's sideward FOV was temporarily blocked while another car moved to various positions at close range of the participant's vehicle. When the FOV was unblocked, drivers had to determine whether there was another vehicle in the adjacent lane; and, if so, whether the vehicle was behind the participant's car with enough clearance for the participant to move into the other lane, or if the two vehicles overlapped and it was not possible to move to the left. Participants were tested with the confederate vehicle in five different positions: 1) out of view, 2) in the adjacent lane just behind the participant's vehicle, 3) just overlapping with the participant's vehicle, 4) in the blind spot of the planar mirror (which was too small to accommodate a passenger car in the adjacent lane), and 5) in the direct FOV. Participants' responses were measured using one of three buttons and the participants' faces were recorded using a camera in order to register glance behavior. A second camera was used to record the car coming from behind, thus providing data necessary to determine the distance

between the two vehicles. Analysis of the recordings took place beginning at the point where the participant indicated the last safe gap. The video analyst then marked the outer contours of both front wheels of the second car. A computer was used to calibrate the number of pixels between the two points which resulted in the distance between the two cars. Glance behavior for the last safe gap task was analyzed for 10 s preceding the last safe gap response. Analysts examined whether the participant was looking ahead, looking at the driver's side mirror or looking over one's shoulder. For the vehicle detection task, analysis began when the participant's view was no longer obstructed. Gaps accepted for the non-planar mirrors were all significantly smaller (i.e., less safe) as compared to gap acceptance using the planar mirror. The 2000 mm ROC aspheric mirror produced average gaps which were greater than the 1400 mm convex and aspheric mirrors, but this difference did not reach significance.

Based on the aspheric mirror research findings, the image distortion produced by larger FOV C/VIS cameras may have an effect on drivers' cut-in distances to adjacent vehicles when changing lanes. Drivers will either cut in closer because the adjacent vehicle will be closer than it appears on the C/VIS monitor, or they will cut in further away as a way of compensating for the uncertainty of the vehicle's position.

Evaluating Indirect Visibility Systems

Measuring Drivers' Visual Sampling Behavior

IVSs can be evaluated through the analysis of drivers' visual sampling behavior. Eye movements have been examined in terms of the number of eye glances, total glance time, mean glance time to a particular location, total eyes-off-road time, and total task time (i.e., the time to complete a task; Olsen, 2003).

Olsen (2003) examined 16 drivers' eye glance patterns during the 3 s prior to 3,227 slow lead-vehicle lane changes. Emphasis was placed on the 3 s just prior to the lane change (lane change latency) because drivers make their go/no-go decision during that period (citing Lee, Olsen, & Wierwille, 2004). The discrete eye glance positions examined included forward, rearview (center) mirror, left mirror, right mirror, left window, right window, left blind spot, right blind spot, and instrument cluster. The eye glance data were analyzed similar to Tijerina, Garrott, Stoltzfus, & Parmer (2005) and Lee, Olsen, & Wierwille (2004); that is, glance location was evaluated in terms of the proportion of times that at least one glance occurred to a particular location. Glance durations were examined for locations of interest and included the transition time to the locations of interest. Olsen also performed a glance link analysis. The glance link analysis was used to analyze eye glance patterns prior to lane-change initiation in the manner described by Wierwille (1981) and Lee, Olsen, and Wierwille (2004). Link value probabilities, or the probability of a glance transition between two specific glance locations in the 3 s prior to lane-change initiation, were computed. It should be noted that the probabilities do not indicate the order in which glances occurred but do indicate the likelihood of glancing from one glance location to another or vice versa. Olsen found that the most likely glance locations prior to lane changes were the forward view, rearview mirror, and left mirror.

Using the same data, Lee, Olsen, and Wierwille (2004) also computed the probability of a transition between two glance locations. Eye glance data were also analyzed for a period of 3 s

prior to the onset of the lane change up until the change actually began. Eye glance analysis was conducted separately for left and right lane changes as it was anticipated that their patterns would be distinct. The authors found that the highest eye glance probability is on the forward roadway. Left and right lane changes have left and right rearview mirror glance probabilities of 0.52 and 0.21, respectively.

Ayres, Li, Trachtman, and Young (2005) assessed the benefits provided by passenger-side rearview mirrors in a lane-change scenario. Participants drove an instrumented vehicle on a test route of approximately 10.5 km and they were asked to make both left and right lane changes while their eye and head movements were recorded using dash-mounted cameras. Participants looked at the inside rearview mirror during 97.5 percent of rightward lane changes. However, the passenger-side mounted rearview mirror was used in only 65 percent of rightward lane changes. Large individual differences were noted in mirror-scanning behavior; however, these may be explained by the relatively small sample size. Additionally, individual differences in rearview mirror use were indicated by the variations in drivers' self-reported use of the exterior rearview mirror during rightward lane changes.

Tijerina, Garrott, Stolzfox, and Parmer (2005) presented the eye glance behavior of passenger car and van drivers before the start of discretionary lane changes. A total of 19 van drivers and 20 passenger car drivers drove an instrumented vehicle in daylight and dry pavement conditions on a test route that included public highways and city roads. A total of 549 total lane changes were analyzed in terms of drivers' eye glance behaviors 10 s before the lane change started. Tijerina, et al. found that for left-to-right (i.e., rightward) lane changes the probability of a glance to the center mirror was substantially higher than was the probability of a glance to the right side mirror. Additionally, they found that the probability of a glance to the center mirror was substantially less for leftward lane changes than it was for rightward lane changes, and the probability of a glance to the left side mirror in leftward lane changes was appreciably higher than the probability of a glance to the right side mirror in rightward lane changes. Tijerina et al., found the results were the same for both van and passenger car drivers, and for highway and city driving.

In an early study of mirror sampling in driving, Mourant and Rockwell (1972) recorded eye behavior while drivers traversed a neighborhood (3.4 km) and freeway (6.9 km) route. Participants included both novice and experienced drivers who had eye glance and mirror sampling recorded as they completed turns, lane changes, and merges. Analysis indicated that experienced drivers make more fixations on the exterior rearview mirror, and have longer average glance durations for the exterior rearview mirror, as opposed to novice drivers. However, in a later study with a similar method examining a smaller number of drivers in multiple age ranges, Mourant and Donohue (1977) determined that experience was positively correlated with the number of glances but was independent of the glance duration. These findings indicate that novice and beginning drivers may have some degree of difficulty in accurately sampling information from a vehicle's exterior rearview mirrors.

Likewise, eye movement studies of drivers merging onto highways have indicated that drivers begin sampling exterior rearview mirrors well before reaching the merge/closure point (Bhise, 1973). Mourant and Donohue (1974) examined mirror scanning behavior with drivers using convex (1016 mm ROC) and planar right rearview mirrors. Drivers' eye behavior was measured

as they executed lane changes on a fixed route on public roads. Results indicated that convex mirrors allow drivers to reduce the number of fixations required on the mirror while executing a lane change. Another finding was that the addition of a non-planar right rearview mirror did not affect the mirror sampling behavior from the left planar rearview mirror. Thus, drivers using convex and planar mirrors on the same vehicle did not appear to incur difficulties in adapting to the mixed system.

Drivers typically sample mirrors more frequently during lane-change maneuvers, with sampling for a left lane change requiring more total time than a right lane change (Mourant & Donohue, 1974). Yet, the time required for drivers to sample information from a mirror varies considerably. Taoka (1990) lists average values for sampling information from several in-vehicle displays. The left exterior rearview mirror had a mean glance duration of 1.10 s (SD = 0.30, 5th Percentile = 0.68 s, 95th Percentile = 1.65 s), while the interior rearview mirror had a mean glance duration of 0.75 s (SD = 0.36, 5th Percentile = 0.32 s, 95th Percentile = 1.43 s). Clearly, drivers demonstrate considerable spread in their sampling characteristics, making the optimization of vehicle mirrors a priority.

Olson et al. (In Press) investigated the impact of driver distraction in CMV operations: 4,452 SCEs (i.e., crashes, near-crashes, crash relevant conflicts, and unintentional lane deviations) were identified in the data set along with 19,888 baseline events (uneventful, routine driving epochs). Analyses examined drivers' eye locations as they performed tasks while operating a CMV. Olson et al. (In Press) found that tasks associated with high odds ratios (e.g., complex tasks) were associated with high eyes-off-road times, which suggested that tasks that draw the driver's visual attention away from the forward roadway should be minimized or avoided (Hanowski et al., 2008; Hanowski, 2004; Olson et al., In Press).

Measuring Lane-Change Performance

Olsen (2003) examined 3,227 slow lead-vehicle lane changes over 23,949 miles which were completed by 16 commuters. He examined four independent variables of route (interstate or highway), usual vehicle (sedan driver or sport utility vehicle [SUV] driver), gender, and experimental vehicle (experimental sedan or experimental SUV). Dependent variables included lane-change duration, severity, urgency, direction, velocity, range, range-rate or relative velocity, time-to-collision, steering wheel position, brake pedal use, lateral acceleration, eye glance position, turn signal use, and turn signal timing. Lane changes were categorized in terms of the initial direction of the lane change (e.g., a lane change in which the subject vehicle [SV] moved from the right lane into the left lane was categorized as a "left" direction lane change because the movement was to the left). Three data collection systems were used: a video system, a sensor system, and a radar system. Olsen (2003) rated all lane-change events using a 7-point severity rating scale where 1 represented unconflicted and 7 represented physical contact. Additionally, lane changes were rated in terms of urgency, which was rated on a 4-point scale (1 = not urgent, 4 = critical) which indicated how soon the lane change was needed based on the time-to-collision (TTC) with the closest vehicle ahead or behind (for accelerating vehicles such as tailgaters). Olsen notes that the severity rating addressed the situation in the destination lane and the urgency rating addressed the situation in the driver's current lane.

Olsen (2003) identified lane changes in terms of specific initiation and end points. The beginning of the lane change or lane change attempt was determined through the monitoring of one or more of the following:

1. The vehicle begins to move laterally relative to the lane.
2. Driver initiates a steering input intended to change the direction of the vehicle relative to the lane.
3. Driver returns gaze to the forward view after looking in mirrors or looking directly toward the side or rear.
4. The vehicle leaves the lane at least temporarily.

The end point of the lane change or attempted lane change was noted as the point when the vehicle settled in the new lane (or in the original lane for a passing maneuver). Settling time was defined in terms of motion relative to the lane boundaries; that is, when the vehicle's lateral velocity relative to the lane is below a threshold for a specified period of time. Lane-change maneuvers were monitored for 10 s prior to the starting point to the end of the lane change. Olsen found that on the interstate, lane changes were performed less often with lower urgency ratings, as compared to highway lane changes. Additionally, drivers of sedans were more likely to make lane changes than were drivers of SUVs.

Lane changes have been described several different ways. Chovan, Tijerina, Alexander, & Hendricks (1994) describe lane changes as a deliberate and substantial shift in the lateral position of a vehicle. Worrall and Bullen (1970) define lane changes as a three-part process comprised of 1) the head portion which represents the time and distance required for a vehicle to move from a straight-ahead path to the first intercept of the lane line; 2) the completion of the maneuver which ends once the vehicle crosses the line; and 3) the tail portion of the maneuver which is the time and distance required for a vehicle to return to a straight-ahead path in the destination lane after crossing the lane line. Van Winsum, De Waard, & Brookhuis (1999) view lane changes as a three-step sequential process based on driver's steering where: the first phase begins with the initial turn of the steering wheel to a maximum angle, the second phase begins when the steering wheel is turned in the opposite direction and ends when the vehicle heading approaches a maximum that occurs when the steering wheel angle passes through zero (straight-ahead), and the third phase is when the steering wheel is turned to a maximum angle in the opposite direction to stabilize the vehicle in the new lane. Wierwille (1984) noted that lane changes are a two-part process where the first part is represented by a heading deviation which is introduced by a steering input that results in buildup of lateral deviation, and the second part is defined as when the vehicle approaches the correct lateral position in the adjacent lane and the heading deviation is removed by applying a steering correction in the direction opposite that of the initial steering input. Olsen (2003) concluded that a lane change was a process with start and end points where the start is defined as the first lateral movement and the end is the settling point in the new lane.

Bascuñana (1995) studied the characteristics of safe versus unsafe lane-change maneuvers. The dynamic conditions defining a safe lane change are primarily the relative distances and velocities between vehicles at the initiation of the lane change, and the geometry of the lane-change maneuver (e.g., the collision path). Both of these judgments require the driver to accurately sample information from the vehicle's rearview mirrors. There is a strong relationship between visual information processing (such as mirror sampling behaviors) and crash involvement

(Avolio, Kroeck, & Panek, 1985). Understanding how drivers obtain information from exterior rearview mirrors, and how this sampling process affects driver decisions, has practical implications for the design and optimization of CVISs. Mirror sampling has been extensively examined over the past decades, yielding a tremendous amount of information on driver performance.

Kiefer and Hankey (2008) explored the effect of a side blind zone alert (SBZA) system on drivers' lane-change behavior. Sixteen middle-aged (40-50 year old) and 16 older (60-70 year old) licensed drivers participated in four or six 1-hour drives. A 1999 GMC Suburban and a 1998 Cadillac Seville were instrumented with a data acquisition system (DAS) and an SBZA system. Driver behavior was recorded over at least four 1-hour drives over four sessions, during which the SBZA system's availability was held constant for two successive drives. Additionally, eight of the participants participated in two additional 1-hour drives with the SBZA system enabled. Driver behavior was examined during the planning phase (i.e., the time the behavior occurred relative to when the lane change was initiated and the probability of turn signal usage, side mirror glance, inside mirror glance, and over the shoulder glance behaviors is likely) and the execution phase (i.e., the peak lateral decelerations during the actual lane-change maneuver). The frequency of lane changes was also examined. Kiefer and Hankey (2008) found that when the SBZA system was in place, the most common glance behavior for left and right lane changes (i.e., left side mirror for left changes and inside mirror for right changes) was more likely to be observed when the SBZA system was enabled. Additionally, over the shoulder glances were fairly uncommon for both left and right lane changes, suggesting that the SBZA provides information to the driver during side mirror glances that is not obtained through over-the-shoulder (blind zone check) glances prior to an intentional lane change.

Consistent with Olsen (2003) and Lee et al. (2004), Fitch et al. (2009) examined drivers' behavior leading to lane-change crashes and near-crashes and served as a follow-on to the 100-Car Naturalistic Driving Study (Dingus et al., 2006), which had examined the driving habits of 241 participants as they drove their personal vehicles during their daily commutes in the Northern Virginia/Washington, DC area for a period of 12 to 13 months each. Driver eye glance data were analyzed to determine the number of drivers who scanned their surroundings prior to and during the occurrence of the lane-change events. Three event scenarios were used to classify 135 lane-change events (3 crashes and 132 near-crashes; lane-change events were categorized by lane-change direction within each scenario):

1. SV striking or nearly striking an adjacent principal other vehicle (POV) during a planned lane change (termed the SV Sideswipe POV scenario).
2. SV swerving into an adjacent lane to avoid a forward crash threat (termed the SV Swerve to Avoid Forward Crash Threat scenario).
3. Adjacent POV striking or nearly striking the SV as the POV executed a lane change (termed the POV Sideswipe SV scenario).

The start of the lane change was identified as the point in time in which the SV began to change lanes using one of three criteria:

1. The driver initiated a steering input intended to change the direction of the vehicle relative to the lane. This criterion was predominantly used to establish the lane-change initiation.

2. The vehicle began to move laterally relative to the lane. This criterion was used when in-vehicle video footage was not available or during nighttime driving when the in-vehicle image contrast was low.
3. The driver returned his/her gaze to the forward view after looking at mirrors or directly out a window. This criterion was used in conjunction with the second criterion to define the lane-change initiation.

Lane-change events were also identified by event severity (crashes or near-crashes), lane-change direction (i.e., the direction of travel from the perspective of the vehicle executing the lane change), precipitating event (i.e., the action of a driver that begins the chain of events leading up to a crash or near-crash), and driver response to the lane-change event. Eight exterior eye glance locations were reduced to better understand where drivers were looking before and during the lane-change event: left forward, forward, right forward, right window, right mirror, center mirror (i.e., rearview mirror), left mirror, left window. Eye glance data provided insight into glance behavior prior to and during the lane-change maneuver. The eye glance data were collected during the time interval spanning from 8 s to 3 s prior to the initiation of the lane change and were analyzed to explore driver spatial awareness. Fitch et al. (2009) found that some drivers involved in lane change SCEs failed to give proper notice to surrounding vehicles regarding their intent to change lanes and that drivers also failed to adequately scan their surroundings prior to changing lanes.

FLEET SAFETY OFFICIAL INTERVIEWS

C/VISs remain a research priority for both NHTSA and FMCSA. As suggested in the crash database analyses presented earlier, the ability to give commercial vehicle drivers information about their blind spots, or “no-zones,” promises to reduce the number of lane-change/merge crashes. Additionally, the view of the rear blind spot (behind the trailer on a dry-van configured tractor-trailer) should assist drivers with lane changes and backing at terminals, customer sites, and other loading and unloading points.

Previous research yielded significant increases in the understanding of the design and operation of C/VISs. To build on this knowledge, input from commercial carrier safety officials was gathered with respect to the design, implementation, and operation of C/VISs in carrier fleets. The results of the fleet safety official interviews are presented below.

Method

The research team solicited the opinions of safety and fleet management officials at motor carriers using a database of contacts in the trucking industry. Officials at these carriers were interviewed by telephone regarding the potential costs, benefits, and real-world implications for the purchase, deployment, and use of IVSS. This task served to estimate the costs and benefits of IVSS.

As a result of e-mail solicitations sent to nine people (see Appendix A for solicitation scripts), four officials agreed to participate in the interview. Prior to the scheduled interview time, the Statement of Informed Consent (as required by the Virginia Tech Institutional Review Board [IRB]) and briefing on the proposed C/VIS was e-mailed to each participant for review. The four

interviews were collected during the first and second week of November 2008. Appendix B presents the script used to commence the interview. All interviews were one hour or less in duration. Participants were briefed on the C/VIS technology over the phone and via a document that was e-mailed to them earlier on. This briefing provided information on the approximate coverage area, camera types and positioning, monitor positioning, and images produced by the system. (This briefing document is provided in Appendix C.) After the briefing, the interview commenced. Audio recordings and notes from the interview were used to generate summaries of responses to each question.

The questions were grouped into five major areas: safety benefits of the proposed C/VIS, company and driver acceptance of the technology, fleet implementation issues, economic issues, and basic information about the company. The complete list of questions presented to the interviewees is provided in Appendix D.

Results

Company Information

Company Profiles

- The companies represented by the four fleet safety officials operate a range of haul/carry types, with many differences in the number of drivers and power units they operate. The self-reported number of drivers employed or contracted, as well as the number of power units employed or contracted as part of the fleet are described in Table 15.

Table 15. Drivers and Power Units within Fleets

Carrier	Drivers	Power Units	Route Type	Trailer Type(s)
1	105	96	Local/Regional	Flatbed (Oversize)
2	690	300	80% Local, 20% OTR	Tank/Dry Van
3	1,500	1,400-1,500	OTR	Flatbed
4	6,000	6,000	OTR	Dry Van

Note. All numbers are approximate figures provided by interviewee.

OTR: Over the Road

- The company of one of the four interviewees operated different haul/route types. This company operated a mixture of primarily local pickup and delivery (hazardous material tank hauling; approximately 80 percent of its routes) and over the road hauling (OTR, i.e., long haul) (approximately 20 percent of its routes). The remaining companies operated one type of haul/route. These were less-than-truckload/consolidated shipping, local/regional oversize loads, and over-the-road/dedicated accounts.
- The official from the one carrier operating multiple haul/route types believed benefits from a C/VIS would not be equally distributed across all haul types. This official believed the greatest benefits from a C/VIS would be obtained by local pickup and delivery drivers, who would be able to have a greater awareness of the traffic in their blind spots while in heavy traffic areas. This interviewee believed that, although some benefit would still be obtained, OTR drivers who spend most of their driving hours on the highway would experience fewer benefits from the C/VIS. When asked about differences

in benefits, most of the single-haul/route-type carriers did not expect to see large differences in benefits across driver types.

Driver Training

- Three of the companies require regular training of their drivers. When asked about integrating the C/VIS into their existing training, three company representatives believed that it would only require minor changes. The one person who held a differing opinion did not believe that the C/VIS would require any change to his company's existing training program.

C/VIS-Relevant Crashes Experienced

- Interviewees were asked about the frequency and costs associated with lane-change and merge crashes within their company. Wide varieties of responses were observed, reflecting the different operations each carrier ran, and most responses were given in comparative values. The responses of each of the four carriers are provided below:
 - Low in frequency and cost, each incident costs approximately \$8,000 United States Dollars (USD) per occurrence.
 - Extremely low, with one lane-change/merge crash per year for the last two years.
 - Leading in cost, but very low in frequency
 - Approximately 1 percent of crashes, and one of the less costly type of crashes
- Similar to the question regarding lane-change and merge crashes, interviewees were asked to estimate the frequency and costs associated with backing or maneuvering crashes. The responses were varied, reflecting the different operations each carrier ran. Most answers were given in comparative values. The responses of each of the four carriers are provided below:
 - Low absolute frequency, but one of the most common crash types for this carrier. Most occur on job sites as collisions with fixed objects, and are typically very low-cost at approximately \$200 to \$300 USD per instance.
 - Over the past two years, a total of 41 crashes (all low-cost) over 33 million miles. Twenty-six of the crashes were in the past 12 months.
 - Most of this carrier's crashes are backing collisions with fixed objects at job sites. These are not critical crashes; they have a high instance, but are low cost.
 - Most common type of crash for this carrier, accounting for about 50 percent of all its crashes. However, they are not very expensive crashes.

Previously Used Aftermarket Safety Technologies

- Carrier officials were asked if they had previously implemented any aftermarket safety technologies in order to determine their company's general level of acceptance for such systems. All officials reported that their companies had tested aftermarket safety technologies. Many of those technologies were implemented across the respective fleets.
- One company described testing a variety of technologies, including anti-rollover technology, and a system for forward- and driver-view video recording. With respect to

the video recording system, the official reported positive driver reactions. However, the company failed to realize safety benefits from this system and did not implement it.

- Another carrier official described a test of an aftermarket radar system. The company installed sensors on the front, rear, and right sides of nine tractor-trailers and tested the system for a period of 120 days. The company noted a safety benefit and installed the system across the fleet. However, after 36 months the benefit from the system was reduced. The company determined that drivers were becoming less attentive to the system and were habituating to the presence of the system's information. The company then determined that training would be a better approach to safety, and ceased new installations of the radar-based systems. The company official stated that this safety training method has demonstrated a much greater improvement on safety than the radar system provided. The official stated that he was "*increasing mileage, decreasing frequency, putting less equipment [in the truck], but changing the type of training*" and seeing extremely positive safety benefits.
- One official reported testing systems including lane departure warning, front and side radar, and a video-based blind-spot reduction system. The official stated that drivers' reaction to the video-based blind-spot reduction system was initially negative, but the system was accepted after drivers began to see benefits from its use. The company also realized safety benefits from the system.

Safety Benefits

Anticipated Changes in On-Road Driving

- Interviewees were uncertain regarding whether drivers would change their on-road driving behavior with a C/VIS. Two of the four interviewees responded that the driving changes experienced would be a result of the tradeoff between the ability to give the driver more information and negative aspects such as glare from the monitors and the possibility of driver complacency.
- One safety manager noted that the C/VIS was likely to yield a positive change in on-road driving, as "a true professional is looking anyway," so use of a C/VIS would simply make this task easier.
- This individual also expressed concern over driver complacency with the system. One official who believed that a C/VIS would change on-road driving stated that the C/VIS would allow drivers to be more aware of their surroundings and would better enable defensive driving. Another company official stated that any change in on-road driving behavior would depend on the individual driver's characteristics, and the benefits seen were likely to be limited to city driving and backing/docking maneuvers.

Anticipated Changes in Loading/Unloading Site Driving

- Interviewee responses were split regarding changes in driving at terminals, customer sites, and other loading and unloading areas. Two interviewees were of the opinion that the C/VIS would be a benefit to drivers, especially during backing maneuvers. They both

believed that the system would make backing easier for the driver, but would not eliminate the need for drivers to exit the cab and look at the surrounding environment when backing.

- One of the interviewees, with a positive opinion on the C/VIS for backing, expressed concern that the images in the monitor (especially those in the side-view monitors) could be distracting to the driver during a backing maneuver.
- Two respondents did not believe that drivers with a C/VIS would alter their driving habits at terminals and load points. One of them believed that fender mirrors and leaving the tractor's cabin were adequate for the task. The second respondent believed that distance judgments using the C/VIS would be difficult, although the right-side view could be of some use. This interviewee also expressed concern that drivers would be annoyed by the C/VIS and become less likely to use the system at terminals. Interestingly, the respondents with a "no-change" opinion on this question were primarily tank and flatbed carriers.

Forward Vision Problems

- Three of interviewees did not believe that collisions due to forward visibility from the cabin were a significant problem. This was primarily due to the more steeply sloped hood profile of modern tractors. None of the carrier officials interviewed stated that these collisions were a significant contributor to their company's safety record. All respondents expressed opinions that having the forward view would be beneficial in maneuvering at job sites (for identifying and preventing collisions with fixed objects) and terminals, both low-speed driving conditions.
- One respondent stated that a forward vision system would have benefits for drivers in situations such as heavy traffic or tollbooths, where automobile drivers cutting in front of the tractor-trailer are a common safety concern. However, no respondent believed this additional camera view was economically justified.

Company/Driver Acceptance

Initial Driver Reactions to the C/VIS

- Interviewees were asked what Class A CDL drivers' initial reactions to the C/VIS would be. Carrier officials believed driver acceptance would be dependent on how the system was introduced to drivers. They felt that if the system were not given to the drivers specifically as a useful safety tool, drivers would reject the system. For this reason, one interviewee suggested having the drivers act as partners and assisting with the implementation process. If the system was introduced as a system that provides obvious benefits to the driver, it will be more likely to have better driver acceptance. Without this type of introduction, one carrier official said driver "pushback," or resistance, would be likely.
- Most carrier officials believed drivers would express positive opinions towards the C/VIS. One carrier official stated, "True professionals will say 'Wow, nice tool.'"

Additionally, multiple officials believed that once drivers began to use the system, and if they experienced benefits from it, acceptance would spread.

Video Output Recording

- Interviewees were informed that the C/VIS could have the ability to record the video displayed by the system's monitors. When asked about the possibility of recording this video, three interviewees responded that recording video from the C/VIS was a tradeoff between utility and liability. Officials believed video recording brings additional utility to the system by allowing for feedback and additional training of drivers. One official noted his company already has a video recording system in place that is used for training and discipline purposes. This tool, he stated, would be extremely useful as a proactive training device. Another official stated that the availability of video recordings, especially when triggered by sensors in crash conditions, would be an excellent tool for crash reconstruction. The four officials expressed concern over the legal status and associated requirements with what would be considered discoverable evidence in case of investigations and lawsuits.
- In addition, carrier officials were asked for their opinions regarding driver acceptance of a C/VIS that also records system video output. Two officials believed that video recordings from the device would not have an effect on driver acceptance, while the other two believed a decrease in driver acceptance would occur. The two officials who said that driver acceptance would not change stated that their company already employed technologies that record video and other information from the trucks, so drivers were already used to a higher degree of monitoring. The officials who believed that driver acceptance would decrease believed some drivers would resent the monitoring more than others, and drivers would feel it was a reduction of their independence.
- All officials expressed the opinion that driver acceptance of the C/VIS and its recording ability would be highly dependent on how the system is initially described. One official suggested the best way to introduce drivers to the video recording feature, if it is implemented, would be to not attempt to hide the capability (listing as many positives of recording this information as possible) while not over-emphasizing the feature.

Fleet Implementation

Pre-Installed versus After-Delivery Installation

- Interviewees were asked whether they would prefer a C/VIS to come pre-installed on delivery of the power unit, or to install the system as an aftermarket device. Two officials preferred the system to come pre-installed. The other two officials preferred to install the system themselves if the complexity and cost of installing after delivery was not prohibitive. Cost was the largest deciding factor in each official's decision; all would prefer to see the device implemented in the most efficient manner, regardless of pre-installed versus aftermarket installation.
- One safety official also provided more information on this preference by stating that he would prefer to self-install the system for a limited test period. If he determined the

system was ready to be installed across the entire fleet, his preference would be for the units to be installed prior to delivery. This allows him the ability to understand the system before committing to its widespread implementation.

Driver-C/VIS Interaction

- Company officials were asked their opinions on the appropriate level of interaction between drivers and the C/VIS. Officials were unanimous in their desire to see driver interactions with the system kept to an absolute minimum. All believed the system should turn on and off with the ignition of the tractor. One official suggested that the maximum allowable time that the device is allowed to be off should be 15 minutes and the frequency of the off periods should be monitored to ensure drivers are not constantly disabling the system. Another official suggested that the rear view would be the only view able to be switched off.
- Similar opinions were expressed concerning the adjustment of system settings such as screen brightness. All officials believed a minimum number of adjustments should be provided which override automatic adjustments. When manual adjustments need to be made, controls should be simple knobs or push buttons. However, some officials were concerned the minimum levels of settings could effectively allow drivers to disable the system.
- One company official stated that the ideal C/VIS would operate similarly to an Electronic On-Board Recorder (EOBR). The driver would have almost zero interaction with the system and both activation and illumination adjustments would be automatic. As the official said, ideally the *“only requirement is to look at it.”*

Other Features

- Officials were also asked what other features they wished to see included in the C/VIS. Two officials said the system should be a single-purpose device and would ideally not attempt to perform any other functions. The other two officials both mentioned the ability to include truck-operation reporting capabilities using existing in-truck communication systems. Both of these officials felt this capability was vital to the effectiveness of the system and would be necessary for driver continuing training.
- The two officials who wished to see additional features were asked what costs they were willing to incur for the additional functions. One official stated that the communication with company headquarters was an essential feature and should be included in the device. The other official stated that the additional features (including locking the recorded data in crashes, training program integration, and proximity alarms) would need to have a return on investment (ROI) time of less than two years, unless the system was portable across trucks.

Maintenance Concerns

- Carrier officials were also asked about any specific maintenance concerns they had regarding the C/VIS. A frequently mentioned comment was the durability of the system. Durability was especially of concern due to the high levels of vibration experienced at the

mounting points of the camera and liquid crystal display (LCD) monitors. One official stated that the system needs to be vibration-resistant for over 1 million miles.

- The next largest maintenance concern was the practicality of mounting cameras on the sides of the tractor. Two officials (one of whom had tested a camera-based blind-spot-reduction system in the past) had concerns specifically regarding road film (soils, greases, and oils on the roadway surface) and (wintertime) salt residue on the camera lens. One official summarized his concerns as “*500 miles after cleaning, is it still effective?*” The official who previously tested a camera-based system had experienced problems with a buildup of road film on the camera lens. This film prevented the system from operating properly, and resulted in the camera lenses becoming scratched after cleanings.
- Other maintenance concerns were making the system as tamper-proof as possible, making the system easily portable between trucks, and ensuring the system was adaptable to different trailer types (ranging from flatbeds to dry vans).

Economic Issues

Cost-Benefit Analysis/Return on Investment

- Carrier officials were asked to discuss their decision processes regarding the system’s ROI and specifically what factors would be accounted for in their cost-benefit analysis (CBA) of a C/VIS. The factors that would be most likely to factor into the CBA of a C/VIS were the cost of the product, its installation costs, maintenance costs, and lost time associated with truck and driver downtime due to the system. The training costs associated with use of the system were also noted. Potential C/VIS-specific liabilities that carrier officials named included the discoverability of video recordings produced by the device, which could serve as evidence in legal proceedings against them.
- One carrier official stated that it would be difficult to recoup the costs associated with the system due to his company’s extremely low incidence of lane-change/merge and backing/maneuvering crashes. Another official stated that although the cost of crashes and risk management were key factors in the decision of implementing a C/VIS, there were always liabilities associated with business.

System Cost

- Carrier officials were asked to provide an estimate of the cost of the C/VIS, per truck, they would be willing to accept. All officials expressed difficulty in generating an estimate. Most ranged from \$1,000 to 2,000 USD. Two officials stated that the ROI must be obtained over a relatively short time period (one official named a period of under 2 years, another named a 3-year period), and that a return which takes longer than this would be difficult to justify. Many officials also cited the current (at the time of the interview) economic problems the industry was facing as a barrier to purchasing a new technology.

Incentives

- As part of the economic issues of a C/VIS, interviewees were asked if incentives from either the federal government or their insurance providers would influence their decision on whether or not to adopt the C/VIS. The responses were positive to incentives, with all carrier officials stating the presence of incentives would make it more likely for them to adopt a C/VIS. Only one official stated that incentives would not influence the decision on adopting a C/VIS.
- Carrier officials did not have a common preference for tax or insurance incentives for purchasing a C/VIS. Two officials stated that the two types of incentives—tax-based or lower insurance premiums—were approximately equal in weighting. One carrier official stated a clear preference for tax incentives.

Justification of a Full 360° View

- Carrier officials were asked if, in their opinion, providing a full 360° view around the tractor and trailer would be economically justified. The majority of officials stated that it was simply dependent on the cost differential between the C/VIS as described in the briefing, and the full 360° view system.
- One official, referring to the economic issues being experienced by the trucking industry at the time of the interview, stated that two or three years ago the answer would be yes, but today it is no. Another official stated that it was extremely cost-dependent, as the only situations a 360° view would be useful in are maneuvering in close environments. This official did not believe the full 360° view would benefit the typical carrier.

Liabilities Associated with Use of a C/VIS

- Carrier officials were asked if the liability issues regarding the C/VIS, such as video recordings of a crash, would affect their decision to adopt a C/VIS. Officials expressed a variety of opinions.
- One official stated simply that the liabilities of the system could be prohibitive to its adoption. Another safety official stated that the liabilities of the system are a trade-off, whereas the recordings can provide evidence of innocence as well as guilt after an incident. He compared the liability issue to that of existing satellite-based fleet tracking systems, in that the protection such devices provide is always accompanied by some degree of risk.
- Two carrier officials stated that the liability issues with a C/VIS were not concerning at all. One official stated that the only liability associated with a C/VIS would be if the system did not include a “*foolproof and automated*” method of locking the data recording after an incident. This official currently uses other video recording within his company’s fleet, and did not view this as a liability in general.

Top Issue with the C/VIS

- Respondents were asked for the top issue they foresaw in using the C/VIS. A wide range of responses was given, with no carrier officials holding the same top concern with regard to the C/VIS. The total cost of ownership of the C/VIS and driver acceptance were top concerns for two of the officials interviewed.
- The reliability of the C/VIS hardware equipment and the possibility for distraction were of particular concern for one safety official. His concern with distraction centered on the increase in visual scanning the C/VIS equipment would require in addition to existing visual scanning. This official's fleet vehicles are equipped with six mirrors (west coast, spot, and fender mirrors on each side of the tractor); he was concerned about the number of items which the driver must visually monitor to a total of nine items.
- The official with previous experience with a camera-based system stated that his major concern was glare from the monitors. In his previous experience with similar systems, glare from the monitors provided a distraction and could severely restrict nighttime vision. This official also expressed concern with visual distortion through the video system.

Overall Usefulness of the C/VIS

- Carrier officials were asked whether, in general, they believed a C/VIS would be beneficial for their company. Three of the four officials simply stated "yes." They believed the C/VIS would provide some level of safety benefits. The one carrier official providing a differing opinion stated that the device would have some safety value or utility, although he was hesitant to provide an absolute response.

Summary

Four safety and fleet officials, representing four different trucking companies, were interviewed regarding their opinions on a C/VIS. Prior to the interviews, each official received a briefing on the C/VIS goals and their configuration, and had a chance to ask questions regarding the system. During the interviews, officials were asked questions regarding the perceived safety benefits, acceptance by Class A CDL drivers, fleet implementation, and economic issues of C/VIS use. Mixed opinions resulted when interviewees were asked if drivers would change their on-road driving behaviors after receiving a C/VIS. The benefits of the system (namely, easier access to blind-spot information) were balanced by concerns over monitor glare and increased distraction from having to scan three new sources of information in the cab. Two interviewees believed that driving at loading and unloading points would be changed by the C/VIS. Those who thought a change would occur believed the system would assist drivers in avoiding collisions with fixed objects, which was one of the more common collision types experienced by all company personnel interviewed. Maintenance of the system was a concern; specifically, the durability of monitors and cameras after long-term exposure to vibration. The economics of implementing a C/VIS were discussed with fleet and safety managers. Officials believed the benefits of the C/VIS must be balanced against the costs in terms of initial device purchase, and the associated downtime with training, installation, and maintenance of the device. They estimated the device would likely cost between \$1,000 to 2,000 USD each. This, combined with the factors

considered in costs and benefits, led some officials to estimate that the ROI for a C/VIS would be approximately 2.5 years or less. Ensuring that the device was portable between trucks would increase this period somewhat. All officials agreed that incentives, either from the government or the insurance industry, would increase adoption of the technology.

CHAPTER 3. THE ADVANCED C/VIS (A-C/VIS)

A requirement for the TFD was to upgrade the E-C/VIS used in the earlier Smart Road test track testing to a roadworthy system capable of withstanding the wear and tear of daily trucking operations. The A-C/VIS was developed to meet this requirement. The A-C/VIS's design met the established daytime performance specifications set forth by Wierwille, Schaudt, Gupta, et al. (2008), and adopted the features that made the E-C/VIS suitable for nighttime and inclement weather use. This chapter presents the elements of the A-C/VIS's design. Aspects covered include the selected camera, its settings, the camera housing, the selected monitors used to display video to drivers, their placement in the truck cabin, and the DVI. Appendix E compares the A-C/VIS specifications to those pertaining to the E-C/VIS.

A-C/VIS CAMERAS

A Dallmeier MDF3000a camera was selected for the A-C/VIS (Figure 50). The Dallmeier MDF3000a is a compact and lightweight Complementary Metal–Oxide–Semiconductor (CMOS) camera that measures 47 mm (width) x 45 mm (height) x 53 mm (length) in size. Its size made it ideal for mounting to the truck's fenders without extending beyond the allowable vehicle width. The camera uses 17-bit Digital Signal Processing to generate a crisp 540 TV line image of surrounding vehicles. The camera offers controllable color and monochrome modes, which allowed drivers to select a color image for daytime operation, and a monochrome image for nighttime operation. Other features that made the camera suitable for a C/VIS include auto-gain control (AGC), backlight compensation (BLC), and Progressive Scan image capture. Furthermore, because its operating temperature was between -10 °C to 50 °C, and its operating humidity was between 0 - 90 percent, the camera would be able to function under various weather conditions. It is worth noting here that this camera was not observed to fail at any point during the TFD.



Figure 50. Dallmeier MDF3000a Camera. (Source: Dallmeier-Electronic.com, 2010)

The Dallmeier MDF3000a camera was selected for the TFD through a camera selection process. First, a list of candidate cameras was developed by performing web searches, consulting technology magazines, consulting previous research, and performing literature reviews. Second, each camera was given a grade based on its size, resolution, sensitivity, color and monochrome mode, IR light sensitivity, Day/Night switching, and temperature range. Based on preset criteria, four cameras were purchased for testing. Third, the four cameras were evaluated based on the images they produced under visible and IR light in unlit parking lots, unlit highways, and lit

highways. This was accomplished by mounting the candidate cameras to the fender of the test truck and simultaneously collecting video while driving on public highways (Figure 51).



Figure 51. Candidate Cameras Mounted to Fender of Test Truck

The Dallmeier MDF3000a was selected because it produced the clearest image, provided the highest resolution, and had the fastest auto-gain response, which was ideal for minimizing the blooming that arose from passing vehicle headlights. It also provided a software-controllable Day/Night switchover which was necessary for the development of the A-C/VIS in that it allowed drivers to select what mode to use. Of particular interest, the camera had a sensitivity of 1 Lux, which made it difficult to reproduce images in low-light conditions. However, because the A-C/VIS uses IR light illuminators mounted along the side of the trailer to detect objects in low-light conditions (Figure 52), the Dallmeier MDF3000a camera's IR sensitivity was modified by replacing the standard lens with a 900 nm long-pass filter (Cheshire Optical 900 IFLP filter). This filter attenuates light between 720 and 850 nm, allowing the camera to capture IR light and produce images of unlit objects at night.



Figure 52. IR Illuminators Mounted Underneath Trailer

It should be mentioned that previous C/VIS research used the Toshiba IK-64DNA security camera (Figure 53). This camera produced excellent images during the day and at night owing to its high sensitivity (0.0001 Lux) and retractable IR lens. However, this camera was not appropriate for the TFD because of its size (2.48" [width] x 1.97" [height] x 4.57" [length]) and because its moving retractable lens made it susceptible to damage from road vibration.



Figure 53. Toshiba IK-64DNA Camera used in the E-C/VIS Study

Figure 54 presents a screenshot of the multiplexed video captured from candidate cameras mounted to the tractor-trailer's fender. The video image shown in the top-left quadrant was collected by the Toshiba IK-64DNA camera. The video shown in the top-right quadrant was collected by the Dallmeier MDF3000a (with a modified 900 nm long-pass filter). The video shown in the bottom-left quadrant was collected by the next leading candidate camera (Bollide BC2003HD), while the video shown in the bottom-right quadrant was collected by VTECH USA's Sidetracker system. It can be seen that the image produced by the modified Dallmeier MDF3000a camera is comparable to that produced by the Toshiba IK-64 DNA.



Figure 54. Multiplexed View of Candidate Cameras

Camera Settings

The Dallmeier MDF3000a was set to operate in color mode during the daytime and in monochrome mode during the nighttime. At dusk, the day mode automatically switched to night mode once the ambient light dropped below 2 Lux. At dawn, the night mode automatically switched to day mode once the ambient light surpassed 10 Lux. Light levels had to exceed these thresholds for 20 s before the mode was switched in order to inject hysteresis into the system. Drivers were able to override this automatic switchover and select which day/night mode to use. An important feature of the Dallmeier MDF3000a camera was that it allowed the gain to be independently set for both color and monochrome modes. Setting the nighttime gain low (a value of 24 was used) allowed an image minimally affected by headlight bloom to be produced at night, while keeping the daytime gain set to automatically adjust allowed an accurate image to be reproduced in the daytime.

Camera Housing

The TFD required the A-C/VIS to function in various weather conditions. A weatherproof casing for the Dallmeier MDF3000a was designed and developed by the research team (Figure 55). The casing's shape was designed to prevent water from collecting over the camera lens while the vehicle was in operation.

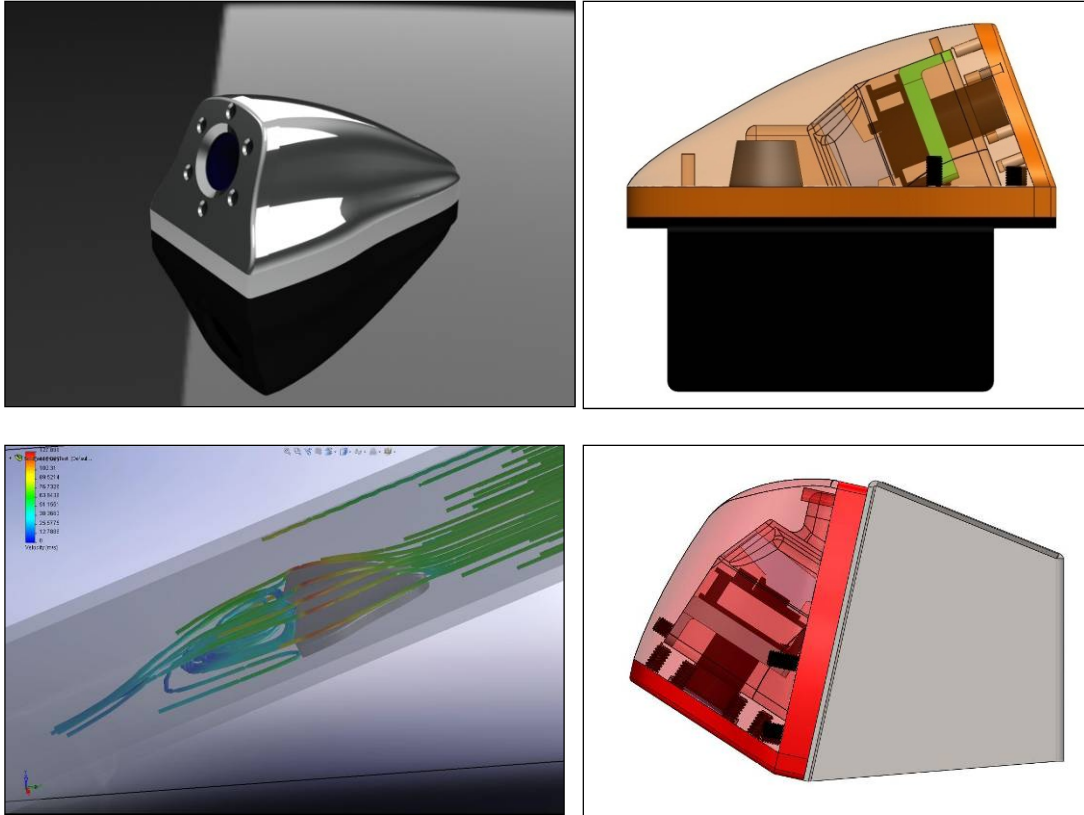


Figure 55. A-C/VIS Camera Housing Design

Camera Location

The A-C/VIS uses three cameras to provide drivers with an all-around view of the area surrounding the tractor-trailer (Figure 56). One camera is mounted on the left fender and is aimed back along the trailer (Figure 57). Likewise, a second camera is mounted on the right fender. The third camera is mounted on the top-rear of the trailer and is aimed down at the area directly behind the trailer. It should be noted that the cameras are mounted such that the tractor-trailer can be seen along the edges of the video images produced on the monitors. The two fender cameras use a 45-degree FOV (similar to the existing fender mirrors), while the rear camera uses a 102-degree FOV that allows the trailer's edge and adjacent lanes to be captured in one image.

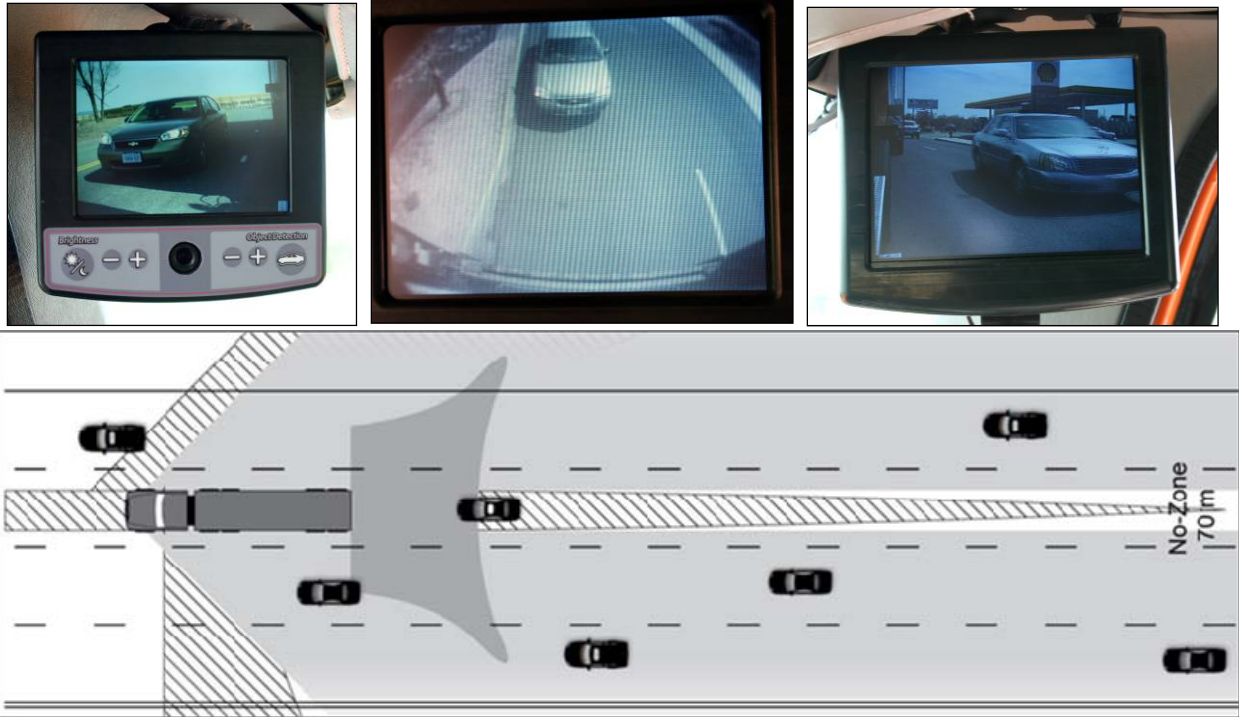


Figure 56. Coverage of the Three A-C/VIS Cameras



Figure 57. A-C/VIS Camera Housing

A-C/VIS MONITORS

The monitors used by the A-C/VIS were selected to meet the specifications set forth in (Wierwille, 2008a). AcceleVision LCD5A and LCD64A monitors were selected because of their sharp image (600 [H] x 234 [V] dots), large viewing angles (110 degree [H] x +15 degree/-35 degree [V]), and ability to be significantly dimmed at night (Figure 58). They were tested during the day inside the truck cabin and were found to provide a clear and bright image (rated at 240 NIT). They were also tested in an unlit room, as well as in the truck cabin at night, and when dimmed, were not found to provide discomfort glare (glare measured to be 1.5 Lux). Both monitors had an extended control board that allowed them to be easily integrated into the monitor housing. The AcceleVision LCD5A display had a 13-cm diagonal that met the Size 1 specification, while the AcceleVision LCD64A had a 16-cm diagonal that met the Size 2 specification (Wierwille, 2008a). The monitors' operating temperature was between -5 °C and 50 °C.



Figure 58. The AcceleVision LCD5A and LCD64A Monitors without Monitor Housings

Monitor Location

The A-C/VIS used three monitors, each displaying an image from one of the three cameras mounted on the tractor-trailer. One monitor was mounted at the top of the left A-pillar and displayed the video image captured by the camera mounted on the left fender (Figure 59). This monitor sat roughly 26 inches from the drivers' eyes. The second monitor was mounted at the top-center of the windshield and displayed the video image captured by the rear wide-angle look-down camera mounted on the trailer. This monitor sat roughly 32 inches from the drivers' eyes. The final monitor was mounted at the top of the right A-pillar and displayed the video image captured by the camera mounted on the right fender. This monitor sat roughly 57 inches from the drivers' eyes.

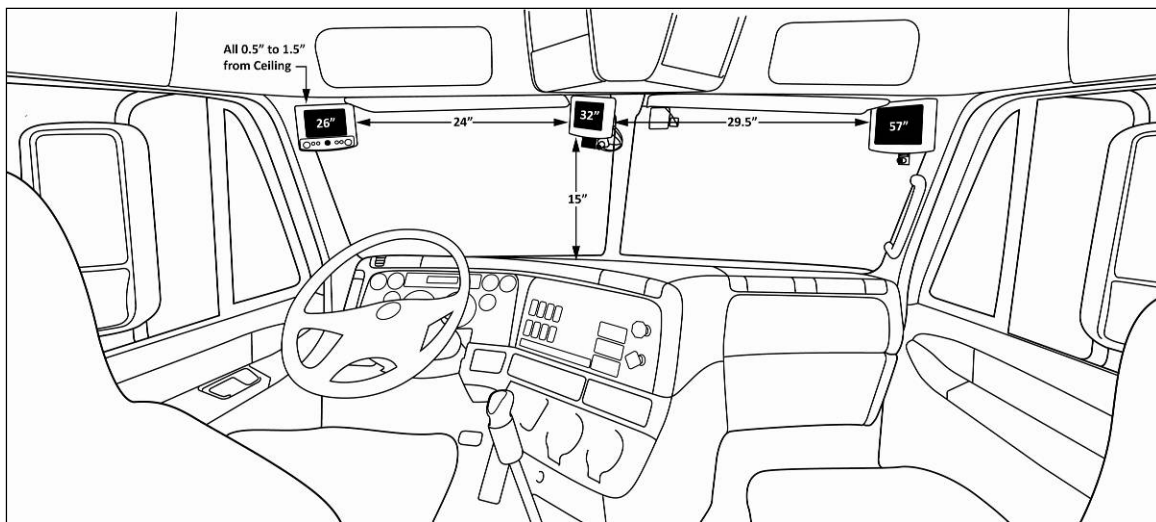


Figure 59. Placement of A-C/VIS Monitors

The placement of the monitors was selected by balancing a multitude of criteria. First, nighttime C/VIS testing revealed that the light emitted from the monitors generated a cross reflection on the side windows. When the monitors were mounted at the bottom of the A-pillars (similar to the E-C/VIS layout), the cross reflection blocked the driver's view of the west coast mirrors. Attempts were made to eliminate this cross reflection by rotating the monitors, and using privacy screens that only allow light to travel within a 20-degree angle from the monitor. However, the rotated monitors were difficult to view, and the privacy screen reflected substantial light during the day. It was determined that cross reflection could not be eliminated, but that it could be controlled. By mounting the monitors at the top of the A-pillars, the reflected light was found to not interfere with the driver's view of the west coast mirrors (Figure 60). This location was also found to reduce the amount of sunlight reflected off the monitors during the day because the eyebrow of the truck cast a shadow across the monitors. The height of the monitors was also expected to encourage drivers to view them as they scanned from the forward roadway to their west coast and convex mirrors.



Figure 60. Cross Reflection Produced by A-C/VIS Monitors on the Left Side Window

The left and right monitors were also mounted such that they did not create new blind spots. By mounting the monitors on top of the A-pillars, they did not block the driver's view of the road. This was desired because monitors mounted on the dash were reported to block the driver's view of the adjacent left lane. Unfortunately, the design of the TFD test vehicle cabin interior did not allow the left monitor to be mounted on the A-pillar without substantial damage. As such, the left monitor was positioned to the right of the left A-pillar. It should be noted that the area covered by the monitor was no greater than the area covered by the sun visor when it was pulled down.

Because the monitors were mounted at the top of the A-pillars, discomfort glare produced by the light they emitted was a potential issue during nighttime driving. This is because bright monitors can hinder a driver's ability to become dark-adapted at night. The selected monitors addressed this issue because their brightness could be reduced to 1.5 Lux. The A-C/VIS programmed this low brightness level as the default nighttime brightness level.

Monitor Housing

The A-C/VIS monitors were housed in a plastic casing. The casing was designed to be rugged and sustain normal wear and tear encountered in the truck cabin. Figure 61 presents an image of

the left monitor housing and the center monitor housing. The right monitor housing was the same as the center monitor housing, only slightly larger to accompany the 16-cm display.



Figure 61. Left and Center Monitor Housing for A-C/VIS

A-C/VIS DRIVER-VEHICLE INTERFACE (DVI)

The left monitor housing housed the DVI controls (Figure 62). The DVI was designed to allow drivers quick and easy access to the functionality offered by the A-C/VIS. Because the A-C/VIS may be used while drivers perform the primary task of driving, special care was taken to avoid the use of on-screen menus to minimize the time drivers took their eyes off the road (Blanco, Biever, Gallagher, & Dingus, 2006). The DVI was designed to allow all functionality to be directly accessed through six buttons. Usability testing was performed to optimize the DVI layout.

The DVI offers drivers two main functions. The first function allows drivers to toggle between the day and night mode. This is accomplished by pressing the larger button on the left-most side of the display. The day mode presents drivers with a color image, while the nighttime mode presents a monochrome image accompanied by IR illumination. The two smaller buttons to the right of the day/night mode button allow drivers to adjust the brightness of the image. The second function allows drivers to activate an object detection feature. The object detection feature operates by tracing white lines around objects captured in the video image. This feature is activated by pressing the larger button on the right-most side of the display. The two buttons to the left of this button allow drivers to adjust the amount of image processing (i.e., thickness and amount of white lines around objects) (Figure 63).



Figure 62. View of DVI on Left Monitor Housing



Figure 63. Example Images of A-C/VIS Object Detection Feature

SUMMARY

The A-C/VIS's design encapsulates many of the features designed into the previously validated E-C/VIS into a roadworthy system. The location of the cameras, camera angles, the use of IR, the location of the IR panels, the sizes of monitors, and the general location of the monitors are replicated. Modifications made from the E-C/VIS were: the use of a smaller, less-sensitive camera that had no retractable IR lens, monitors that were positioned higher up along the windshield to control the cross reflection at night, custom camera and monitor housings, the switchover between day and night mode was both automated and selectable, and an intuitive DVI that was validated through iterative usability tests. One aspect of the TFD was to measure drivers' preferences towards various aspects of the A-C/VIS. The results section in Chapter 7 sheds some light on what truck drivers thought of the A-C/VIS's design.

CHAPTER 4. SELECTION OF COMMERCIALY AVAILABLE C/VIS

INTRODUCTION

A secondary objective of this project was to assess drivers' performance with a commercially available C/VIS. Research was performed to determine what C/VISs were available on the market and what their features were. To assist the C/VIS selection process, a specifications sheet was developed that listed the essential dimensions relevant to the design of a C/VIS (Appendix F). The specifications were gathered from Wierwille (2008a, 2008b). Web searches and contact with those familiar with the C/VIS market identified five candidate C/VISs. Details pertaining to each C/VIS were entered into the specifications sheet to facilitate comparison. Here, the information was gathered from the manufacturers and vendors' websites, and contact with the manufacturers' marketing departments. The system details entered into the specification reflected each vendor's/manufacture's top-of-the-line system. A review of each C/VIS and the completed specification sheets are provided below. A trade study was then performed to select the most appropriate C/VIS for the TFD. Results from the trade study are shown at the end of this chapter. A description of how the selected C/VIS was installed on the trucks used in the TFD concludes this chapter.

IDENTIFIED COMMERCIALY AVAILABLE C/VISs

The following five candidate C/VISs were identified:

- 1) Safety Vision®'s Camera System
- 2) V-TECH USA Sidetracker System
- 3) Winsted Products Dual Camera System
- 4) Mobile Awareness VisionStat Triple Side View Camera System
- 5) ASA Electronic's Voyager System

The specification sheet used to describe each C/VIS is organized into three sections. The first section covers overall system components and includes manufacturer and vendor identification information. The second section focuses on specifications relevant to the cameras used by the C/VIS. The final section deals with the system monitors. Specifications with a "not applicable" listing indicate that the specification is not relevant to the specific C/VIS system. Specifications with a "not available" listing indicate that the information was unknown for the specific C/VIS.

Safety Vision®'s Camera System (Product: SV-CLCD-70)

Safety Vision® offers an onboard camera system that is targeted for mining and construction operations, but can also be tailored to Class 8 trucks. This C/VIS is available in several camera configurations, potentially including both side and rear video. After speaking with a Safety Vision® representative, it was determined that a rear-camera-only system was most commonly purchased for trucking operations. The system as a multiple camera configuration is shown in Figure 64. Specifications pertaining to the Safety Vision® SV-CLCD-70 system are presented in Appendix F.



Figure 64. Safety Vision® On-board Camera System (Source: <http://www.electricmotorsvc.com/safety/>)

V-TECH USA LLC's Sidetracker System

V-TECH USA LLC's Sidetracker system is a stand-alone camera system designed for the trucking industry (V-TECH USA LLC, 2009). It uses weatherproof color video cameras mounted in rugged aluminum housing on the right and left front fenders to display video footage of the no-zone to the driver through two monitors mounted on the dash (Figure 65). This system does not utilize a rear-view camera. The Sidetracker system uses a patented aerodynamic vortex generator design that helps keep the lens free of debris and water while traveling down the highway. The Sidetracker system has been tested and perfected under real-world road conditions from coast to coast, in extreme weather, and on a variety of fleet vehicles. Sidetracker was selected by US XPRESS, one of the nation's top ten carriers, for use on its fleet. Sidetracker reports that over 8,000 units have been installed to date. Specifications pertaining to the Sidetracker C/VIS are presented in Appendix F.



Figure 65. Sidetracker System Monitors

Winsted Products' Dual Camera System Left/Right Side Views (Product: CCH-P70C1TTX2)

The Winsted Products Dual Camera System uses weatherproof cameras mounted on the left and right sides of the truck to display the no-zones to the driver through monitors mounted on the dash. The system uses two 18-cm monitors mounted in a portrait format (Figure 66). The cameras are 6.3-cm inches wide by 4.4 cm high and 4.4 cm deep (Figure 67). Specifications pertaining to the Winsted Products C/VIS are presented in Appendix F.



Figure 66. Winsted Products Dual Monitor (Source: <http://rearviewcamera.net/crv/crviis.dll?mtd=products&part=CCH-P70C1TTX2>)



Figure 67. Winsted Products Camera (Source: <http://rearviewcamera.net/crv/crviis.dll?mtd=products&part=CCH-P70C1TTX2>)

Mobile Awareness – Product: VisionStat™ Triple Side View Camera System

Mobile Awareness offers its VisionStat™ Triple Side View Camera System in a wired and wireless configuration. For the purposes of the current study, a wired system was suggested due to the rate of speed of the vehicle on which system will be installed. The system has three cameras all utilizing IR LEDs to ensure optimal viewing in low-light settings. Two of the cameras are installed on the fenders of either side of the cab to provide views of the no-zones (Figure 68), while the third camera is installed on the rear of the trailer (Figure 69), enabling the operator enhanced vision of the area to the rear of the vehicle. These cameras have been waterproof tested. The 18-cm monitor can be installed near the rearview mirror, on the

dashboard, or in the dashboard centered along the windshield for easy use by the operator (Figure 70). This system allows the driver to continuously monitor the rear-mounted camera and switches to side-view cameras when the driver engages the turn signal. Mobile Awareness has sold approximately 1,000 units of their wired and wireless systems combined. System specifications are presented in Appendix F.



Figure 68. Mobile Awareness Side Camera (Source: http://www.mobileawareness.com/product_detail.php?pid=137)



Figure 69. Mobile Awareness Rear Camera (Source: http://www.mobileawareness.com/product_detail.php?pid=137)



Figure 70. Mobile Awareness Monitor (Source: http://www.mobileawareness.com/product_detail.php?pid=137)

ASA Electronics' Voyager System

ASA Electronics' Voyager system is likely one of the most customizable systems on the market. Consumers can practically build their system from any products offered. This system can accommodate up to four cameras but is generally used in a three-camera configuration. Two weatherproof cameras are installed on either side of the vehicle to allow for viewing of side blind spots (Figure 71), while a third camera is installed on the rear of the trailer to capture views of rear blind spots (Figure 72). The Voyager system uses built-in IR illuminators to maintain viewing even in low-light conditions. The monitor, as shown in Figure 73, is installed within arm's reach of the operator either at the A-pillar supporting the cab or in the center of the windshield near the rearview mirror, on the dashboard, or built into the dashboard. The monitor only displays one view at a time; however, an adaptor can be purchased to enable up to four screens to be displayed at once. System specifications are presented in Appendix F.



Figure 71. Voyager Side Camera (Source: <http://www.asaelectronics.com/commercial.html>)



Figure 72. Voyager Rear Camera (Source: <http://www.asaelectronics.com/commercial.html>)



Figure 73. Voyager Monitor (Source: <http://www.asaelectronics.com/commercial.html>)

Commercially Available C/VIS Trade Study

The study required that one of the identified commercially available C/VISs be selected for the TFD. A trade study (Clemen & Reilly, 2001) was performed to assist with the selection process. Table 16 presents a side-by-side comparison of the C/VIS selection criteria for the five C/VISs that were identified.

Table 16. Summary of C/VIS Features

	Safety Vision®	Sidetracker	Winsted Products	VisionStat™	ASA Voyager
System Activation	Configurable	Push Button	Linked to Ignition	Continuous Reverse - Turn-Signal Activated Side Camera	Reverse Trigger or Push Button
Continuous Viewing	Yes	Yes	Yes	Rear-Only	Yes
IR Illumination	Yes	No	Yes	Yes	Yes
Day/Night Mode Switching	Yes	No	Yes	Yes	Yes
Camera FOV	Rear - 130°	Side - 90°	Side - 70°	Side - 92° Rear - 120°	Side - 93° Rear - 150°
Side-View Camera	Optional	Yes	Yes	Yes	Yes
Rear-View Camera	Yes	No	No	Yes	Yes
Number of Cameras	Up to 4	2	2	3	3
Waterproof Cameras	Yes	Yes	Yes	Yes	Yes

	Safety Vision®	Sidetracker	Winsted Products	VisionStat™	ASA Voyager
Number of Monitors	1	2	2	1	1
Monitor Size	7 inches	5.6 inches	7 inches	7 inches	7 inches
Image Aspect Ratio	16:9	4:3	16:9	16:9 or 4:3	16:9
System Resolution	360 x 59	510 x 492	480 x 234	Rear – 240 x 234 Side – 240 x 117	Rear – 480 x 336 Side – 480 x 168
Operational Temp. Range	14 °F to 122 °F	-4 °F to 176 °F	-22 °F to 140 °F	-4 °F to 158 °F	-4 °F to 149 °F
Units Sold	10,000+	8,000+	1,000+	1,000+	100+
Price	\$995	\$650	\$815	\$795	\$1,200
Commercial Truck Tested	Unknown	Yes	Unknown	Yes	Yes
Intended for Commercial Trucks	No	Yes	Yes	Yes	Yes
In Use By Major Trucking Company	Unknown	Yes	Unknown	No	Yes

Each criterion was then assigned a weight based on importance (Table 17). Rationale for the weightings is explained below.

Table 17. Weightings used in C/VIS Trade Study

Criteria	Weighting Factor
System Activation	3
Continuous Viewing	3
IR Illumination	3
Day/Night Mode Switching	2
Camera FOV	3
Side-View Camera	4
Rear-View Camera	4
Number of Cameras	4
Waterproof	6
Number of Monitors	2
Monitor Size	2
Image Aspect Ratio	2
System Resolution	5
Operational Temp. Range	1
Units Sold	4
Price	1
Commercial Truck Tested	6
Intended for Commercial Trucks	6
In Use by Major Trucking Company	7

With regard to system activation, configurable setups were considered the best overall option. Key/Ignition-Activated setups were rated slightly lower, and event-driven systems which switched between views based on a turn signal were weighted poorly. Continuous video feedback was an overall advantage within the contexts of these systems as it helps replicate the format of information that is obtained from the trucks' mirrors. Driver habituation to continuous monitor views was taken into consideration, but ultimately not regarded as a major factor within the context of C/VIS systems.

When ranking cameras utilized within each system, factors such as the availability of IR illumination, day/night mode switching, the cameras' angles of coverage, and the presence of side and rear-view cameras were considered. Systems with IR illumination were considered superior to systems that lacked this feature. As for day/night mode switching, systems that switched from color to black and white in response to low light levels were rated higher than systems that did not perform this function. This feature allows for additional visibility and sensitivity to headlights, which was considered an advantage within the context of this trade study. The presence of side and rear-view cameras was considered an advantage as each provides additional information to the driver regarding the surroundings. C/VIS whose cameras were optional were rated slightly lower than C/VISs that had a standard camera configuration. Additionally, whether or not each system had waterproof cameras was also considered, though the cameras for all systems considered within this study had this feature.

As for monitors, factors such as the number of monitors present, monitor size, image aspect ratio, and system resolution were considered and weighted accordingly. Having more than one monitor present was considered an advantage for these systems as it allowed for easier viewing of cameras than split-screen systems due to additional monitor space. Systems with larger monitors overall were also considered superior to systems with smaller monitors.

The aspect ratio of images provided through each system was also considered, with a larger aspect ratio being rated slightly superior to smaller aspect ratios. Greater monitor resolutions were also considered advantageous with regard to this study, due to the additional information provided to the driver. If the system utilized a split-screen layout, then the resolution was adjusted for the image produced by each camera on the screen and listed accordingly.

Various miscellaneous system characteristics were also considered within this study, including operational temperature range, units sold, and unit price. Systems with the ability to function in a wider range of temperature were obviously considered superior to those with more constricting ranges. Additionally, cheaper systems and systems that had sold more units were also considered superior due to the additional commercial prevalence they would tend to possess.

Finally, each system was categorized based on whether or not it was designed specifically for commercial tractor-trailers as well as whether it had been actually tested on these vehicles. Systems that were specifically designed for and tested on tractor-trailers were considered vastly superior to systems lacking either of those characteristics. Additionally, acceptance by a major trucking fleet was also considered, with systems that were utilized by a major fleet as of August 2008 being considered far superior to systems which had not been accepted by such a fleet.

The scores assigned to each C/VIS and category are shown in Table 18. Here, scores ranged from 1 to 7, with 1 representing a very poor rating and 7 representing a very high rating. The rating of a system within each category was then multiplied by the weighting factor for the category, which represents the assigned importance of each criterion, to produce a total score. The total scores are also shown in Table 18. The C/VIS with the highest total score was selected for the TFD.

Table 18. Trade Study Weighted Scores for Each C/VIS

		Safety Vision®		Sidetracker		Winsted Products		VisionStat		ASA Voyager	
	Weighting Factor	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
System Activation	3	7	21	6	18	7	21	3	9	6	18
Continuous Viewing	3	7	21	7	21	7	21	3	9	7	21
IR Illumination	3	7	21	1	3	7	21	7	21	7	21
Day/Night Mode Switching	2	7	14	1	2	7	14	7	14	7	14
Camera FOV	3	6	18	6	18	4	12	6	18	7	21
Side-View Camera	4	7	28	7	28	7	28	7	28	7	28
Rear-View Camera	4	7	28	1	4	1	4	7	28	7	28
Number of Cameras	4	7	28	4	16	4	16	6	24	6	24
Waterproof	6	7	42	7	42	7	42	7	42	7	42
Number of Monitors	2	4	8	7	14	7	14	4	8	4	8
Monitor Size	2	7	14	6	12	7	14	7	14	7	14
Image Aspect Ratio	2	7	14	6	12	7	14	7	14	7	14
System Resolution	5	2	10	7	35	4	20	2	10	3	15
Operational Temp. Range	1	5	5	7	7	7	7	7	7	7	7
Units Sold	4	7	28	6	24	3	12	3	12	3	12
Price	1	4	4	7	7	4	4	4	4	2	2
Commercial Truck Tested	6	1	6	7	42	1	6	7	42	7	42
Intended for Commercial Trucks	6	4	24	7	42	7	42	7	42	7	42
In Use by Major Trucking Company	7	1	7	7	49	1	7	1	7	1	7
		Safety Vision 341		Sidetracker 396		Winsted Products 319		VisionStat 353		ASA Voyager 380	

SELECTED C/VIS: VTECH USA'S SIDETRACKER SYSTEM

The trade study identified VTECH USA LLC's Sidetracker system as the ideal commercially available C/VIS for the TFD (V-TECH USA LLC, 2009). Two major factors behind this decision were that the Sidetracker system had been tested specifically within the trucking industry as well as accepted for general use by a major trucking company. This was important because the system would have to endure long periods of data collection and road vibration. Additionally, the Sidetracker system was the most cost-effective option and had the most units sold of systems designed specifically for commercial trucks, and was second in the number of units sold for all C/VIS systems overall. The installation of the commercially available C/VIS on the test vehicles is described below.

Commercial C/VIS's Cameras

One commercially available C/VIS camera was mounted on the truck's right fender, while a second commercially available C/VIS camera was mounted on the left fender. Both cameras were held within a weatherproof housing that was aerodynamically designed to use passing air to remove water and debris from the lens while the truck was in motion (Figure 74).



Figure 74. Commercial C/VIS Camera and Weatherproof Housing Installation

Commercial C/VIS's Monitors

The commercially available C/VIS had two monitors for viewing both cameras simultaneously. For the purposes of this research, multiple monitors were considered advantageous to a split-screen design, as this allows for larger individual camera views, despite the potential for faster view transition with multiple feeds present on a single monitor. The video image produced from the right fender camera was viewed using a monitor mounted on the right side of the steering wheel on the dash. The video image from the left camera was reversed and viewed using a monitor mounted on the left side of the steering wheel on the dash (Figure 75). V-TECH USA LLC provided a specification showing how the dual monitors were to be mounted inside the cab (Figure 76). It should be noted that the monitors were angled towards the driver's face. However,

the driver was responsible for setting the preferred brightness, contrast, color, and tint levels for each monitor.



Figure 75. Commercial C/VIS's Monitor Installation

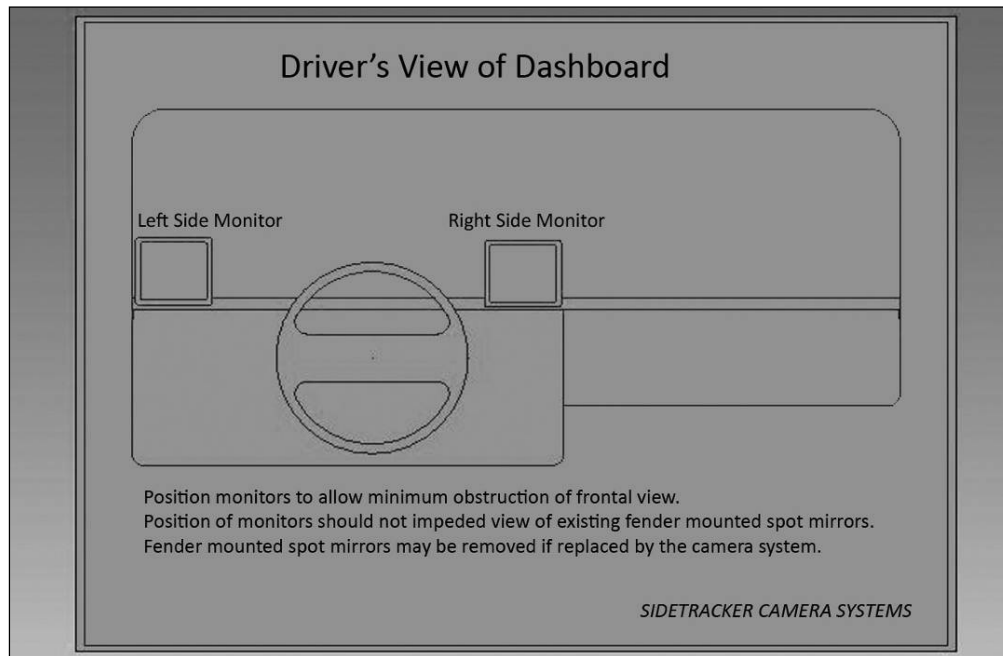


Figure 76. Monitor Mounting Specification

CHAPTER 5. PRELIMINARY TESTING

INTRODUCTION

Prior to performing the TFD, preliminary testing was performed to determine the vision enhancements offered by both the A-C/VIS and the commercially available C/VIS. The testing was performed for two main reasons:

- 1) To investigate participant's object detection and identification performance with the A-C/VIS to see how it compared to participants' performance with the E-C/VIS prototype that was measured during earlier testing (Schaudt et al., 2009; Wierwille et al., in press).
- 2) To compare participants' object detection and identification performance with the A-C/VIS to their performance with the commercially available C/VIS through a within-subject comparison.

METHODS

Participants

Eight personnel from the research institution participated in the preliminary testing. Participants were recruited on a first available, first served basis. Six males and two females participated. Participants mean age was 26 years old (Minimum = 24 years old, Maximum = 35 years old). All had valid driver's licenses and a minimum visual acuity of 20/40. All were unfamiliar with C/VISs prior to partaking in the study. Commercial drivers were not recruited because the experiment was preliminary and feedback from those with a background in transportation human factors was desirable after the experiment was over.

Test Vehicle

A Freightliner C120 Cab and a 48-foot long trailer were acquired for this study. The tractor-trailer was loaned by Schneider National's Winchester, Virginia operation. The tractor-trailer was the same model as those used in the TFD.

Apparatus

Data Acquisition System (DAS)

The DAS used for this study is based on a microcomputer which receives, processes, and stores data for sensors positioned throughout the vehicle. The DAS unit was mounted in the cab of the truck underneath the passenger seat in a position allowing access to the removable hard drive which was used to store the collected data (Figure 77).



Figure 77. Data Acquisition System

Video Recording

Eight cameras were mounted inside the experimental vehicle. These cameras provided three views of the driver, a view of the forward roadway, a view of the left and right sides of the trailer, and a view of the rear of the trailer (Figure 78).

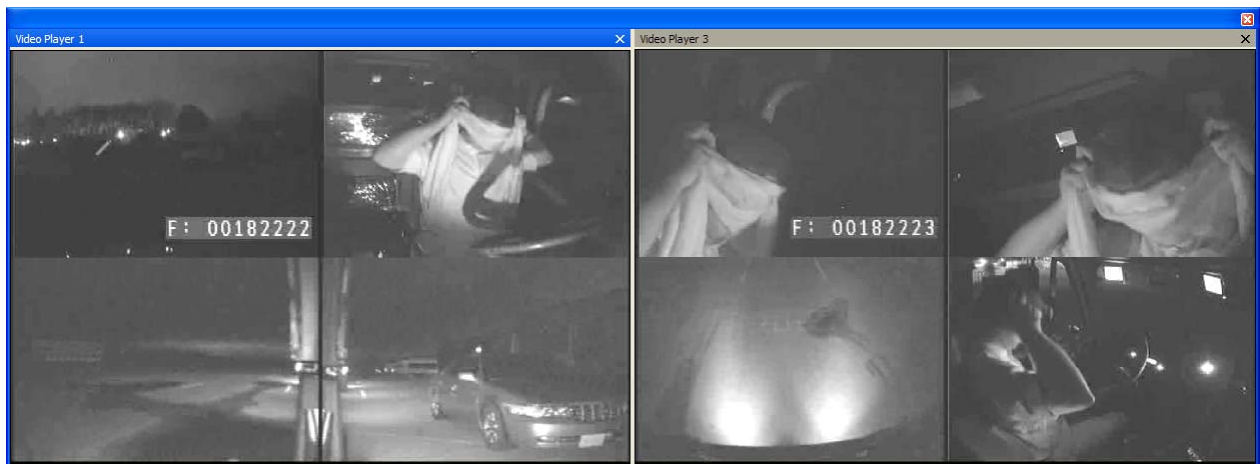


Figure 78. Multiplex View from Interior Cameras used in the Static Tests

Procedure

Employees from the research institution were asked to participate in the study because the experiment was preliminary and feedback from those with a background in transportation human factors was desirable. Those who volunteered were greeted at the research institution and escorted to the participant preparation room where they were required to present a valid driver's license. Once this was done, they were asked to read and sign the Informed Consent Forms (Appendix G). The experimenter answered any questions the participant had. Participants then performed a Snellen eye examination. For this experiment, 20/40 vision was required.

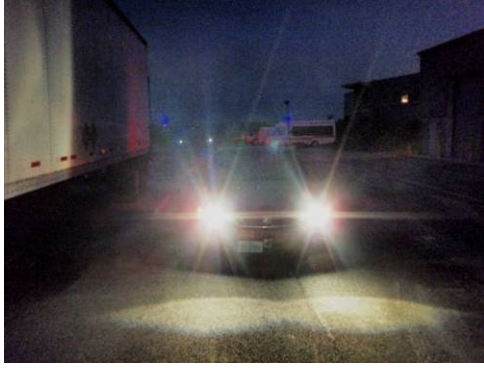
Participants were then accompanied by an experimenter to a parking lot. The experimenter demonstrated the safe way to climb into the driver's seat of the stationary Freightliner C120 Cab. The participant climbed into the driver's seat with the experimenter standing behind him or her for support. The experimenter then sat in the passenger seat.

After making sure the participant was comfortable, the experimenter explained the study details. The test apparatus consisted of a stationary tractor-trailer with video monitors installed inside the cabin. The monitors displayed a video feed from cameras mounted on the side and rear of the tractor-trailer. The participant's task was to use these monitors, along with the existing mirrors, to look for objects placed around the trailer. Participants were blindfolded and wore hearing protection in between trials so they did not see or hear the on-road experimenter positioning objects around the vehicle (Figure 79).



Figure 79. Participant Wearing Blindfold and Hearing Protection in the Static Tests

For each trial, one of four objects was placed around the vehicle: 1) 2002 Red Cadillac STS with headlights on, 2) 2002 Red Cadillac STS with headlights off, 3) a pedestrian, or 4) a stop sign (Figure 80).



1. Vehicle (lights ON)



2. Vehicle (lights OFF)



3. Pedestrian



4. Stop Sign

Figure 80. Objects Used in Static Evaluation

The order in which the objects were placed around the test vehicle was adapted from the order used to evaluate the E-C/VIS (Wierwille et al., in press). Here, two orders were devised, each consisting of 16 trials, in which the four objects were placed in specific locations. Participants experienced one order for the commercially available C/VIS and the second order for the A-C/VIS. The orders differed enough such that participants were not able to foresee which object was going to be presented next. However, every participant experienced the objects in the same position for each C/VIS. The orders are shown in Table 19. It should also be noted that the order in which participants experienced the A-C/VIS and the commercially available C/VIS was counterbalanced.

Table 19. Order of Trials

Trial	Object	Condition	Position of Object
1	Car Lights On	Commercial C/VIS	1
2	Pedestrian	Commercial C/VIS	2
3	Pedestrian	Commercial C/VIS	3
4	Car Lights Off	Commercial C/VIS	4
5	Stop Sign	Commercial C/VIS	5
6	Pedestrian	Commercial C/VIS	6
7	Car Lights Off	Commercial C/VIS	7
8	Car Lights Off	Commercial C/VIS	8
9	Pedestrian	Commercial C/VIS	9
10	Car Lights On	Commercial C/VIS	10
11	Stop Sign	Commercial C/VIS	11
12	Stop Sign	Commercial C/VIS	12
13	Car Lights Off	Commercial C/VIS	13
14	Car Lights Off	Commercial C/VIS	14
15	Pedestrian	Commercial C/VIS	15
15.5	Car Lights Off	Commercial C/VIS	15.5
16	Car Lights Off	A-C/VIS	16
17	Pedestrian	A-C/VIS	17
18	Stop Sign	A-C/VIS	18
19	Pedestrian	A-C/VIS	19
20	Car Lights On	A-C/VIS	20
21	Car Lights Off	A-C/VIS	21
22	Pedestrian	A-C/VIS	22
23	Car Lights Off	A-C/VIS	23
24	Stop Sign	A-C/VIS	24
25	Pedestrian	A-C/VIS	25
26	Pedestrian	A-C/VIS	26
27	Car Lights Off	A-C/VIS	27
28	Stop Sign	A-C/VIS	28
29	Car Lights Off	A-C/VIS	29
30	Car Lights On	A-C/VIS	30
30.5	Car Lights Off	A-C/VIS	30.5

The position of the objects is shown in Figure 81 and Figure 82. Figure 81 shows the area made visible by the A-CVIS in grey. The A-C/VIS has a rear wide-angle look-down camera and IR illumination to provide participants with a complete view of the rear of the trailer as well as night vision. The fender-mounted cameras use a 45-degree FOV to reduce image distortion (the reduced distortion helps drivers estimate distance to surrounding objects). However, because of the cameras' 45-degree FOV, there was an interest in determining whether participants would be able to detect objects placed in the no-zone located beside the right of the cab. Trials 5, 18, 15.5, and 30.5 were designed to investigate this.

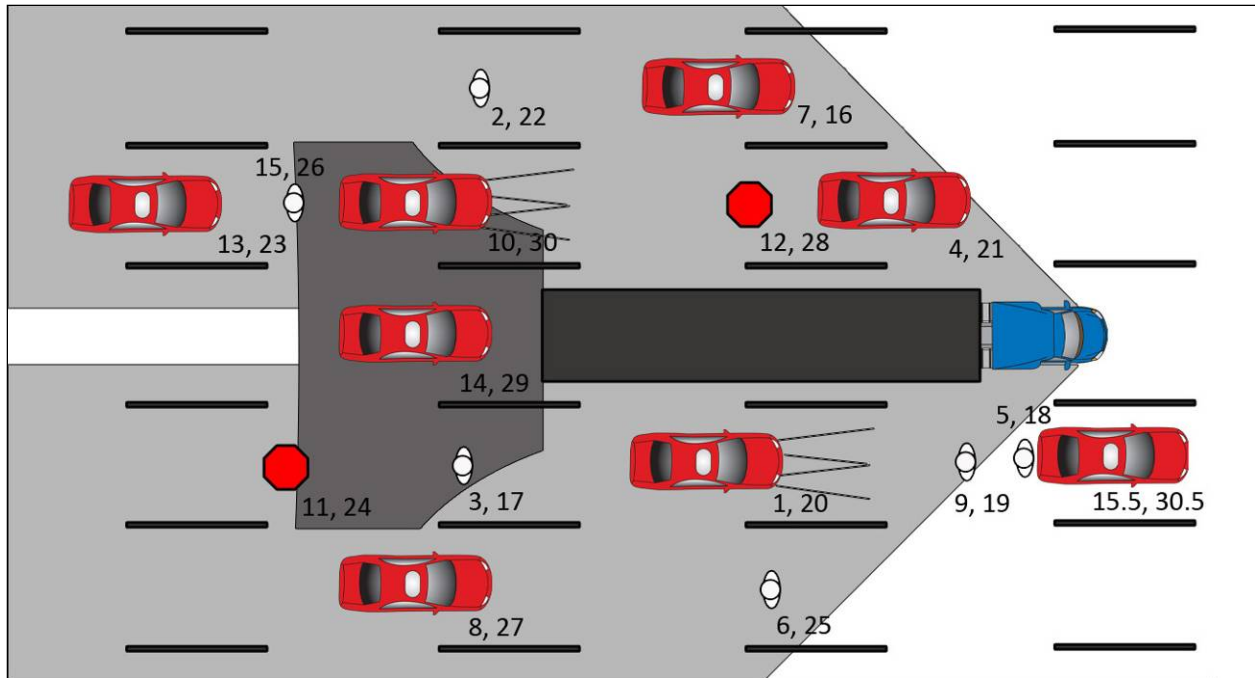


Figure 81. Object Position and A-C/VIS Field of View; Note: Although the A-C/VIS has a 45-Degree FOV, there is IR Illumination

In contrast to Figure 81, Figure 82 shows the area made visible by the commercially available C/VIS. Here, the commercial C/VIS's FOV is 90 degrees and allows the objects placed at positions 5, 18, 15.5, and 30.5 to be seen during the day. However, the lack of night vision makes these objects difficult to see in the monitors. It should also be noted that the commercially available C/VIS does not provide drivers with a view directly behind the trailer through a rear wide-angle look-down camera.

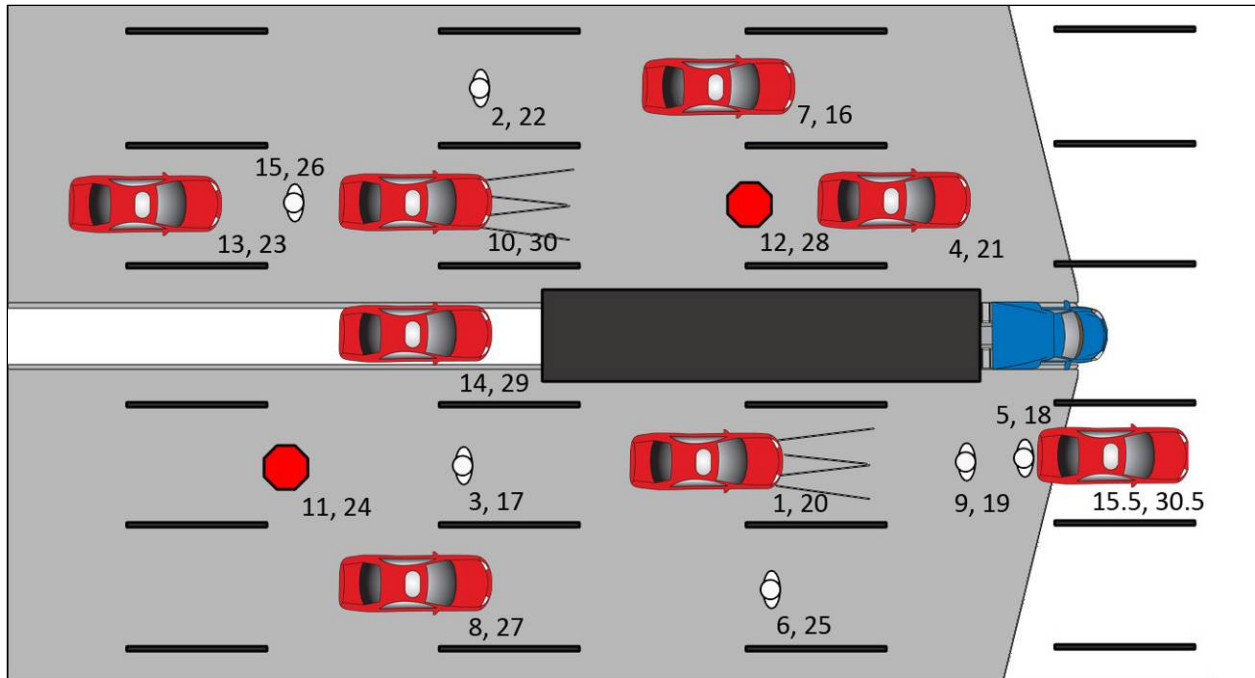


Figure 82. Object Locations and Commercial C/VIS FOV; Note: Although the Commercial C/VIS has a 90-Degree FOV, there is no IR Illumination

Once an object was in position, the in-vehicle experimenter tapped participants on the shoulder to indicate that they may remove their blindfold and hearing protection and look up at the monitors. The experimenter then asked the participants three questions (also shown in Appendix H):

1. Can you see an object?
2. If yes, what is it?
3. How well can you see it (on a 7-point Likert scale with 1 being extremely unclear and 7 being extremely clear)?

Video data were collected of each participant performing the study. Once all trials were completed, the experimenter exited the trailer and assisted the participant out of the cab. This study was conducted in nighttime sessions and took 45 minutes to complete. The tractor-trailer remained stationary throughout the experiment.

Experimental Design

Drivers' performance with the A-C/VIS and the commercially available C/VIS was evaluated through a one-way non-parametric analysis. The specific non-parametric tests used are listed in the results section.

Independent Variables

The independent variables used to analyze the data collected from the static evaluation are presented below.

C/VIS (E-C/VIS, A-C/VIS, Commercial C/VIS) - Between-Subjects

The C/VIS independent variable allows the comparison of drivers' performance with the E-C/VIS, the A-C/VIS, and the commercially available C/VIS. Here, participants' object detection performance with the A-C/VIS and the commercially available C/VIS was compared to earlier tests performed with the E-C/VIS. It should be noted that only two objects were common to the tests performed in the current study and the tests performed with the E-C/VIS (Wierwille, 2008b). The common objects were a pedestrian and a stop sign. Therefore, the three C/VISs are compared using only drivers' detection performance to these common objects.

C/VIS (A-C/VIS, Commercial C/VIS) — Within-Subject

The C/VIS independent variable also allows the comparison of drivers' performance with the A-C/VIS and the commercially available C/VIS. By using the same driver to evaluate each system, objective results can be used to evaluate whether the image enhancements offered by the A-C/VIS led to better object detection than that obtained with the commercially available C/VIS. For this comparison, all four objects were used: 1) a pedestrian, 2) a stop sign, 3) a vehicle with its headlights on, and 4) the same vehicle with its headlights off.

Dependent Variables

The C/VISs were evaluated by measuring the number of objects that participants were able to correctly detect at night. The percentage of detected objects that participants were able to correctly identify was also determined. In the cases where drivers were able to detect an object, their ratings of the clarity of the images generated by the C/VIS monitor were recorded.

RESULTS

Object-Detection Accuracy

Participants' object detection accuracy when using the E-C/VIS, the A-C/VIS, and the commercially available C/VIS to detect pedestrians and stop signs was investigated. A chi-squared test did not find participants to be significantly more accurate at detecting the pedestrian and stop sign with the A-C/VIS than they were with the E-C/VIS (100 percent correct versus 96 percent correct, respectively; $\chi^2(1) = 2.0364$, $p = 0.1536$) (Figure 83). However, a Cochran-Mantel-Haenszel test found that participants were significantly more accurate at detecting the pedestrian and stop sign with the A-C/VIS than they were with the commercially available C/VIS (100 percent correct versus 36 percent correct, respectively; $Q(1) = 52.5789$, $p < 0.0001$). Participants were also significantly more accurate at detecting the pedestrian and stop sign with the E-C/VIS than they were with the commercially available C/VIS ($\chi^2(1) = 46.0427$, $p < 0.0001$). It should be noted that the trailer lights were not turned on during testing with the A-C/VIS or the commercially available C/VIS and that the C/VISs are designed to support drivers in detecting vehicles with their headlights on in a dynamic setting. Object detection scores may also be lower considering the fact that non-commercial drivers who are not experienced in scanning the large areas around a tractor-trailer participated in the study. Nevertheless, the results demonstrate the benefit of the enhancements provided by the A-C/VIS.

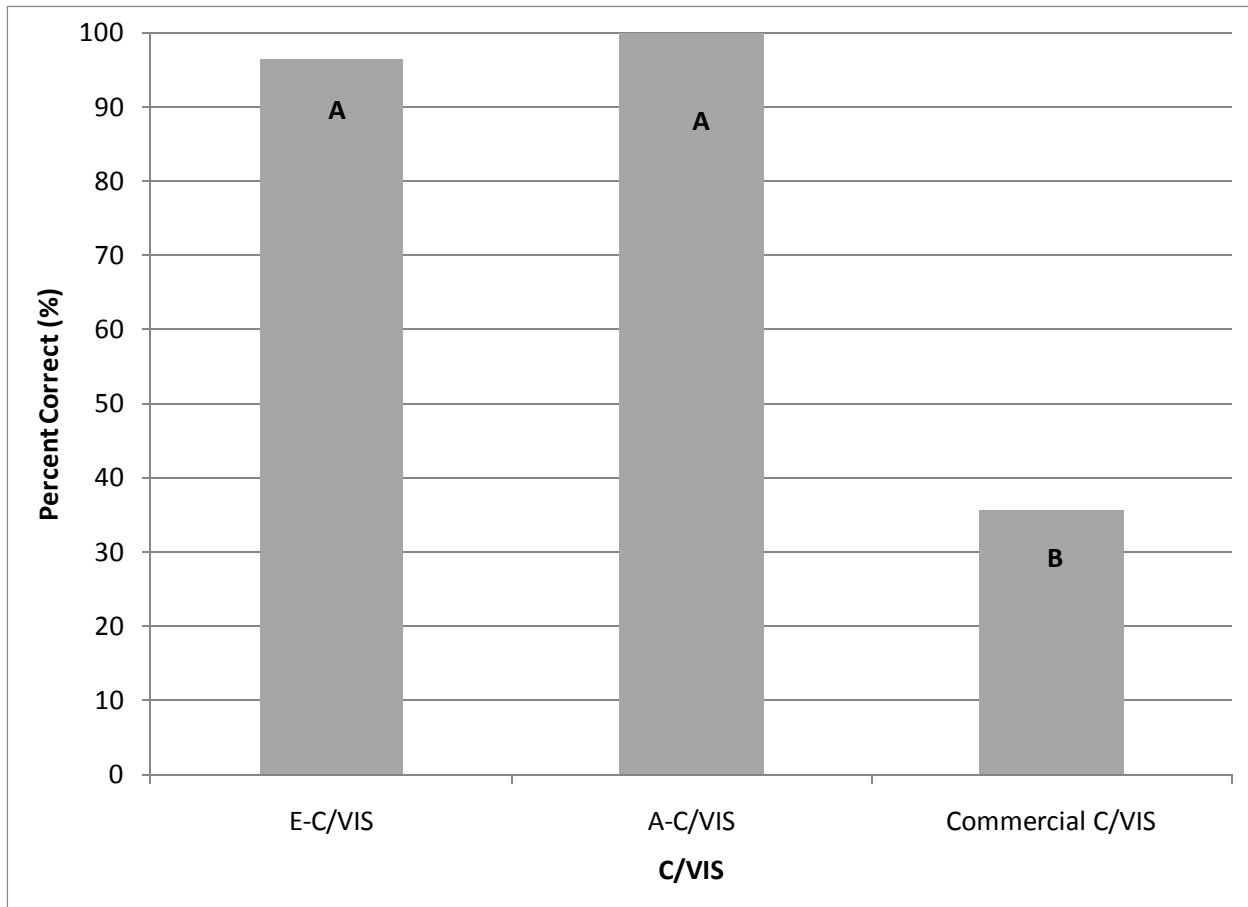


Figure 83. Participants' Object-Detection Accuracy of Pedestrian and Stop Sign (Different Letters Represent a Statistically Significant Difference)

When considering all objects tested, it was found that participants were significantly more accurate at detecting objects with the A-C/VIS than they were with the commercially available C/VIS ($Q(1) = 48.1932, p < 0.0001$). Participants correctly detected 86 percent of the objects with the A-C/VIS and 45 percent of the objects with the commercially available C/VIS. Figure 84 shows the object detection scores obtained with the A-C/VIS and commercially available C/VIS for each of the four objects tested. It can be seen that participants detected the vehicle with its headlights on every time. However, the pedestrian was harder to detect.

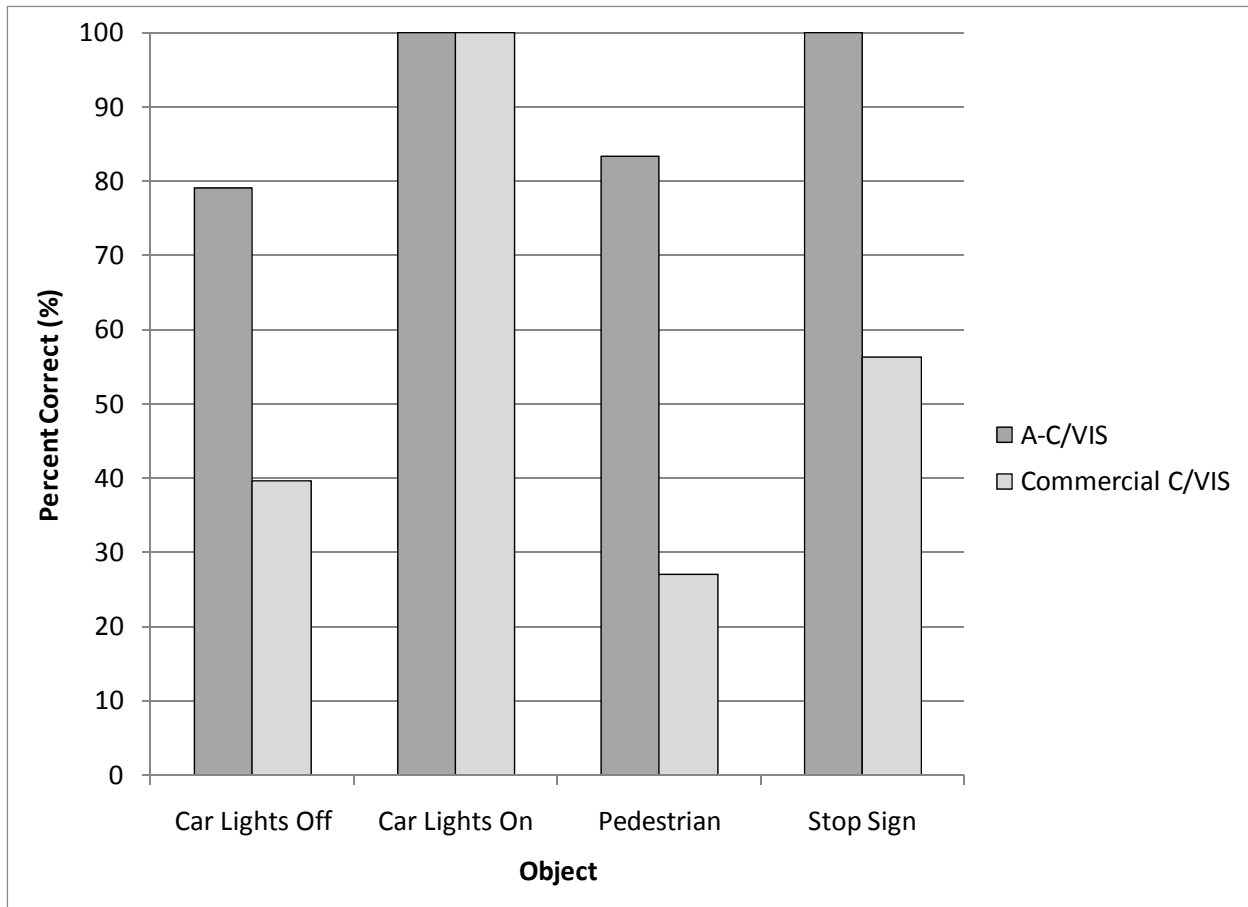


Figure 84. Object Detection Scores Obtained with the A-C/VIS and Commercial C/VIS by Object Type

Figure 85 shows the object detection scores obtained with the A-C/VIS and the commercially available C/VIS for each of the 16 object positions. Participants showed difficulty detecting a pedestrian positioned beside the trailer (Positions 2 and 3), a stop sign placed away from the trailer (Positions 11 and 12), and a vehicle with its headlights off parked to the left of the truck (Position 4) when using the commercially available C/VIS, but were able to detect it when using the A-C/VIS. This was likely because the A-C/VIS provides a night vision enhancement that uses IR light to illuminate surrounding objects.

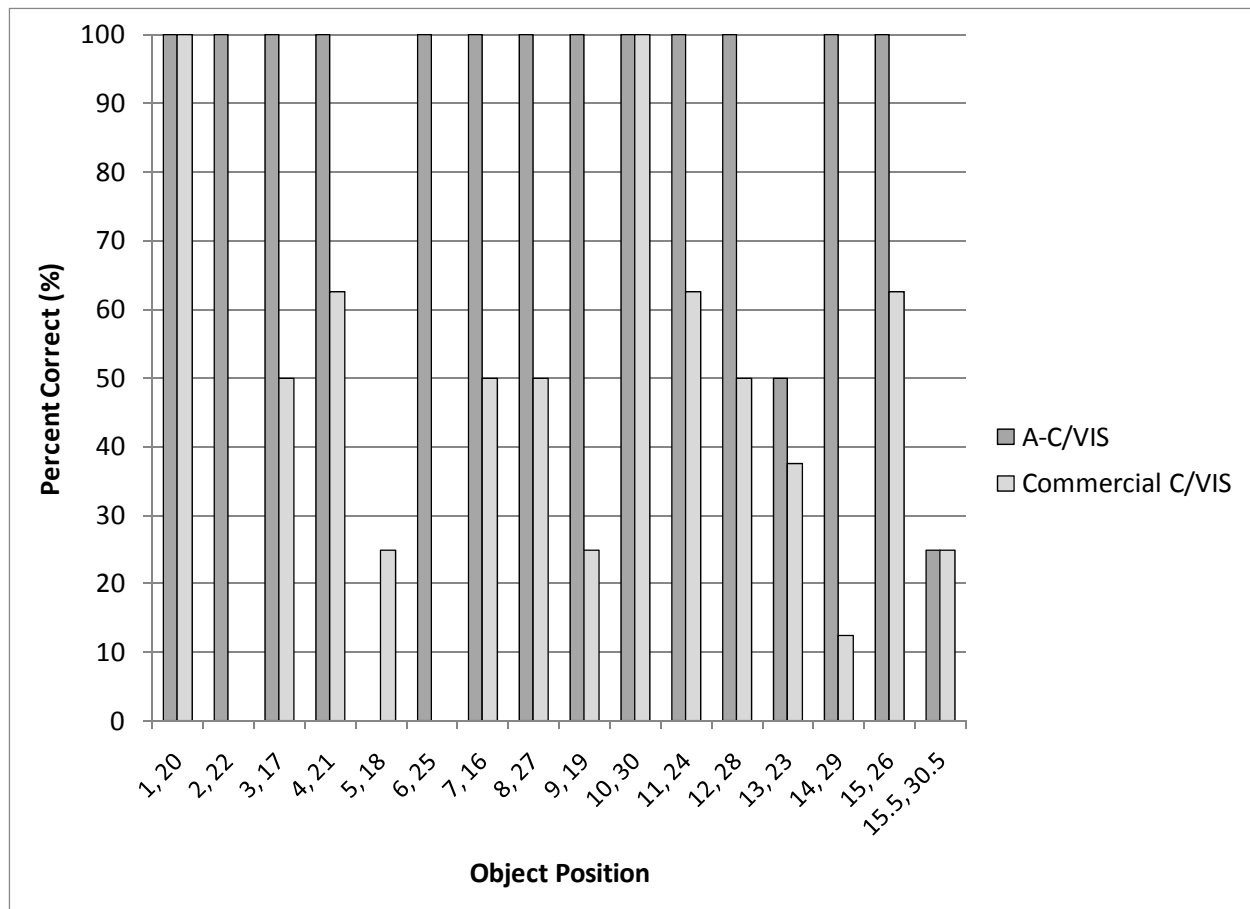


Figure 85. Participants' Object-Detection Accuracy to All Objects

Participants detected a vehicle parked behind the trailer (Position 14) when using the A-C/VIS, but did not detect it when using the commercially available C/VIS. This was likely because the A-C/VIS provided a rear view of the area behind the trailer.

Participants detected a pedestrian in the front right blind spot (Position 5) 25 percent of the time when using the commercially available C/VIS. However, none of the participants detected the pedestrian in this location when using the A-C/VIS. This was likely because the commercial C/VIS camera's wider FOV spanned the pedestrian, whereas the pedestrian was outside of the view of the A-C/VIS's right fender camera. It is possible that participants may have detected the pedestrian more often with the commercially available C/VIS had it been made visible using a night vision enhancement. However, it should be noted that participants may not have thought to use the right door window when scanning the environment. Nevertheless, the lack of ambient lighting would still have made it difficult to detect the pedestrian in that position.

Participants showed difficulty in detecting a vehicle with its headlights off positioned in the front right blind spot when using either C/VIS. The lack of ambient lighting may have made it difficult to detect the vehicle with the commercially available C/VIS even though the vehicle was positioned in the right fender camera's FOV. The placement of the vehicle outside of the camera's FOV may have made it difficult for participants to detect it with the A-C/VIS. Had this

vehicle had its headlights on, however, all participants would have detected it. This was demonstrated at the end of the study.

Object Recognition Accuracy

Figure 86 shows the percentage of trials in which participants correctly identified an object provided that the object was correctly detected. Participants correctly identified the pedestrian and stop sign 100 percent of the time with the E-C/VIS, 93 percent of the time with the A-C/VIS, and 80 percent of the time with the commercially available C/VIS. For the incorrect trials, participants mainly failed to recognize what the object was altogether rather than mistaking it for something it was not.

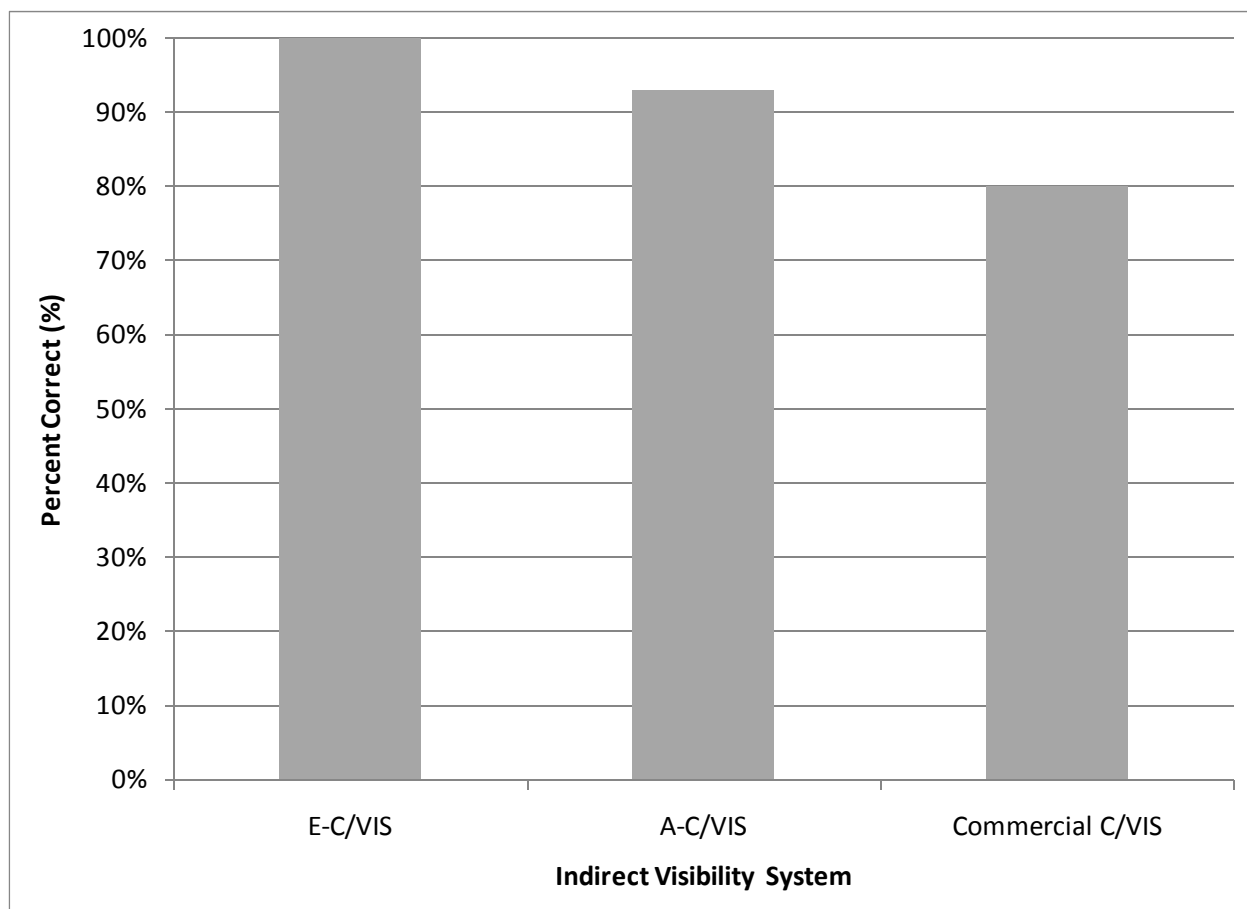


Figure 86. Participants' Object Recognition Accuracy

C/VIS Image Clarity

For the trials in which participants correctly detected an object, participants rated the clarity of the image the C/VIS generated. Participants rated the clarity of the A-C/VIS as "Clear" (mean rating = 5.41, standard error (SE) = 0.18, $n = 110$), while they rated the image from the commercially available C/VIS as "Neutral" (mean rating = 3.86, SE = 0.32, $n = 57$). Figure 87 presents the clarity rating scale for the reader's convenience.

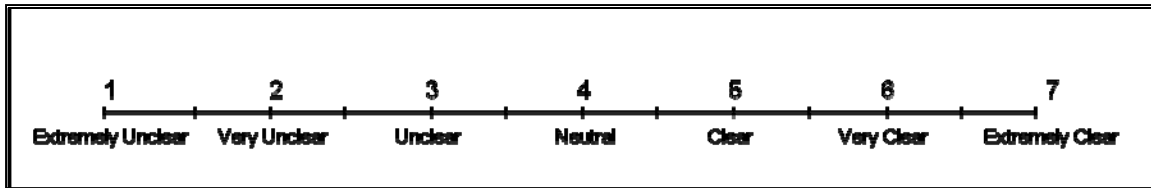


Figure 87. Clarity Rating Scale

DISCUSSION

This study investigated participants' ability to detect and identify objects placed around a tractor-trailer using a C/VIS. The results show that non-CMV-driver participants' object detection and identification scores obtained when using the A-C/VIS were equivalent to the object detection and identification scores obtained by CMV drivers using the E-C/VIS. The tests also showed that participants were significantly more accurate at detecting objects with either the A-C/VIS or E-C/VIS than they were with the commercially available C/VIS. This was likely due to the night vision enhancements offered by the IR illumination on the trailer as well as the third rear wide-angle look-down camera. These enhancements allowed participants to also identify the type of object present once it was detected.

At the same time, the tests show that object detection performance may not be perfect with the A-C/VIS. Both a pedestrian and an unlit vehicle placed in the right fender no-zone went undetected by participants who were not CMV drivers. This may be because the 45-degree FOV used by the A-C/VIS was not wide enough to show these objects on the monitors. However, it is important to note that participants may not have known how to properly scan the environment around a tractor-trailer. Additionally, participants showed equal difficulty in detecting the pedestrian and vehicle when using the commercially available C/VIS owing to the lack of ambient lighting. Nevertheless, once the lights of the vehicle parked in the right no-zone were turned on, all participants detected its presence. C/VISs are designed to assist drivers in a dynamic environment and so this result should not be construed as a failure of the systems to operate. Furthermore, it is important to realize that the established C/VIS specifications state that a 45-degree FOV was most appropriate for the left and right fender cameras because it reproduced an image similar to that of the fender-mounted mirrors, would be familiar to drivers, and would allow drivers to recognize the size and behavior of adjacent vehicles (Wierwille et al., in press). A major concern regarding a camera's FOV is that as FOV increases, objects displayed in the camera image become substantially smaller. The A-C/VIS was designed to meet the E-C/VIS specifications (Wierwille et al., in press), which were established to help CMV drivers perform lane change maneuvers. Since this camera FOV had been validated earlier through dynamic testing (Wierwille, Schaudt, Spaulding, et al., 2008), the 45-degree FOV camera was selected for the TFD.

CONCLUSION

The static tests performed allowed direct comparisons to be made between the A-C/VIS, the commercially available C/VIS, and the previously tested E-C/VIS. The results show that the performance obtained with the E-C/VIS is maintained with the A-C/VIS. It was also shown that the enhanced features of the E-C/VIS and the A-C/VIS (i.e., the third rear camera and night vision enhancement) allow participants to detect unlit objects significantly better than with the

commercially available C/VIS. The data collected from these preliminary tests help define the enhanced visibility each C/VIS provides and assist with the assessment of CMV drivers' performance with the C/VIS during the TFD.

CHAPTER 6. TECHNOLOGY FIELD DEMONSTRATION METHODS

The purpose of the TFD was to investigate the implementation of C/VISs in a real-world operation. The three main objectives were to determine: 1) the effect of C/VISs on drivers' involvement in SCEs, 2) the effect of C/VISs on drivers' lane-change performance, and 3) drivers' opinions of C/VISs. The methods used to collect and reduce naturalistic driving data, as well as driver opinion data, to fulfill these objectives are presented in this chapter.

PARTICIPANTS

A total of 15 Class-A CDL-qualified drivers from Schneider National's Winchester, Virginia operation were recruited to participate in the TFD. Of these, 11 drivers completed all four months of participation in the study while one driver (Participant 15) voluntarily ended his employment at Schneider upon completing his third month of the study. This participant ended the study on August 13, 2010. Due to the time line of the study, this participant could not be replaced as this would have taken data collection through December 2010. Thus, 11 participants completed all four months of data collection while 1 participant completed three months of data collection.

Data collection began on July 30, 2009 and ended on September 23, 2010. Table 20 provides the participant demographics for this study. Note that begin and end dates of participation may add up to more than the completed months. This is due to the participant vacations, holidays, and vehicle maintenance that were taken into account to ensure that four months of data were collected. Six of these participants drove a truck/trailer combination equipped with the A/CVIS system and the other six participants drove a truck/trailer combination equipped with the commercially available C/VIS. Because there were a limited number of Schneider drivers that could be assigned to routes that allowed 48-ft trailers to be used, and would be permanently coupled to tractors through the duration of the study, participants were not selected according to their age or gender. All participants had a minimum visual acuity of 20/40 and could read and speak the English language. With regard to in-vehicle technologies, all participants had experience with dispatching devices. Two of the participants had experience with electronic onboard recorders but none of the participants had experience with forward collision warning systems, lane departure warning systems, or blind spot monitoring systems. Eight of 12 participants reported having experience with cellular phones. Additionally, 6 of 12 participants had experience using Global Positioning System (GPS) units.

Table 20. Participant Demographics

P#	Group	Age	Height (cm)	Glasses/Contacts	Ethnicity	Begin Date	End Date	Months Complete
1	A/CVIS	40	183	Yes	Caucasian	7/30/2009	12/2/2009	4
3	A/CVIS	40	175	No	Native American	10/15/2009	3/30/2010	4
4	A/CVIS	40	183	Yes	Caucasian	3/22/2010	9/7/2010	4
5	A/CVIS	53	175	Yes	Caucasian	5/13/2010	9/23/2010	4
13	A/CVIS	50	175	No	Caucasian	12/22/2009	5/6/2010	4
15	A/CVIS	26	165	Yes	Caucasian	4/13/2010	8/13/2010	3
7	Commercial C/VIS	29	178	No	Caucasian	8/12/2009	12/15/2009	4
8	Commercial C/VIS	27	188	Yes	Caucasian	8/19/2009	12/15/2009	4
9	Commercial C/VIS	37	188	No	Caucasian	9/21/2009	1/20/2010	4
10	Commercial C/VIS	38	188	Yes	Caucasian	3/8/2010	7/6/2010	4
12	Commercial C/VIS	39	178	Yes	Caucasian	1/26/2010	5/25/2010	4
14	Commercial C/VIS	48	173	No	Caucasian	3/22/2010	8/12/2010	4
	Mean:	39	179					
	SE:	2.5	2.0					
	Minimum:	26	165					
	Maximum:	53	188					

The majority of the participants' driving was performed at night. Participant shifts began as early as 4 p.m. and as late as 1 a.m. Participant shifts ended as early as 3:30 a.m and as late as 11 a.m. All participants traveled solo for the duration of their shifts. Table 21 provides participant experience levels and daily driving characteristics.

Table 21. Participant Experience Levels and Driving Characteristics

P #	Group	Years Experience	Years at Schneider	Daily Driving Hours	Shift Length (hr)	Mean Daily km Driven
1	A/CVIS	18.0	2.0	50.0	10.0	443
3	A/CVIS	2.0	2.0	48.0	9.0	423
4	A/CVIS	12.0	0.4	50.0	10.5	543
5	A/CVIS	7.5	6.0	40.0	9.0	514
13	A/CVIS	12.0	0.02	50.0	10.0	480
15	A/CVIS	0.7	0.2	38.0	10.0	500
	Mean:	8.7	1.8	46.0	9.8	484
	Median:	9.8	1.2	49.0	10.0	490
	SE:	2.7	0.9	2.3	2.3	18.3
7	Commercial C/VIS	2.0	1.7	60.0	9.0	358
8	Commercial C/VIS	1.8	1.8	47.5	9.0	394
9	Commercial C/VIS	12.0	1.6	55.0	9.5	445
10	Commercial C/VIS	16.5	0.1	50.0	12.0	361
12	Commercial C/VIS	12.8	12.8	35.0	11.0	439
14	Commercial C/VIS	30.0	0.02	50.0	12.0	370
	Mean:	12.5	3.0	49.6	10.4	395
	Median:	12.4	1.6	50.0	10.3	382
	SE:	4.3	2.0	3.4	0.6	15.9

TEST VEHICLES

Schneider National provided six Freightliner C120 Century tractors from their Winchester, Virginia operation (Figure 88) for use in the TFD. The tractors were attached to 48-foot long trailers, which were the longest trailers available at this operation. In order to minimize interference with the data collection system, the study required that the tractors remained permanently coupled with these trailers. The Winchester operation was selected because it was the closest to the research team, the easiest operation to access, and the most cost-effective to travel to with respect to collecting data throughout the TFD. Although the six tractors were not ordinarily permanently coupled to the 48-foot trailers, Schneider National was able to maintain their pairing owing to the economic downturn that occurred during the TFD.



Figure 88. Freightliner Century 120 Tractor with 48-ft Trailer

A-C/VIS Turn Signal and Side Marker Light Diffusers

Early testing with the A-C/VIS revealed that the optional side marker lights/turn signal lights mounted on the side of the Freightliner C-120 trucks could create a large bright spot on the monitor. This is because the side-mounted lights were positioned close to the fender-mounted cameras. To reduce discomfort glare and noise from this constant blooming, translucent plastic guards were placed in front of the turn signal lights, not on top of them (Figure 89). These plastic guards lowered the amount of light directly shined into the fender-mounted camera, reducing the size of the bright spot on the monitor from the turn signal light. The amount of light shined in all other directions by the turn signal light was not reduced by the guards. It should be noted that the side turn signal lights are used to alert adjacent vehicle drivers of the truck's intent to change lanes. The turn signal light diffusers did not prevent the turn signal lights from being seen. The

side turn signal lights could also still be seen when directly facing the front of the truck because the plastic guards were translucent. Additionally, the mandatory turn signal lights positioned on the front of the truck were not guarded and could be clearly seen.



Figure 89. A-C/VIS Light Diffuser Mounted in Front of Right Turn Signal

Figure 90 shows how the light diffusers reduced the constant blooming produced by the side marker lights on the A-C/VIS monitors. Figure 91 shows how the light diffusers reduced the blooming produced by the turn signal lights.



**Figure 90. Left: A-C/VIS Monitor Showing Side Marker Light without Light Diffuser;
Right: A-C/VIS Monitor Showing Side Marker Light with Light Diffuser**



Figure 91. Left: A-C/VIS Monitor Showing Side Turn Signal Light without Light Diffuser; Right: A-C/VIS Monitor Showing Side Turn Signal Light with Light Diffuser

As will be demonstrated in the results section, drivers of trucks equipped with the commercially available C/VIS complained about the blooming from the side marker and turn signal lights on the monitors at night. To reduce the discomfort glare from the monitors, the turn signal light diffusers were also installed on the commercial C/VIS-equipped trucks. Figure 92 shows how the light diffusers reduced the constant blooming produced by the side marker lights on the commercial C/VIS's monitors. Figure 93 shows how the light diffusers reduced the blooming produced by the turn signal lights.



Figure 92. Left: Commercial C/VIS Monitor Showing Side Marker Light without Light Diffuser; Right: Commercial C/VIS Monitor Showing Side Marker Light with Light Diffuser

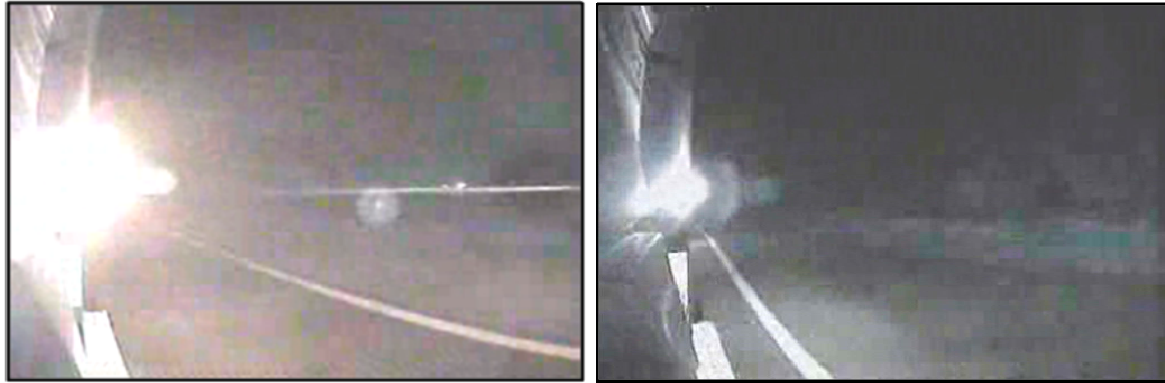


Figure 93. Left: A-C/VIS Monitor Showing Side Turn Signal Light without Light Diffuser; Right: A-C/VIS Monitor Showing Side Turn Signal Light with Light Diffuser

DATA ACQUISITION SYSTEM

The DAS allowed for the continuous collection of driver and roadway video, as well as parametric data pertaining to the vehicle, its location, and its distance to surrounding objects, over an extended period of time. This allowed driver behavior and vehicle status in the instances prior to an SCE to be examined. The DAS's reliability was central to the TFD.

The DAS used in the TFD was designed, developed, and enhanced during the last decade by the research institution. Previous versions of the system were used in several on-road studies (Blanco et al., in press; Hanowski et al., 2008). The main DAS unit and its components are described below.

Main DAS Unit

The main DAS unit consisted of a Pentium-based computer that was mounted under the passenger seat of the truck (Figure 94). The DAS received and stored data from a network of sensors distributed throughout the vehicle. The sensors used in the TFD included an interface box to the vehicle network, an accelerometer for longitudinal and lateral acceleration, a radar system that measured range and range rate to lead and trailing vehicles in the adjacent lanes, a video-based lane-tracking system that measured lane-keeping behavior, a light meter, a temperature/humidity sensor, a GPS sensor for location, and continuous video recordings of the driver and roadway to validate the sensor-based findings. These sensors are described in detail below. Data were stored on an external hard drive, which could store several weeks of driving data before requiring replacement. The DAS was constructed to automatically start when the truck's ignition was turned on. Data were recorded directly to a hard drive that was locked in place to prevent tampering.



Figure 94. The DAS Unit Installed Under the Passenger Seat

Video Cameras

Eight digital video cameras were used to record continuous video of the driver and the environment. Four cameras were used to record video of the roadway, including: 1) a view of the forward roadway, 2) a backwards-facing view of the left side of the tractor-trailer, 3) a backwards-facing view of the right side of the tractor-trailer, and 4) a top-down view of the rear of the trailer. Furthermore, four cameras were used to record video of the driver, including: 1) a left-facing view of the driver's face, 2) a center-facing view of the driver's face, 3) a right-facing view of the driver's face, and 4) an over-the-shoulder view of the driver. IR illumination was used to view the driver's face at night. The three cameras that were aimed at the driver's face were mounted underneath the C/VIS monitors. As a result, the facial views of the A-C/VIS-drivers were captured from cameras mounted along the top of the windshield (where the A-C/VIS monitors were located) (Figure 95), while the facial views of the drivers using the commercial C/VIS were captured from cameras mounted close to the dash (where the commercial C/VIS's monitors were located) (Figure 96). This allowed a reductionist to determine when the driver was looking at the monitors (by determining whether the driver was looking into the camera). The eight camera views were multiplexed into two videos. A timestamp (frame number) was included in both video files. The frame number was used to time-synchronize the video files, as well as the parametric data. Because the video data were digital, they could be synchronized together and simultaneously displayed with the parametric data when being analyzed. The data were also compressed for efficient archiving and retrieval.



Figure 95. Eight A-C/VIS Camera Images Multiplexed into Two Images



Figure 96. Eight Commercial C/VIS Camera Images Multiplexed into Two Images

Ambient Light Sensor

The outside ambient illumination level was recorded by a light sensor mounted on the back of the left monitor, facing out. The most prominent feature of the light sensor was that its spectral sensitivity was close to that of the human eye (Osram Opto Semiconductors, 2010). Its logarithmic output allowed greater resolution at low light levels and less resolution at higher light levels (i.e., it has more resolution between 1 and 2 Lux where there is a visible difference in

light level compared to a range of 50,000 to 50,001 Lux, where the human eye cannot discriminate this difference).

Temperature/Humidity Sensor

A temperature and humidity sensor was developed to measure the wet-bulb temperature, which was used to determine the likelihood of freezing temperatures and fog. The temperature sensor was an Analog Devices ADD22100, which was capable of measuring temperatures from -50°C to $+150^{\circ}\text{C}$. The humidity sensor was a Honeywell HIH-4031, which was capable of measuring up to 100-percent relative humidity with an accuracy of ± 3.5 percent. Both sensors were tested for accuracy. The temperature/humidity sensor was housed inside a 2.5-cm plastic cube and mounted to the exterior of the cab behind the cab shield to minimize contamination.

Radar System

Each test vehicle was instrumented with three radar units: 1) one on the front bumper (Figure 97), 2) one under the left west coast mirror, and 3) one under the right west coast mirror (Figure 98). The radar units provide a means to measure range, radial relative speed, and azimuth angle relative to the sensor. From the radar data, the clearance to an adjacent vehicle at the time of the lane-change initiation was measured. The radar data were also used to compute the TTC to lead and adjacent vehicles.



Figure 97. Radar Unit Mounted on the Front of the Truck (Left) and Close View of Radar Unit Mounted on the Front of the Truck (Right)



Figure 98. Radar Unit Mounted on the Left and Right West Coast Mirrors

GPS

A GPS device was mounted on top of the truck to provide data on the truck's location. The sensor was a complete 8-channel parallel tracking GPS receiver designed to operate at the L1 frequency. Data output included measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, and status/strength of satellite signal acquisition, as well as time and date data. The receiver was able to acquire a position fix with minimal delay after power cycling.

Lane Tracker

A lane tracker tool developed by the researchers called "Road Scout" was included in the DAS. The Road Scout consisted of a single analog monochrome camera, a personal computer (PC) with a frame grabber card, and an interface-to-vehicle network for obtaining ground speed (note the "grabbed" video frames were not stored, but were processed algorithmically in real time to calculate the vehicle position relative to road lane markings). Once installed, Road Scout's software automatically calibrated itself to determine camera position; no elaborate calibration procedure was required. The following variables were reported by Road Scout:

- Distance from center of truck to left and right lane markings (estimated max error < 6 in., average error < 2 in.)
- Angular offset between truck centerline and road centerline (estimated max error < 1 degree)
- Approximate road curvature
- Confidence in reported values for each marking found
- Marking characteristics, such as dashed versus solid and double versus single
- Status information, such as in-lane or solid line crossed

Yaw Rate Sensor

A yaw rate (gyro) sensor was installed in the main DAS unit to provide a measure of steering instability (i.e., jerky steering movements). It had a range of $\pm 75^\circ/\text{sec}$ with a resolution of $0.03\text{V}/^\circ/\text{sec}$.

X/Y Accelerometer

Accelerometers instrumented in the truck were used to measure longitudinal (x) and lateral (y) accelerations. It had a range of ± 2 g with a resolution of 0.03 g.

Vehicle Network

The vehicle network refers to the from-the-factory on-board data collection system. The format of messages and data collected by on-board microprocessors is defined by SAE J1587 (Society of Automotive Engineers, 2002). These microprocessors are installed on the vehicle at the truck manufacturing facility, not by the research team. Depending on the truck model, year, and manufacturer, there are several data network protocols or standards that can be used, including those defined by J1939 (Society of Automotive Engineers, 2001), J1587 (Society of Automotive Engineers, 2002), and J1708 (Society of Automotive Engineers, 1993). After assessing the data requirements associated with the current study, it was decided that the data defined by J1708 (Society of Automotive Engineers, 1993) would be accessed. An interface was developed to access the data and bring it into the DAS data set. Some of the measures accessed from the truck's vehicle network were dependent on the make, model, and year of the vehicle. A measure of the miles traveled by the vehicle, brake pedal use, cruise control use, and turn signal use were acquired through the vehicle network.

PROCEDURE

The procedures used to collect and reduce the naturalistic driving data are described below.

Vehicle Instrumentation

Six trucks from Schneider National's Winchester, Virginia operation were instrumented for the TFD. Three trucks were instrumented with the A-C/VIS, while the other three trucks were instrumented with the commercially available C/VIS. For each truck, it took four days to install the DAS and the C/VIS, perform extended daytime and nighttime driving tests to ensure all components were operational when exposed to heavy vehicle vibration, and make adjustments based on beta testing. Each truck was instrumented at the research institution one at a time. It should be noted that neither the DASs nor the C/VISs were operational during the transport of the truck to and from the research team's location. Furthermore, none of the drivers that transported the trucks partook in the study.

For the most part, the installations of the C/VIS and DAS for all trucks were identical. However, the following aspects of the installations are noteworthy. First, every tractor-trailer had a rear wide-angle look-down camera mounted to the trailer. Although the video image collected from it was only fed to the center monitor in the A-C/VIS-equipped trucks, every truck's DAS recorded this video feed. This was done so that the data collected from each vehicle were similar, despite which C/VIS was installed. On the other hand, the following differences existed between the A-C/VIS and the commercial C/VIS installations. First, the surveillance cameras used to record drivers' eye glances were mounted to the C/VIS monitors. As a result, there were cameras mounted to the three monitors along the top of the windshield for the A-C/VIS-equipped trucks, while there were cameras mounted to the two monitors on the dash of the trucks equipped with the commercial C/VIS; with the third camera mounted to the top of the right A-pillar to help the

reductionist identify when a glance to the right west coast mirror was made. Each truck had a fourth wide-angle camera installed at the top center of the windshield to capture the drivers' general behavior and operation of the steering wheel.

The video feeds of the left and right adjacent lanes were collected using the respective C/VIS cameras. As such, the video image varied between the A-C/VIS and the commercial C/VIS-equipped trucks, simply because of the different FOVs offered by each lens. Furthermore, IR illuminators were only installed on the A-C/VIS-equipped trucks, making the video image for the left and right adjacent lanes on the commercial C/VIS-equipped trucks substantially darker. Nevertheless, adjacent vehicles could still be perceived. Finally, because the A-C/VIS components were software controllable, various aspects of its DVI—such as day/night mode, brightness, object detection feature use, and object detection level—were recorded by the DAS. In contrast, only the power of the commercially available C/VIS could be recorded by the DAS. Brightness, contrast, tint, and color levels could not be recorded from the commercial C/VIS.

Vehicle Data Collection

Every week an experimenter visited the Schneider National terminal in Winchester, Virginia to inspect the test equipment for proper operation and to retrieve the collected data. If any equipment was damaged, the experimenter made the necessary repairs on site. Tools and spare test equipment were brought to the test site during each visit. During this visit, the experimenter also replaced the hard drives with empty hard drives to ensure there was sufficient storage for the subsequent data collection interval.

The data were downloaded from the hard drives each week. A random sample of ten files from each hard drive was inspected for data issues. A quality assurance report was generated and circulated to the data collection team so that the appropriate repairs could be scheduled. Each file on the hard drive was then inspected to verify that the appropriate driver was operating the test vehicle. Non-participating drivers would sometimes shuttle the tractors prior to the participant's shift, and so these files had to be deleted upon their discovery so that they were not erroneously included in the data set. The researchers ensured that none of the shuttle drivers participated in the study.

Participant Data Collection

Once a driver indicated a willingness to participate in the study, an experimenter screened each potential participant to confirm eligibility. Each participant had to meet the following criteria to qualify for participation: 1) be 21 years old or older, 2) hold a valid Class A CDL, 3) have normal or corrected to normal vision, 4) not be pregnant, 5) possess the ability to operate a tractor with a 48-ft trailer, and 6) be willing to have a video camera record his/her face and body whenever the vehicle was turned on. To confirm eligibility, the experimenter met the participant one hour prior to the start of his/her shift. During this meeting the experimenter explained the C/VIS, the purpose of the study, and what was expected of the participant over the course of the next four months. The experimenter then explained that the C/VIS would be deactivated for the first month, and the participant should drive as he or she normally does during this time. In addition to explaining this information, the experimenter completed the following tasks and questionnaires (see Appendix I):

1. Administered the Snellen eye test
2. Asked the participant to read and sign the informed consent form
3. Asked the participant to complete a W-9 tax form
4. Administered the Demographic Questionnaire
5. Administered the Pre-study Questionnaire
6. Administered the Driving Questionnaire

Following this initial meeting, the experimenter met with each participant before the start of his/her shift at the Winchester operation every two weeks. The experimenter called each participant a day in advance to schedule these meetings. At each meeting the participants completed the driving questionnaire (Appendix J).

On the participant's third meeting (one month into the study), the C/VIS was activated. During this meeting, the experimenter explained the C/VIS system to the participant in detail and went through a training manual (Appendices K and L), which was then left in the truck for future reference. This training manual showed the participant the various settings and how they could be adjusted. The experimenter also explained the specific purpose of the left and right fender cameras, as well as the rear wide-angle look-down camera (to those driving an A-C/VIS-equipped truck). In addition to going through the training manual, the participant was taken to the truck to make sure he was fully aware of the location and functionality of the installed equipment. Furthermore, the participant was given cleaning supplies for the camera lenses and asked to clean them at least once a week. The participant then drove the remainder of the study (three months) with the C/VIS system activated and continued to meet with the experimenter every two weeks. In addition to completing the driving questionnaire, the A-C/VIS drivers also completed the A-C/VIS Questionnaire (see Appendix M), while the drivers who had used the commercially available C/VIS completed the Sidetracker Questionnaire (see Appendix N) during these visits.

After the participant completed four months of driving, the experimenter scheduled a final meeting with the participant. During this meeting, the A-C/VIS drivers completed a final A-C/VIS questionnaire (Appendix O), while the drivers who had used the commercial C/VIS completed a final Sidetracker Questionnaire (Appendix P). Participants then completed the participant contact form (Appendix Q). Furthermore, the participant was asked if he would like to experience the other C/VIS system. If the participant agreed, the experimenter trained the participant on how to use the other C/VIS system. The participant then drove a 10-minute loop around Winchester, Virginia with the experimenter in the vehicle to experience the operation of the other C/VIS system. Once the participant finished the 10-minute loop, the experimenter administered a follow-up questionnaire. A-C/VIS drivers completed a Sidetracker Questionnaire after driving with the commercially available C/VIS for 10 minutes (Appendix R), while the drivers who had used the commercial C/VIS completed the A-C/VIS Questionnaire after driving with the A-C/VIS for 10 minutes (Appendix S).

The participant was then compensated for his/her time in the study. Compensation was \$100 per week plus a \$100 bonus for completing the study and cleaning the C/VIS. The experimenter then thanked the participant for his time and notified Schneider National that the participant had completed the study. Finally, the experimenter called the participant one month later to

administer a follow-up questionnaire (Appendix T). Appendix U shows the routes participants drove while in the study.

EXPERIMENTAL DESIGN

The TFD's experimental design consisted of a 2 (C/VIS) x 2 (Condition) Mixed Factors design. However, some dependent variables were investigated further by including additional factors in the experimental design. All independent and dependent variables are described below. The expanded experimental designs for these variables are presented in the results chapter.

Independent Variables

Condition (Baseline, Test) – Within-Subject

Each driver spent four months in the study. The drivers' first month in the study comprised the Baseline condition. Here, the C/VIS was installed on the truck, but was disabled. Drivers did not receive the enhanced views offered by the C/VIS. The subsequent three months comprised the Test condition. Here, the C/VIS was enabled and automatically turned on when the ignition was turned on. It should be noted that drivers only benefit from a C/VIS if they look at it. Therefore, just because the C/VIS was enabled does not mean that drivers benefit from it.

C/VIS (A-C/VIS, Commercial C/VIS) - Between-Subjects

The TFD was designed to investigate driver performance with a commercially available C/VIS as well as driver performance with a C/VIS that provided vision enhancements at night and in inclement weather conditions. As such, six drivers were assigned to a tractor-trailer outfitted with the commercially available C/VIS, while the other six drivers were assigned to a tractor-trailer outfitted with the A-C/VIS. Driver performance with the A-C/VIS was compared to driver performance with the commercial C/VIS through a between-subjects comparison.

Figure 99 illustrates the four experimental groups formed by the C/VIS and Condition independent variables.

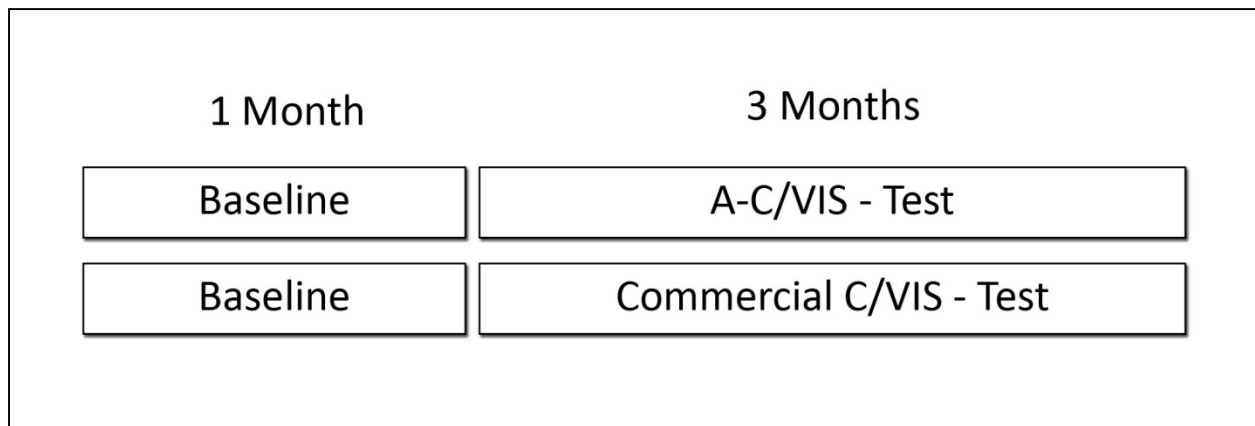


Figure 99. Experiment Groups for the TFD

Month (1, 2, 3, and 4) – Within-Subject

A Month independent variable was incorporated into the experimental design to further investigate specific dependent variables when inferential statistics using the expanded experimental design were appropriate. The levels of the Month independent variable were Month 1 (the Baseline condition), and Months 2, 3, and 4 (the Test condition). Driver performance across their months in the study was investigated through a within-subject comparison.

Direction (Left and Right) —Within-Subject

When analyzing drivers' lane-change performance, it was believed that drivers' execution of left lane changes would vary from their execution of right lane changes (Fitch et al., 2009). As such, a direction independent variable was added to the experimental design when performing inferential statistics on drivers' lane-change performance. Drivers' left and right lane-change performance was investigated using within-subject comparison.

Dependent Variables

The dependent variables used to measure drivers' performance with, and attitudes towards, the C/VISs are described below.

Drivers' Safety-Critical Event (SCE) Rate

In assessing the safety benefits of a drowsy driver warning system, Blanco et al. (2009) operationally defined the SCE rate as the number of SCEs that drivers experienced per 100 hours of driving over 5 km/h. This definition was used in the TFD to control for drivers' exposure in the C/VIS. It was hypothesized that the C/VISs would allow drivers to develop spatial awareness faster (through fewer mirror glances, or shorter mirror glances) than with the conventional mirror system, allowing them to spend more time looking at the forward roadway and be less likely to miss an unfolding conflict. The SCE rate in the Test condition was therefore hypothesized to be lower than the SCE in the Baseline condition.

Clearance to Adjacent Vehicle at Lane-Change Initiation

The rear-facing radar units allowed the distance to, and approach rate of, a trailing vehicle in the adjacent lane to be measured with precision. In investigating drivers' lane-change performance, this distance at the initiation of the lane change, or clearance, was recorded and investigated. A lane change was operationally defined to begin when the driver initiated a steering input with the intention to change lanes. This point was identified using captured video of the driver's hands on the steering wheel as well as video of the forward roadway and lane tracker data. It was hypothesized that drivers' mean clearance in the Test condition would differ from drivers' mean clearance in the Baseline condition owing to the enhanced visibility offered by the C/VISs.

Elapsed Time from Lane-Change Initiation to Crossing the Lane Markings

In investigating drivers' lane-change performance, the elapsed time from the lane-change maneuver being initiated to the vehicle's outermost tire touching the lane markings was measured. This point was identified using video captured of the forward roadway. The elapsed

time from lane-change initiation to crossing the lane markings was used to investigate how quickly drivers entered the adjacent lane. This variable was used to provide insight on how aggressive drivers' lane-change maneuvers were. It was hypothesized that the elapsed time from lane-change initiation to crossing the lane markings in the Test condition would differ from this elapsed time in the Baseline condition owing to the enhanced visibility offered by the C/VIS.

Lane-Change Duration

The duration of the lane-change maneuver was also recorded. A lane change was operationally defined to end when the vehicle's trajectory stabilized in the destination lane. The distance to the lane markings variable collected by the "Road Scout" lane tracker, as well as the captured video of the forward roadway, was used to identify this moment in time. The lane-change duration was measured to help determine whether drivers' lane-change performance changed once a C/VIS was available.

Drivers' Eye Glance Probability

Drivers' eye glance fixations were manually reduced on a frame-by-frame basis using the video recorded of the drivers' faces (the video data were collected at 10 Hz). Obtrusive eye glance measurement equipment was not used in this study, allowing drivers' natural eye glance patterns to be observed. The eye glance locations listed below were recorded; however, the left forward, forward, and right forward locations were pooled together for the analyses in this study. Figure 100 depicts the main locations recorded for A-C/VIS drivers, while Figure 101 depicts the main locations recorded for A-C/VIS drivers.

1. Left Window (LW)
2. Left West Coast/Convex Mirrors (LWM)
3. Left Monitor (LM)
4. Left Fender Mirror (LFM)
5. Left Forward (LF)
6. Forward (F)
7. Center Monitor (If Applicable)
8. Right Forward (RF)
9. Right Fender Mirror (RFM)
10. Right Monitor (RM)
11. Right West Coast/Convex Mirrors (RWM)
12. Right Window (RW)
13. Instrument Panel (speedometer) (IP)
14. Center Stack (Dash)
15. Cell Phone
16. Interior Object
17. Passenger
18. No Video
19. Glance Location Unknown
20. Eyes Closed
21. Other

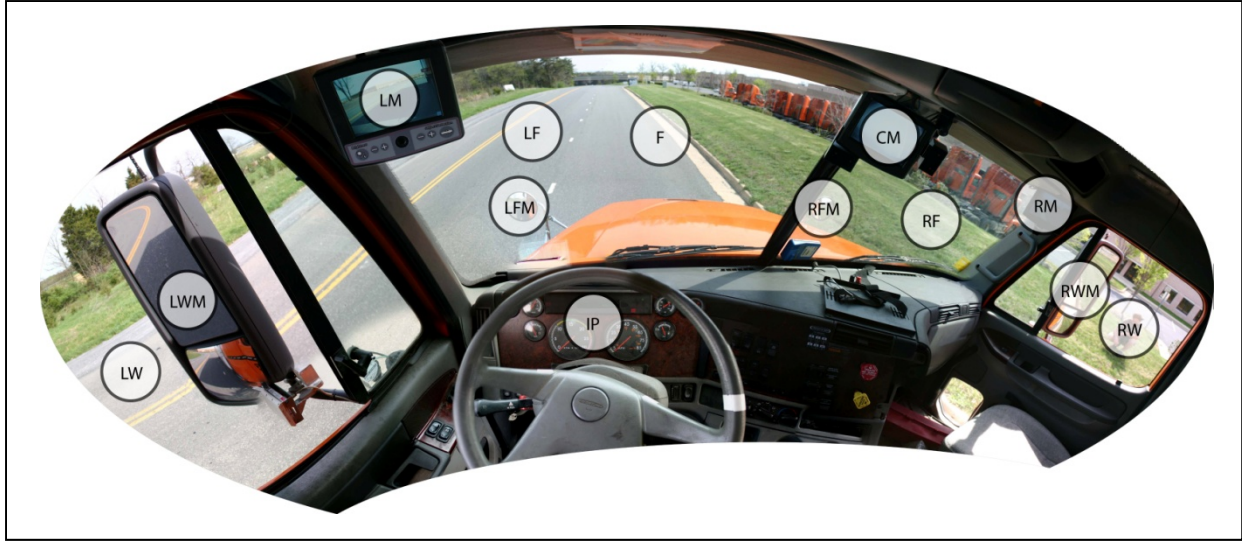


Figure 100. Eye Glance Locations for Drivers of A-C/VIS Trucks

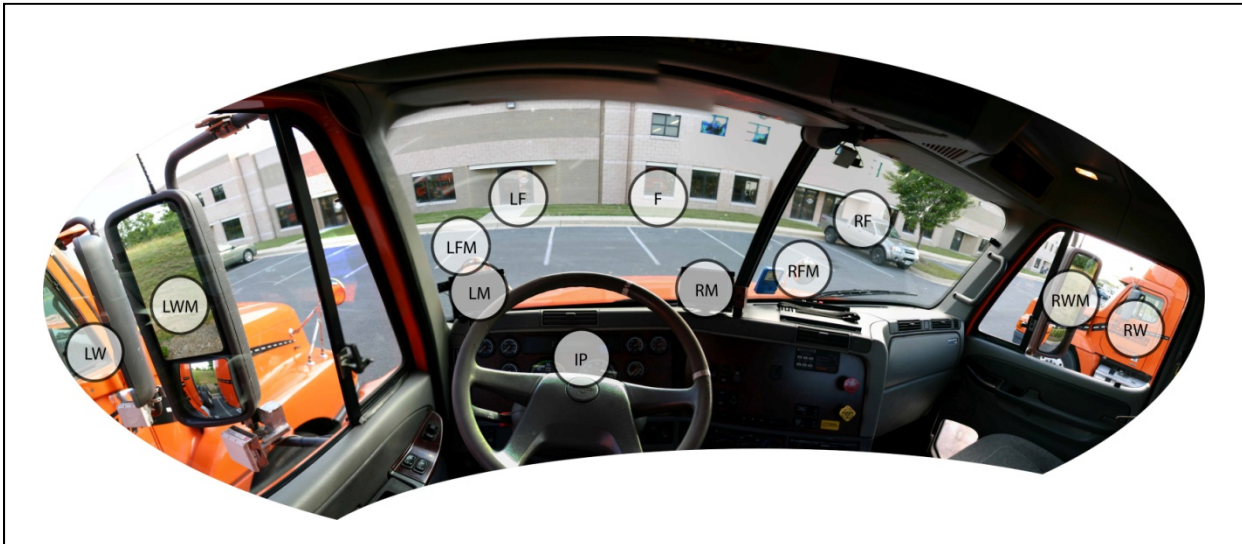


Figure 101. Eye Glance Locations for Drivers of Commercial C/VIS-equipped Trucks

A comprehensive investigation of drivers' visual behavior was performed in this study. The primary measure was their eye glance probability. The probability that drivers looked in a specific location was computed using the methods presented in Wierwille (1981). Here, the eye glance probability for location i was computed as:

$$P_i = \frac{\text{number of fixations on location } i}{\text{Total number of fixations}}$$

Drivers' visual behavior during the 8 s before experiencing an SCE was analyzed. Drivers' visual behavior from the 8 s before initiating a lane change to 5 s after initiating the lane change was also analyzed. This corresponded to 81 fixations per SCE (8 s of data at 10 Hz), and 131 fixations for each lane change maneuver (15 s of data at 10 Hz). The eye glance probabilities

were computed and then averaged across all SCEs or lane-change maneuvers to develop point estimates. These first order statistics were used to explain the likelihood drivers looked at a specific location.

Percentage of SCEs/Lane Changes in which Drivers Looked at least Once

The frequency of SCEs, or lane changes, during which drivers looked at least once in a given location during the 8-second, or 15-second, interval prior to the event or maneuver, , respectively, was analyzed. This measure was used to assess which locations drivers gathered information from at least once in the SCEs and maneuvers sampled.

Mean Number of Glances Prior to Lane Changes

The mean number of times drivers looked at a recorded eye glance location during the 8 s prior to experiencing an SCE, or 15-second interval when making a lane change, was analyzed. This measure was used to help explain the eye glance probability measure, in that eye glance probability is a function of the number of eye glances to a location, and the duration of those glances.

Mean Glance Duration Prior to Lane Changes

The mean duration of each eye glance was analyzed. This measure was used to help explain the eye glance probability measure, in that eye glance probability is a function of the number of eye glances to a location, and the duration of those glances.

Driver Preferences towards the C/VIS

Drivers' attitudes towards the C/VISs were measured using questionnaires (Appendices I through R). The questionnaires measured dimensions that include: 1) usefulness, 2) acceptance, 3) discomfort glare, 4) presence of blind spots, 5) misperception, and 6) maintenance.

DATA REDUCTION

There were two primary event types associated with these data: SCEs and lane-change maneuvers. An SCE occurred when there were one or more vehicles involved in a conflict, and at least one of those vehicles had to perform an evasive maneuver. A lane-change maneuver of interest occurred when the participant-driver changed lanes in the presence of another vehicle.

The Data Analysis and Reduction Tool (DART) software was used to support the data reduction of SCEs and lane-change maneuvers. There were three main steps involved in the data reduction process. The first step was to run event- trigger algorithms on all of the data to flag potential events of interest (either SCEs or lane-change maneuvers). The second step was to validate the event triggers by visually inspecting the video data pertaining to them, and the final step was to record the attributes that pertain to the events. Each of these steps is described in more detail below.

Safety-Critical Event Reduction

Trigger Algorithms

The first step in the SCE data reduction process was to identify events of interest, including crashes, near-crashes, and crash-relevant conflicts. Each of these events may or may not have involved an interaction with another vehicle. DART was used to find events of interest by scanning the data set for notable actions, including hard braking, quick steering maneuvers, short TTC, and lane deviations. To identify these actions, threshold values (“triggers”) were developed. Table 22 displays the five triggers and their event signatures.

Table 22. Triggers and Trigger Values Used to Identify Critical Incidents

Trigger Type	Definition	Description
Longitudinal Acceleration (LA)	Hard braking or sudden acceleration	Deceleration greater than or equal to 0.20 G. Speed greater than or equal to 1.6 km/h.
Time-to-Collision (TTC)	The amount of time (in s) that it would take for two vehicles to collide if one vehicle did not perform an evasive maneuver.	A forward TTC value of less than or equal to 2 s, coupled with a range of less than or equal to 76 m, a target speed of greater than or equal to 8 km/h, a yaw rate of less than or equal to $6^\circ/\text{s}$, and an azimuth of less than or equal to 0.12° .
Swerve (S)	A sudden “jerk” of the steering wheel to return the truck to its original position in the lane.	Swerve value of greater than or equal to 2 rad/s^2 . Speed greater than or equal to 8.05 km/h.
Analyst Identified (AI)	An event that is identified by the analyst but has not been identified by a trigger.	Event that was identified by a data analyst viewing video footage; no other trigger listed above identified the event (i.e., LA, TTC, etc.).

These event signatures, or trigger types, were selected based on data collected in the 100-Car Naturalistic Driving Study (Dingus et al., 2006). They have been refined to reflect heavy-vehicle kinematics and were shown to be effective in the Drowsy Driver Warning System Field Operational Test (DDWS FOT) (Hanowski et al., 2008) study and the Naturalistic Truck Driving Study (Blanco et al., in press).

Trigger Validation

The DART software scanned the data set and flagged potential events of interest with a trigger for review. A 75-second epoch was created for each trigger; an epoch consists of 1 min prior to the trigger and 15 s after the trigger. The result of the automatic scan was a data set that included both valid and invalid triggers.

Valid triggers were those where recorded dynamic-motion values actually occurred and were verifiable in the video and other sensor data (also identified by an analyst); one or more valid triggers may be included in an SCE. Invalid triggers were those triggers where sensor readings

were spurious due to a transient spike or some other anomaly (false positive). The validity of all triggers was determined through video review. Triggers determined to be invalid were not analyzed further. Valid triggers continued to be analyzed and classified as conflicts or non-conflicts. Conflicts were valid triggers that also represent a traffic conflict (e.g., crash). Non-conflicts were triggers that did not create safety-significant traffic events, even though their trigger values were valid (“true trigger”). Non-conflicts were analogous to nuisance alarms, where the threshold value for that particular trigger was set ineffectually. To reiterate, in non-conflict triggers the sensor reading was correct (e.g., the recorded vehicle acceleration occurred), but no actual traffic conflict occurred. Examples of valid triggers that were non-conflicts include hard braking by a driver in the absence of a specific crash threat, or a high swerve value from a lane change not resulting in any loss-of-control, lane departure, or proximity to other vehicles. While such situations may have reflected at-risk driving habits and styles, they did not always result in an SCE.

To determine the validity of the trigger, data analysts observed the recorded video and data plots of the various sensor measures associated with each 75-second epoch. The vehicle sensor measures, represented in pull-down menus in DART, are shown in Figure 102.

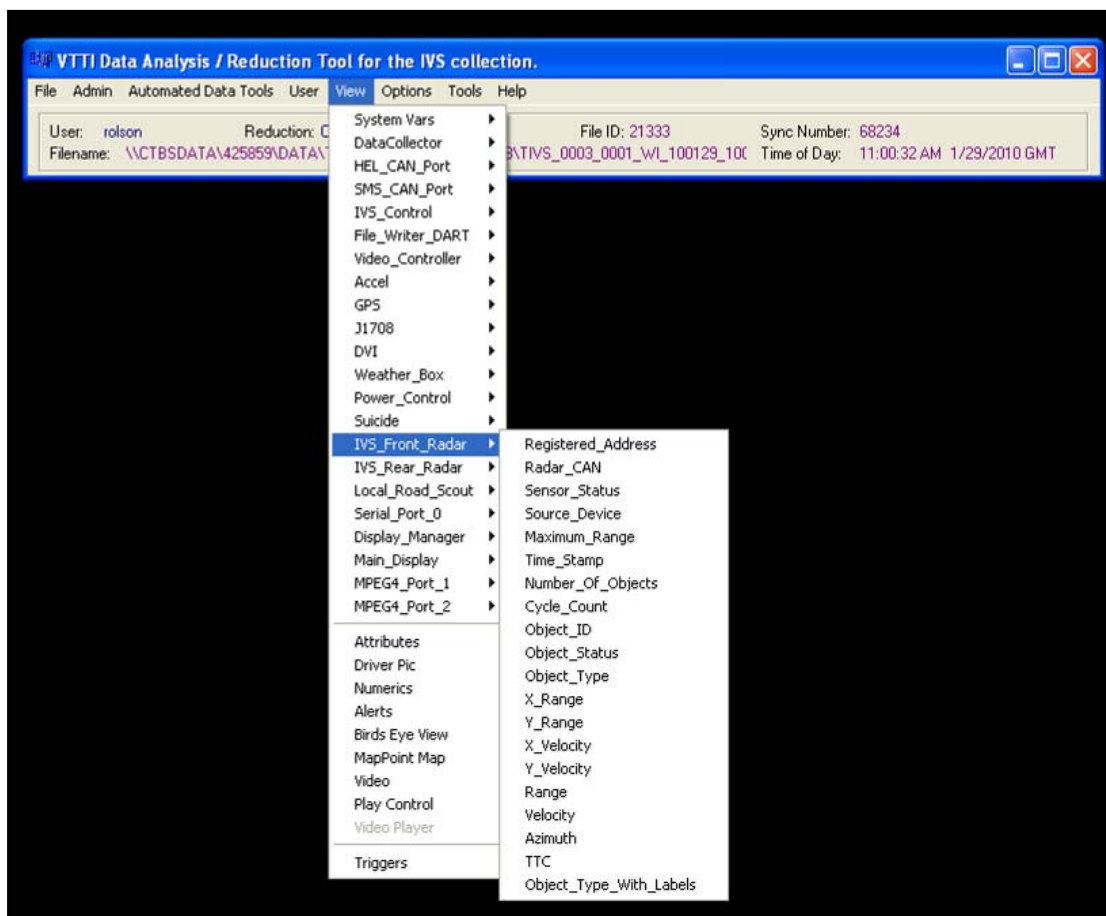


Figure 102. Screen Shot of a Pull-Down Menu Showing the Plots that can Aid in Determining the Validity of Triggered Events

Note that the lower the trigger values were set, the more false-positive triggers, non-conflict triggers, and less severe conflicts (i.e., crash-relevant conflicts) that were identified. The trade-off was that lower trigger values resulted in relatively few missed valid events. The goal of setting the lower, optimum trigger value was to identify all of the most severe events (crashes and near-crashes) without having an unmanageable number of false-positive triggers, non-conflict triggers, and low-severity conflict events. The training manual for the trigger validation process is shown in Appendix U.

Figure 103 shows an example of a valid trigger for longitudinal acceleration. In this example, the Trigger Chart shows the trigger at the same point that the Accel_X plot shows the value reached -0.267 G , indicating a sharp deceleration of the vehicle. For this example, the longitudinal acceleration trigger was set at -0.20 G ; therefore, anytime the software detected a longitudinal acceleration with a magnitude greater than -0.20 G , a trigger was created. Looking closely at the video in the top right quadrant, a vehicle can be seen in front (and to the left) of the SV. At this point, a pickup truck has begun to change lanes, crossing a solid lane line, directly into the lane in front of the instrumented vehicle, and the driver of the instrumented truck brakes to avoid the pickup truck.



Figure 103. Example of a Validated Trigger where the LA was of Greater Magnitude than the Pre-set Value of -0.20 g

Figure 104 shows an example of a non-conflict that had a valid swerve (quick steering) trigger. During this event, the driver was changing lanes. The Trigger Chart shows the trigger appeared when the swerve value reached 2.48 (the value for this trigger was set at ≥ 2.0). After reviewing

the video, it was seen that there were no vehicles in front or to the side of the instrumented vehicle and the driver was simply changing lanes.

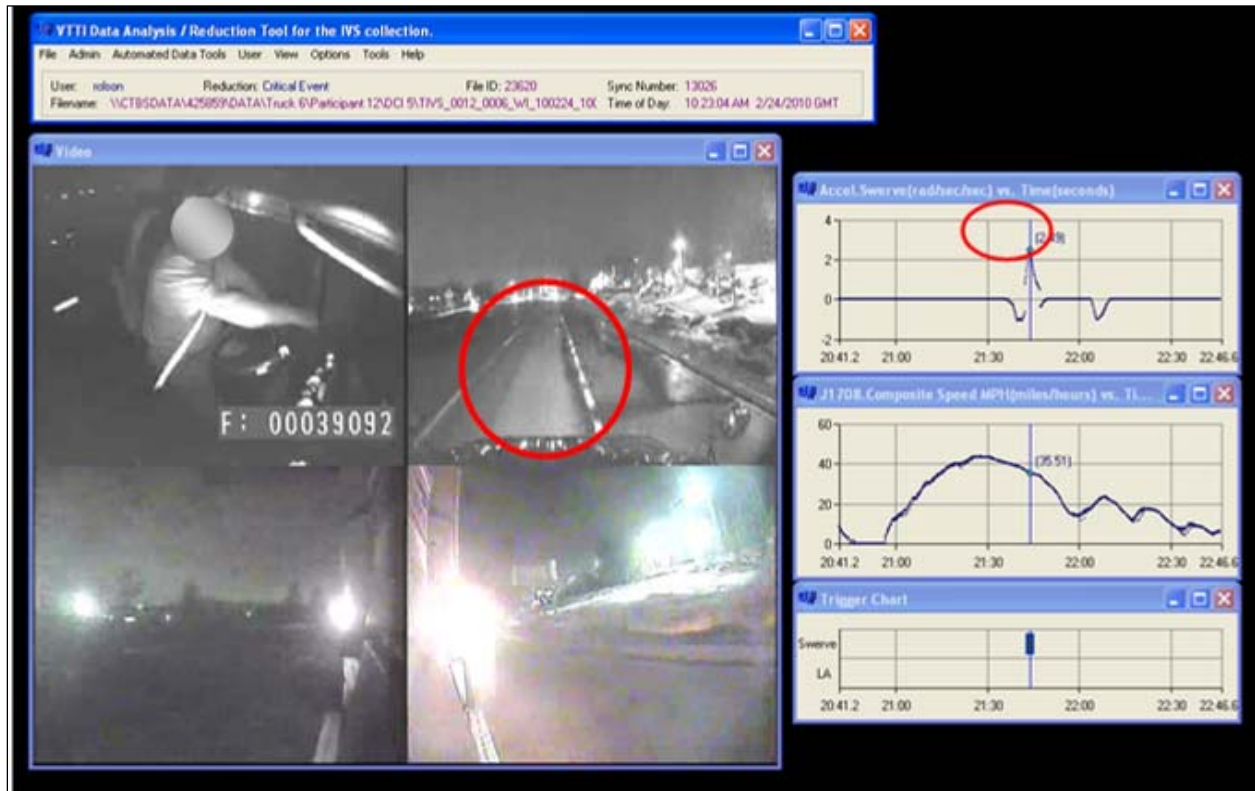


Figure 104. Example of a Non-Conflict Event (with a Valid Trigger) where the Driver's Swerve (Quick Steering) was 2.49 (trigger set to ≥ 2.0)

An expert analyst reviewed all valid triggers to determine if they were to be used in the analysis. Next, each valid event was classified into an SCE type and assigned variables from the data directory; each of these steps is described below.

Classify Valid Events to a Safety-Critical Event Type

The valid triggers were classified into one of five SCEs: crash, crash: tire strike, near-crash, crash-relevant conflict, and illegal maneuver. Descriptions for each event type are listed in Table 23.

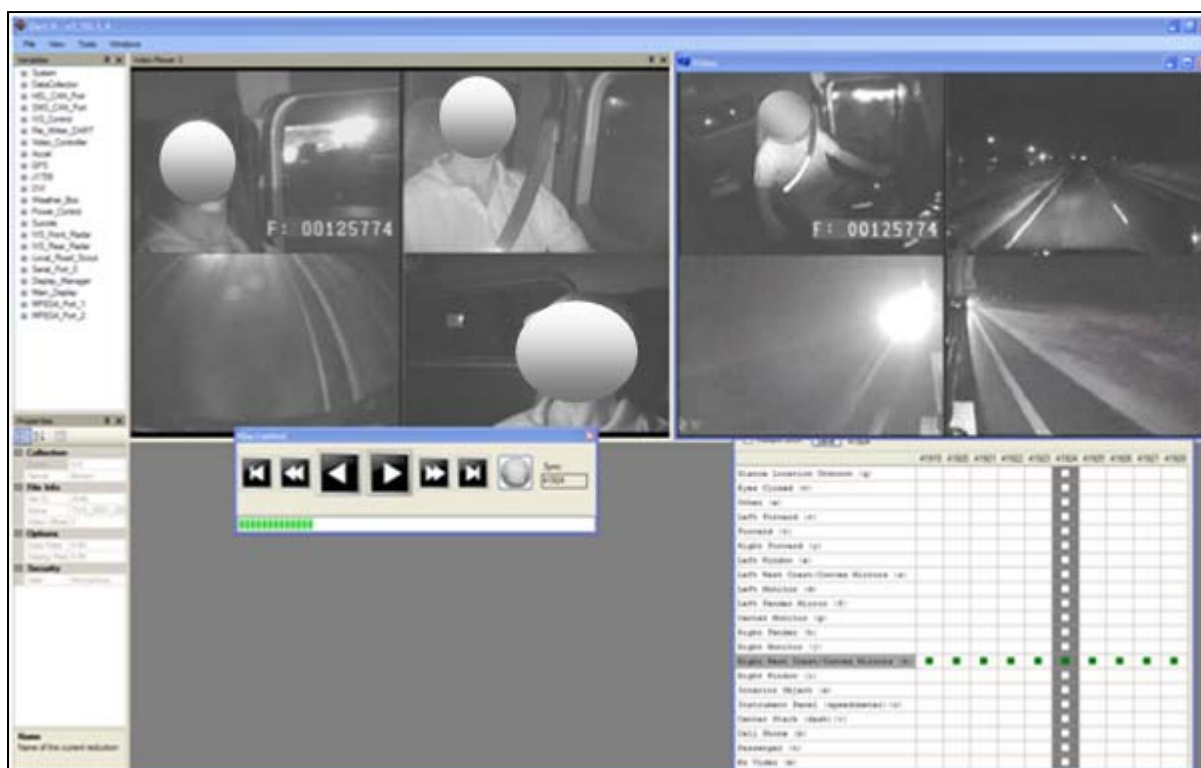
Table 23. Description of Each Event Type

Event Type	Description
Crash	Any contact with an object, either moving or fixed, at any speed.
Curb Strike: Avoidable	Any contact with a curb or median where it is apparent that the driver could have performed a maneuver to avoid the contact.
Curb Strike: Unavoidable	Any contact with a curb or median where it is apparent that the driver could not have performed a maneuver to avoid the contact. The most likely cause for these events is poor roadway design.
Near-Crash	Any circumstance that requires a rapid, evasive maneuver (e.g., hard braking, steering) by the subject vehicle (SV) or any other vehicle, pedestrian, cyclist, or animal, in order to avoid a crash.
Crash-Relevant Conflict	Any circumstance that requires a crash-avoidance response on the part of the SV, any other vehicle, pedestrian, cyclist, or animal that was less severe than a rapid evasive maneuver (as defined above), but greater in severity than a normal maneuver. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs.
Illegal Maneuver	Any circumstance where either the SV or the other vehicle performs an illegal maneuver such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.

Applying the Data Directory

A data directory was used to reduce and analyze all SCEs. This data directory was originally developed by Hickman et al. (in press) in a preliminary analysis of the DDWS FOT data. The same data directory was also used in Blanco et al. (in press). The DART software presented the data analyst with a series of variables consisting either of a blank space for entry of specific comments or provided pull-down menus for the analyst to select the most applicable option. The analyst coded variables such as pre-event movement, critical reason for the conflict, distraction(s), road condition, weather condition, as well as many others (Appendix V). To ensure accuracy, an expert data analyst reviewed all valid SCEs to verify that they were valid, and then applied the data directory.

A second data directory of eye glance locations was used to analyze driver glance behavior 8 s before and 5 s after the SCEs. This analysis required the analyst to view all eight camera views, which are set up as quadrants in two separate video files. A beta version of the DART software (Dart II) was created in order to sync, view, and reduce both video files simultaneously. Glance locations were coded for each frame of data starting 8 s (80 data frames) prior to the initiation of the lane change through 5 s (50 data frames) after the initiation of the lane change. The glance locations and eye glance protocol applied in this reduction are listed in Appendix W. The three close-up face views that were available allowed analysts to accurately distinguish between glances to and around the monitors of the A-CIVS (Figure 105) and the commercial C/VIS (Figure 106). An expert analyst reviewed the lane-change reduction for approximately 50 percent of all valid SCEs (randomly selected) during the reduction process and provided feedback to the analyst. This sampling was raised to 100 percent for the first week of each condition (baseline and test) for each driver.



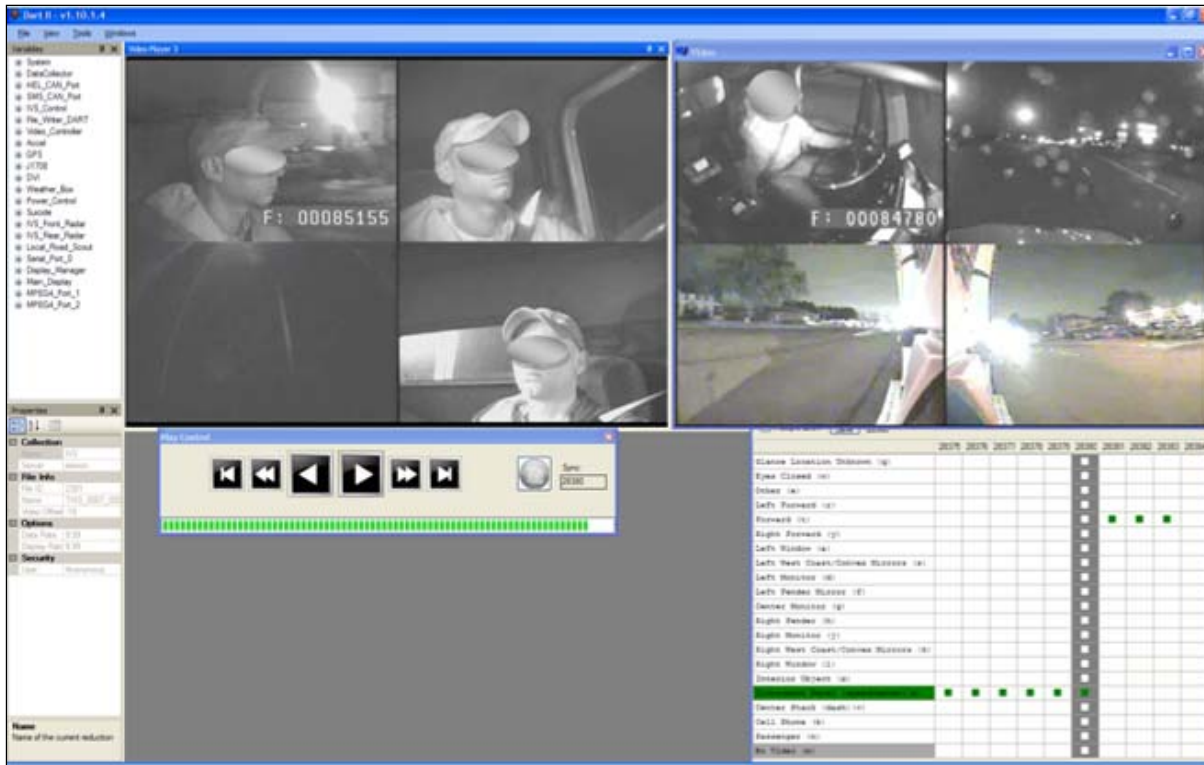


Figure 106. Data Analyst Video Set-Up for Performing Eye Glance Reduction in DART II on a Commercial C/VIS Driver

Lane-Change Maneuver Reduction

Trigger Algorithms

The first step in the lane-change maneuver data reduction process was to identify potential lane changes of interest. The DAS installed in each truck included a video processing box that fed information into lane-tracking software. The DART software was then able to scan all the data to identify instances of lane changes that occurred when the truck was traveling at least 56 km/h on a straight road (≤ 0.04 degrees/second curvature). The 56 km/h criteria was chosen because heavy vehicles performing lane changes at speeds less than 56 km/h have a significant bend between the tractor and the trailer, thus reducing the fender-mounted radar system's ability to correctly measure distance to trailing vehicles. The remaining steps taken to complete the lane-change data reduction are described in more detail below.

Trigger Validation

Once lane-change triggers were created, they were randomly reviewed by an analyst until it was possible to obtain 11 valid lane changes per week of driving. A valid lane change was defined as the participant-driver changing lanes while a vehicle was present in the destination lane next to or behind the trailer and while valid rear radar data for that adjacent vehicle were present (Figure 107).

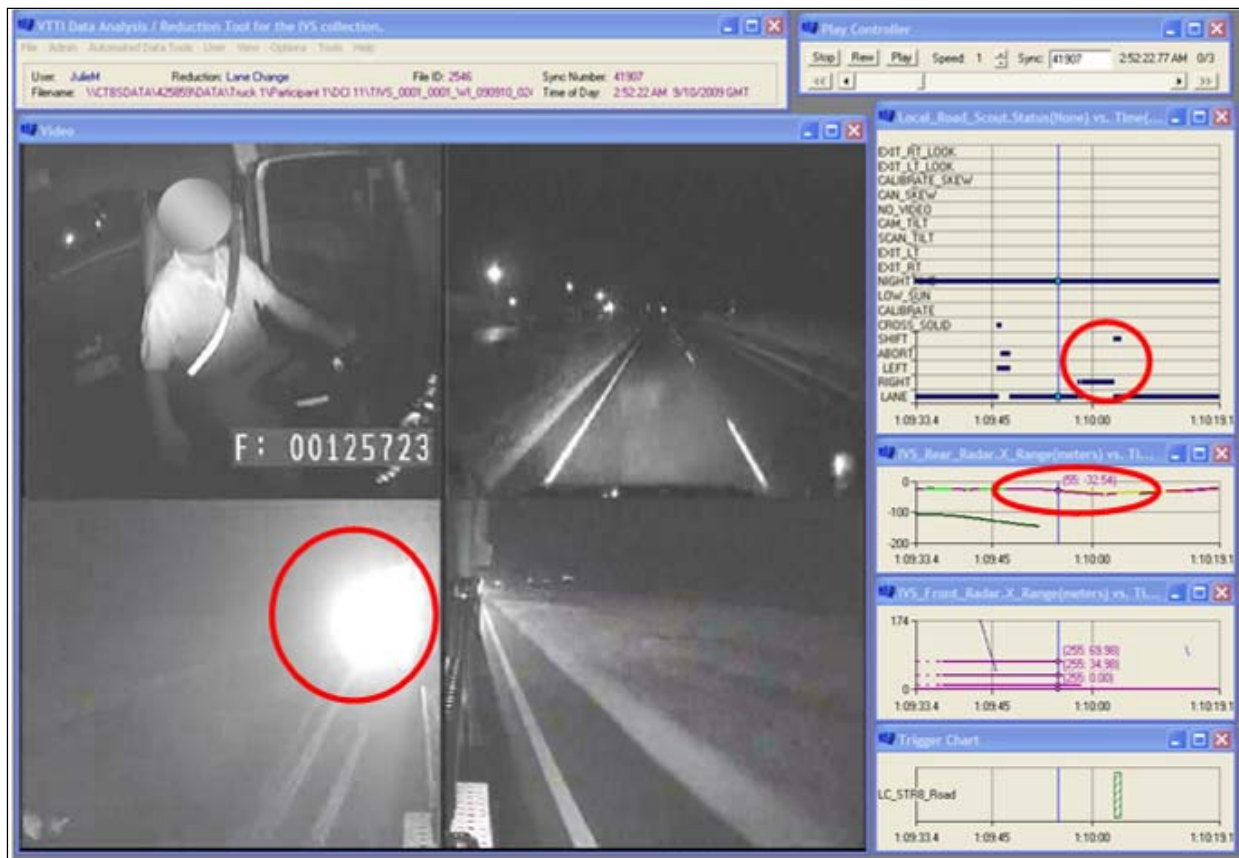


Figure 107. Example of a Valid Lane-Change Maneuver where the Driver Changes from the Left to the Right Lane with a Vehicle Present in the Destination Lane and Valid Rear Radar Data

A week was defined as five nights of driving, although not necessarily consecutive nights of driving. For example, drivers typically worked from Monday night through Friday night, but if the truck was in the shop on Monday and Tuesday, the week might start on Wednesday night and go through the following Tuesday night (the driver would not have driven the instrumented truck on Saturday or Sunday night). If it was not possible to obtain 11 valid lane changes per week, then the default goal was to obtain 44 lane changes per month (i.e., four weeks), and other weeks within a given month would be oversampled to meet this target. The goal was to obtain a total of 2112 valid lane changes across the entire data set, including: 264 lane changes performed in the Commercially available C/VIS-Baseline condition, 792 lane changes performed in the Commercially available C/VIS-Test condition, 264 lane changes performed in the A-C/VIS-Baseline condition, and 792 lane changes performed in the A-C/VIS-Test condition. An expert analyst reviewed all valid lane-change maneuvers to determine if they were to be used in the analysis. Next, each valid lane change was assigned variables from the data directory.

Applying the Data Directory

A data directory of summary measures was used to reduce and analyze all lane-change maneuvers. The DART software presented the data analyst with a series of variables consisting either of a blank space for entry of specific comments or provided pull-down menus for the

analyst to select the most applicable option (Figure 108). The analyst coded variables such as conflict severity, lane change type, distance to and approach rate of other vehicles present in both original and destination lanes, road condition, and weather condition, as well as many others (Appendix Y). To ensure accuracy, an expert data analyst reviewed a minimum of three valid lane changes per week to verify that they were valid and that the data directory had been properly applied.



Figure 108. Example of the Data Charts Referenced During Application of the Lane Change Summary Measure Directory. Referenced Views Include Front and Rear Radar Parameters, Turn Signal Indicators, and Lane Marking Distance Measures

Again, a second data directory of eye glance locations was used to analyze driver glance behavior 8 s before and 5 s after the initiation of a lane change. The glance locations and eye glance protocol applied in this reduction are presented in Appendix Z.

Driver Preference Data Reduction

Once every two weeks, all the drivers' questionnaire responses were manually entered into a Microsoft Excel database. After the initial data entry was complete, a second researcher validated the data entry to ensure that all questionnaire responses were accurately entered into Excel. This Excel database was subsequently transferred into a SAS database for questionnaire analysis.

CHAPTER 7. RESULTS

Drivers' performance with a C/VIS was investigated through three main analyses. The first set of analyses investigated whether drivers' involvement in SCEs decreased when driving with a C/VIS. The second set of analyses investigated whether drivers' lane-change performance changed when driving with a C/VIS. The final set of analyses investigated drivers' opinions of the C/VISs and their driving performance with them. Whether the C/VISs negatively affected drivers' performance was concurrently investigated. The results from these analyses are presented in this chapter.

DRIVER INVOLVEMENT IN SAFETY-CRITICAL EVENTS

Driving Data Statistics

A total of 448,285 km of driving data was collected, spanning a total of 5,661 hours, from the 15 drivers that participated. The video and parametric data together comprise 3.62 Terabytes. In triggering events of interest from this data set, 339 unique SCEs were identified. Forty percent of the SCEs were identified by hard-braking triggers, 25 percent were identified by swerve triggers, 4 percent were identified by TTC triggers, and 16 percent were identified by reductionists (the remaining 14 percent were identified by a combination of triggers, predominantly hard-braking and serve triggers [5 percent] and hard-braking and TTC triggers [5 percent]). A total of 80,529 triggers were found to be benign, making the overall hit rate for the SCE triggers to be 0.50 percent. These statistics demonstrate that SCEs are rare occurrences.

The data set analyzed in this report consists of data from the 12 drivers that completed the study. This data set contains 412,417 km of driving data, spanning 5,161 hours; this amounted to 3.35 Terabytes of data. A total of 277 SCEs were identified from these 12 drivers.

SCE Classification

Information pertaining to the conditions that were present when the SCEs were recorded is presented below. This information is meant to provide the reader with an understanding of the SCEs that were recorded in this study. It is not meant to suggest the factors that lead to the occurrence of SCEs.

Pre-Crash Event

Table 24 classifies the observed SCEs by their pre-crash event category. It can be seen that 27 percent of the SCEs had a pre-crash event originating from an object or animal, 39 percent had a pre-crash event originating from another motor vehicle, 1 percent had a pre-crash event originating from a pedestrian, and 33 percent had a pre-crash event originating from the SV.

Table 24. SCE Pre-Crash Event Categories

Pre-Crash Event Category	Frequency	Percent	Specific Pre-Crash Event	Frequency	Percent
Object/Animal Related	74	27.0	OBJECT OR ANIMAL: Animal approaching roadway	1	0.4
			OBJECT OR ANIMAL: Animal in roadway	40	14.4
			OBJECT OR ANIMAL: Object - unknown location	1	0.4
			OBJECT OR ANIMAL: Object in roadway	32	11.5
Other Motor Vehicle Related	108	39.0	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over left lane line	23	8.3
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over right lane line	16	5.8
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, across path	3	1.1
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, intended path not known	1	0.4
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into opposite direction	1	0.4
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into same direction	6	2.2
			OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From opposite direction - toward or over left lane line	1	0.4
			OTHER MOTOR VEHICLE IN LANE: Other vehicle stopped	6	2.2
			OTHER MOTOR VEHICLE IN LANE: Traveling in opposite direction	1	0.4
			OTHER MOTOR VEHICLE IN LANE: Traveling in same direction while decelerating	43	15.5
			OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with higher speed	1	0.4
			OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with lower steady speed	6	2.2
Pedestrian Related	3	1.0	PEDESTRIAN, PEDALCYCLIST, OR OTHER NON-MOTORIST: Pedestrian in roadway	3	1.1
Subject Vehicle Related	92	33.0	THIS VEHICLE LOSS OF CONTROL DUE TO: Poor road conditions	1	0.4

			THIS VEHICLE TRAVELING: Crossing over (passing through) intersection	3	1.1
			THIS VEHICLE TRAVELING: Toward or off the edge of the road on the left side	30	10.8
			THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	37	13.4
			THIS VEHICLE TRAVELING: Toward or over the lane line on left side of travel lane	16	5.8
			THIS VEHICLE TRAVELING: Toward or over the lane line on right side of travel lane	2	0.7
			THIS VEHICLE TRAVELING: Turning left at intersection	2	0.7
			THIS VEHICLE TRAVELING: Turning right at intersection	1	0.4
Total	277	100.0	Total	277	100.0

Table 25 provides additional information regarding how these SCE pre-crash event categories divide across the various grades of SCE severity.

Table 25. SCE Pre-Crash Event by Severity

Pre-Crash Event	Crash	Curb Strike: Unavoidable	Curb Strike: Avoidable	Near-Crash	Crash- Relevant	Illegal Maneuver	Total
OBJECT OR ANIMAL: Animal approaching roadway	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
OBJECT OR ANIMAL: Animal in roadway	0.0%	0.0%	0.0%	1.1%	13.4%	0.0%	14.4%
OBJECT OR ANIMAL: Object - unknown location	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
OBJECT OR ANIMAL: Object in roadway	1.1%	0.0%	0.0%	0.7%	9.8%	0.0%	11.6%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over left lane line	0.0%	0.0%	0.0%	0.7%	7.6%	0.0%	8.3%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over right lane line	0.0%	0.0%	0.0%	0.4%	5.4%	0.0%	5.8%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, across path	0.0%	0.0%	0.0%	0.0%	0.7%	0.4%	1.1%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, intended path not known	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into opposite direction	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%

OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into same direction	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	2.2%
OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From opposite direction - toward or over left lane line	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
OTHER MOTOR VEHICLE IN LANE: Other vehicle stopped	0.4%	0.0%	0.0%	0.4%	1.4%	0.0%	2.2%
OTHER MOTOR VEHICLE IN LANE: Traveling in opposite direction	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
OTHER MOTOR VEHICLE IN LANE: Traveling in same direction while decelerating	0.0%	0.0%	0.0%	0.0%	15.5%	0.0%	15.5%
OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with higher speed	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with lower steady speed	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	2.2%
PEDESTRIAN, PEDALCYCLIST, OR OTHER NON-MOTORIST: Pedestrian in roadway	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	1.1%
THIS VEHICLE LOSS OF CONTROL DUE TO: Poor road conditions	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.4%
THIS VEHICLE TRAVELING: Crossing over (passing through) intersection	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	1.1%
THIS VEHICLE TRAVELING: Toward or off the edge of the road on the left side	0.0%	0.7%	9.8%	0.0%	0.4%	0.0%	10.8%
THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.4%	2.2%	7.9%	0.4%	2.5%	0.0%	13.4%
THIS VEHICLE TRAVELING: Toward or over the lane line on left side of travel lane	0.0%	0.0%	0.0%	0.4%	5.4%	0.0%	5.8%
THIS VEHICLE TRAVELING: Toward or over the lane line on right side of travel lane	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.7%
THIS VEHICLE TRAVELING: Turning left at intersection	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.7%
THIS VEHICLE TRAVELING: Turning right at intersection	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.4%
Total	2.2%	2.9%	17.7%	4.3%	72.6%	0.4%	100.0%

Table 26 shows the trigger logic that identified the valid SCEs. SCEs are classified by their severity and pre-crash event to provide insight into what triggers were tied to the observed pre-crash events. It can be seen that the majority of the crashes observed involved an object in the roadway and were triggered by the SV performing a hard deceleration (LA trigger). The majority of the near-crashes involved an animal in the roadway and were triggered by the SV braking and swerving. Finally, the majority of the crash-relevant conflicts involved a lead vehicle

decelerating in the SV's lane and were triggered by the SV performing a hard deceleration or swerve.

Table 26. SCE Pre-Crash Event by Severity and Trigger Logic

Severity	Pre-Crash Event	LA	Swerve	TTC	User Defined	Total
Crash	OBJECT OR ANIMAL: Object - unknown location	0.0%	0.0%	0.0%	16.7%	16.7%
	OBJECT OR ANIMAL: Object in roadway	50.0%	0.0%	0.0%	0.0%	50.0%
	OTHER MOTOR VEHICLE IN LANE: Other vehicle stopped	0.0%	0.0%	0.0%	16.7%	16.7%
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.0%	16.7%	0.0%	0.0%	16.7%
	Column %	50.0%	16.7%	0.0%	33.3%	100.0%
	Total	3	1	0	2	6
Curb Strike: Unavoidable	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the left side	12.5%	0.0%	0.0%	12.5%	25.0%
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.0%	0.0%	0.0%	75.0%	75.0%
	Column %	12.5%	0.0%	0.0%	87.5%	100.0%
	Total	1	0	0	7	8
Curb Strike: Avoidable	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the left side	2.0%	2.0%	0.0%	51.0%	55.1%
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.0%	8.2%	0.0%	36.7%	44.9%
	Column %	2.0%	10.2%	0.0%	87.8%	100.0%
	Total	1	5	0	43	49
Near Crash	OBJECT OR ANIMAL: Animal in roadway	16.7%	11.1%	11.1%	0.0%	38.9%
	OBJECT OR ANIMAL: Object in roadway	5.6%	11.1%	0.0%	0.0%	16.7%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over left lane line	5.6%	5.6%	0.0%	0.0%	11.1%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over right lane line	5.6%	0.0%	0.0%	0.0%	5.6%
	OTHER MOTOR VEHICLE IN LANE: Other vehicle stopped	5.6%	0.0%	0.0%	0.0%	5.6%
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.0%	5.6%	0.0%	0.0%	5.6%
	THIS VEHICLE TRAVELING: Toward or over the lane line on left side of travel lane	0.0%	5.6%	0.0%	0.0%	5.6%
	THIS VEHICLE TRAVELING: Turning right at intersection	5.6%	5.6%	0.0%	0.0%	11.1%

Severity	Pre-Crash Event	LA	Swerve	TTC	User Defined	Total
	Column %	44.4%	44.4%	11.1%	0.0%	100.0%
	Total	8	8	2	0	18
Crash-Relevant Conflicts	OBJECT OR ANIMAL: Animal approaching roadway	0.4%	0.0%	0.0%	0.0%	0.4%
	OBJECT OR ANIMAL: Animal in roadway	12.9%	2.5%	2.5%	0.4%	18.3%
	OBJECT OR ANIMAL: Object in roadway	2.1%	9.6%	0.0%	0.0%	11.7%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over left lane line	7.1%	2.1%	0.4%	0.0%	9.6%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From adjacent lane (same direction) - toward or over right lane line	6.3%	0.4%	0.4%	0.0%	7.1%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, across path	0.8%	0.0%	0.4%	0.0%	1.3%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, intended path not known	0.4%	0.0%	0.0%	0.0%	0.4%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into opposite direction	0.4%	0.0%	0.0%	0.0%	0.4%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From crossing street, turning into same direction	2.1%	0.8%	0.0%	0.0%	2.9%
	OTHER MOTOR VEHICLE ENCROACHING INTO LANE: From opposite direction - toward or over left lane line	0.4%	0.0%	0.0%	0.0%	0.4%
	OTHER MOTOR VEHICLE IN LANE: Other vehicle stopped	1.3%	0.8%	0.4%	0.0%	2.5%
	OTHER MOTOR VEHICLE IN LANE: Traveling in opposite direction	0.4%	0.4%	0.4%	0.0%	1.3%
	OTHER MOTOR VEHICLE IN LANE: Traveling in same direction while decelerating	13.3%	4.2%	7.5%	0.0%	25.0%
	OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with higher speed	0.4%	0.0%	0.0%	0.0%	0.4%
	OTHER MOTOR VEHICLE IN LANE: Traveling in same direction with lower steady speed	2.1%	0.4%	0.4%	0.0%	2.9%
	PEDESTRIAN, PEDALCYCLIST, OR OTHER NON-MOTORIST: Pedestrian in roadway	0.0%	0.8%	0.0%	0.4%	1.3%
	THIS VEHICLE LOSS OF CONTROL DUE TO: Poor road conditions	0.0%	0.4%	0.0%	0.0%	0.4%
	THIS VEHICLE TRAVELING: Crossing over (passing through) intersection	1.3%	0.0%	0.0%	0.0%	1.3%

Severity	Pre-Crash Event	LA	Swerve	TTC	User Defined	Total
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the left side	0.0%	0.4%	0.0%	0.0%	0.4%
	THIS VEHICLE TRAVELING: Toward or off the edge of the road on the right side	0.0%	2.9%	0.0%	0.0%	2.9%
	THIS VEHICLE TRAVELING: Toward or over the lane line on left side of travel lane	2.1%	3.3%	1.3%	0.4%	7.1%
	THIS VEHICLE TRAVELING: Toward or over the lane line on right side of travel lane	0.8%	0.0%	0.0%	0.0%	0.8%
	THIS VEHICLE TRAVELING: Turning left at intersection	0.8%	0.4%	0.0%	0.0%	1.3%
	Column %	55.4	29.6	13.8	1.3	100.0%
	Total	133	71	33	3	240

Fault Assignment

An experienced reductionist assigned the fault of every recorded SCE to the SV driver, the other motor vehicle driver, animal, or pedestrian, or the environment. Forty three percent of the 277 SCEs were the fault of the SV driver, 41 percent were the fault of another motor vehicle driver, animal, or pedestrian, and 16 percent of the SCEs had no fault assigned (i.e., they were attributed to the environment).

Lighting Condition

Figure 109 shows the percentage of SCEs that occurred in the observed lighting conditions. Recall that the trucking operation investigated was a delivery service that operated primarily at night. It can be seen that 70 percent of the SCEs were recorded at night.

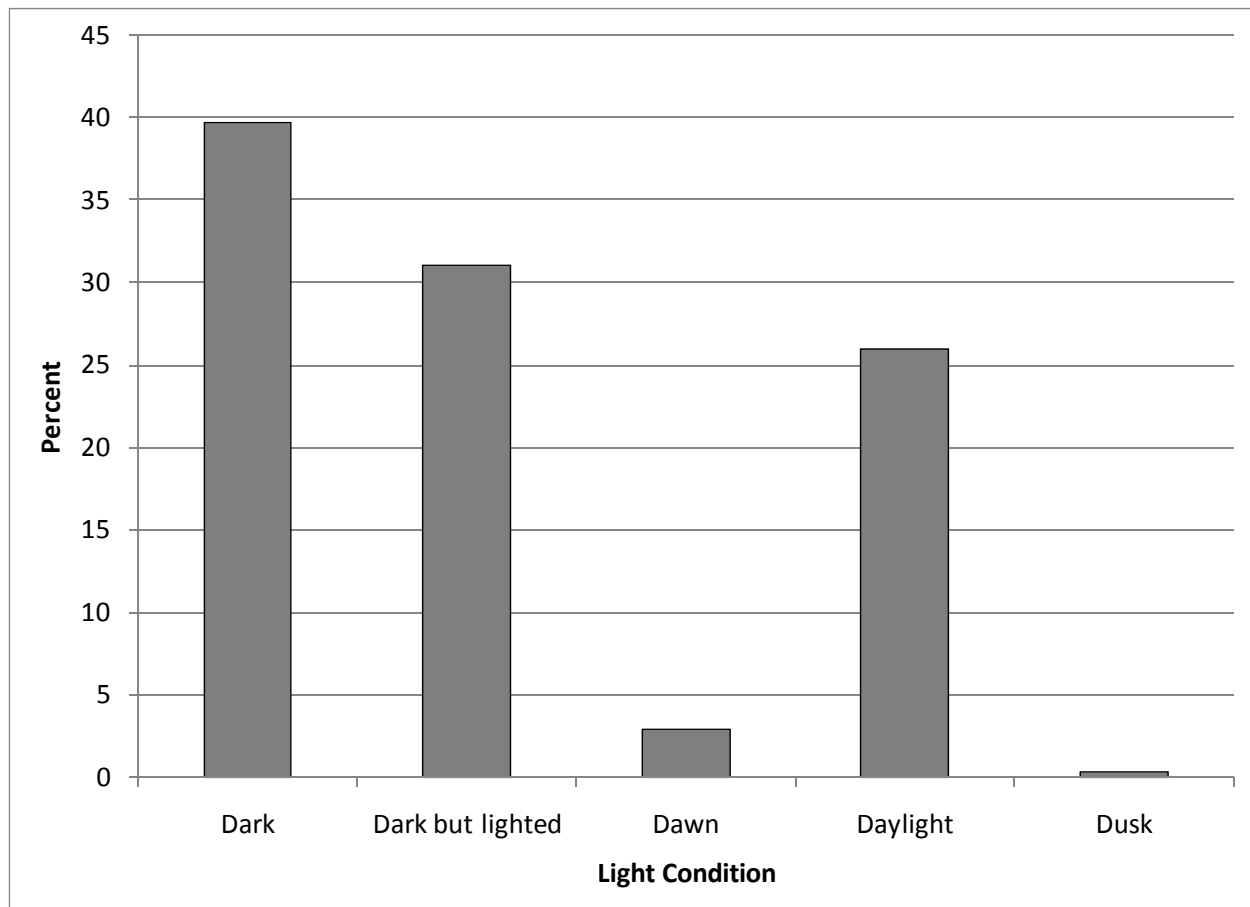


Figure 109. SCEs by Lighting Condition

Weather Condition

Figure 110 presents the percentage of SCEs that occurred in the recorded weather conditions. The majority of the recorded SCEs occurred when there were no adverse weather conditions. It should be noted, however, that there was a particularly harsh winter during this data collection interval. Unfortunately, the tremendous amount of snow damaged the trailers and closed the trucking operation, which prevented data from being collected. The subsequent down time was outside of the experimenter's control.

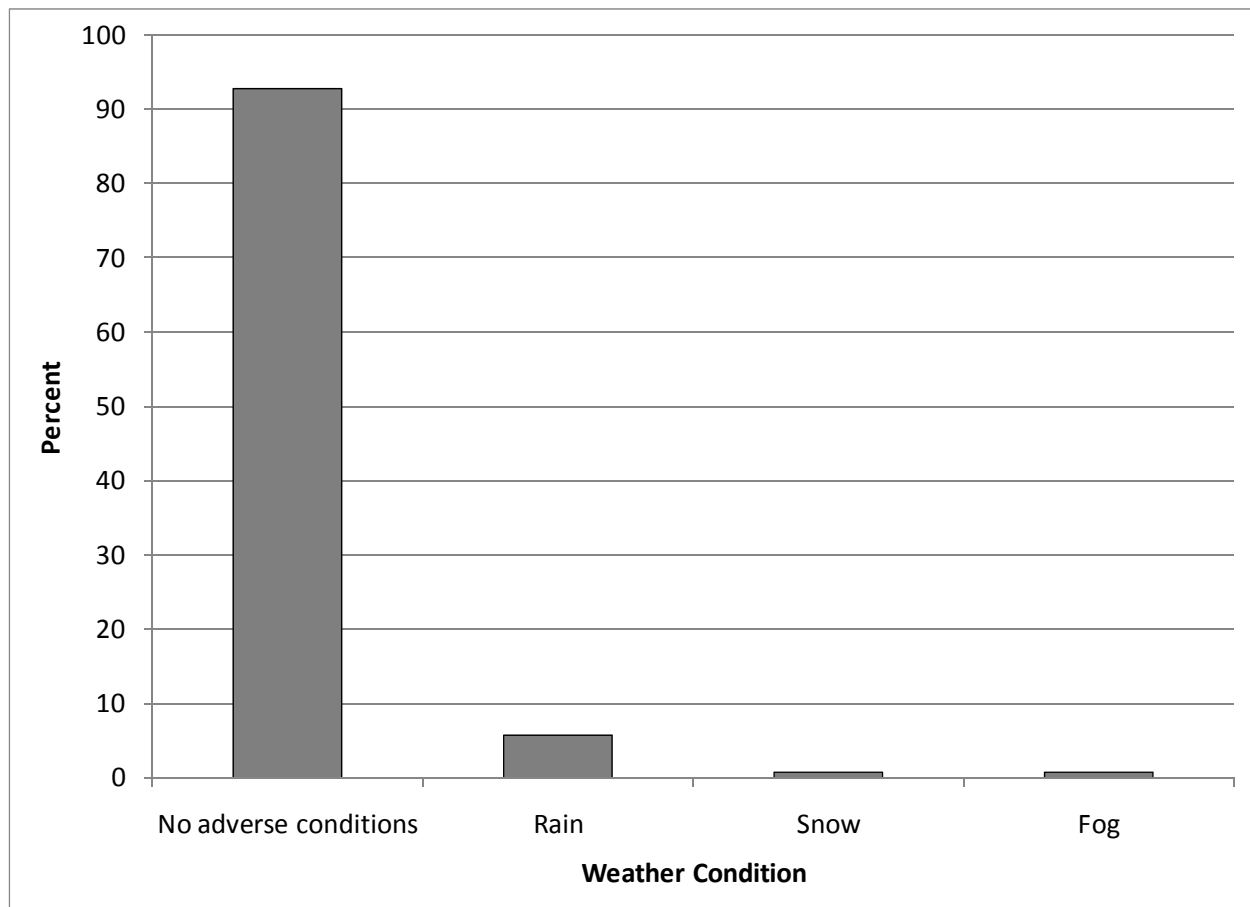


Figure 110. SCEs by Weather Condition

Roadway Surface

Figure 111 presents the percentage of SCEs that occurred for the recorded roadway surface conditions. The majority of the recorded SCEs occurred when the roads were dry. Ten percent of the SCEs occurred when the roads were wet.

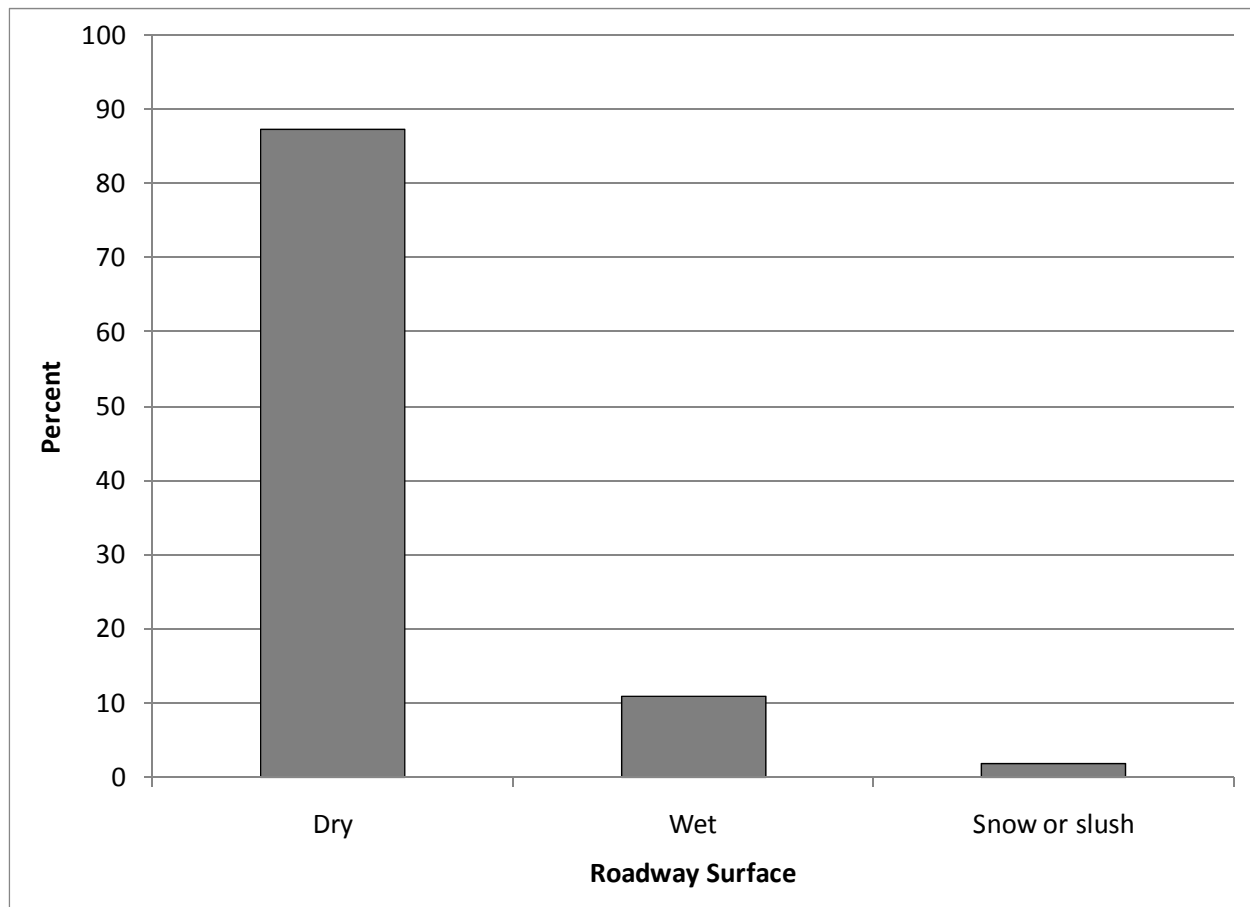


Figure 111. SCEs by Roadway Surface

Roadway Junction

Figure 112 shows the percentage of SCEs that were occurred in the vicinity of various roadway junctions. It can be seen that 45 percent of the SCEs occurred on a non-junction arterial, while 40 percent occurred within, or close to, an intersection.

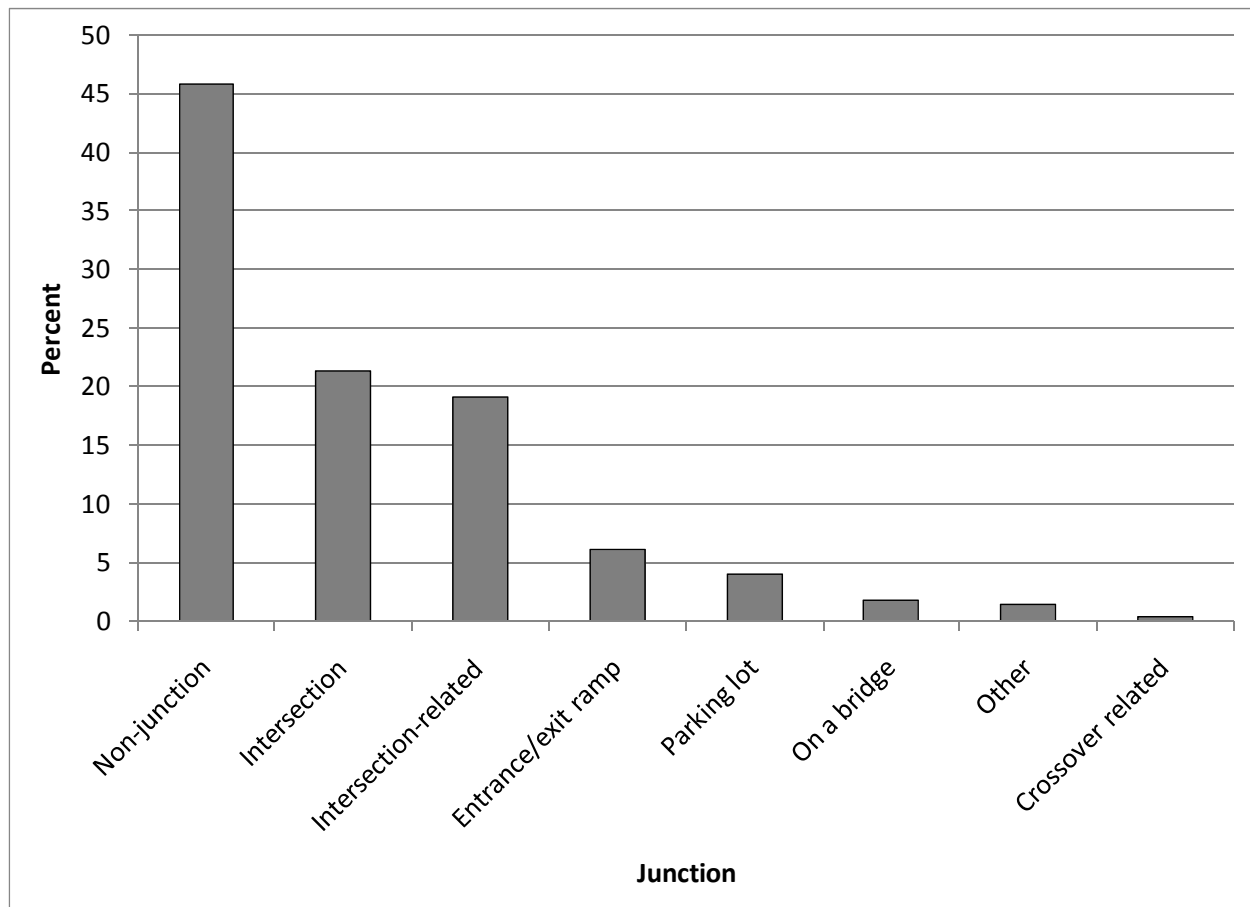


Figure 112. SCEs by Junction

Traffic Density

Figure 113 shows the percentage of SCEs that occurred in the various levels of service (LOS) that traffic engineers use to qualify the traffic density on the roadway (Appendix X presents a description of the various LOS). It can be seen that the majority of the SCEs occurred with a traffic density equal to LOS A, which is indicative of free flow conditions, and LOS B, which is indicative of stable traffic flow in the presence of other vehicles.

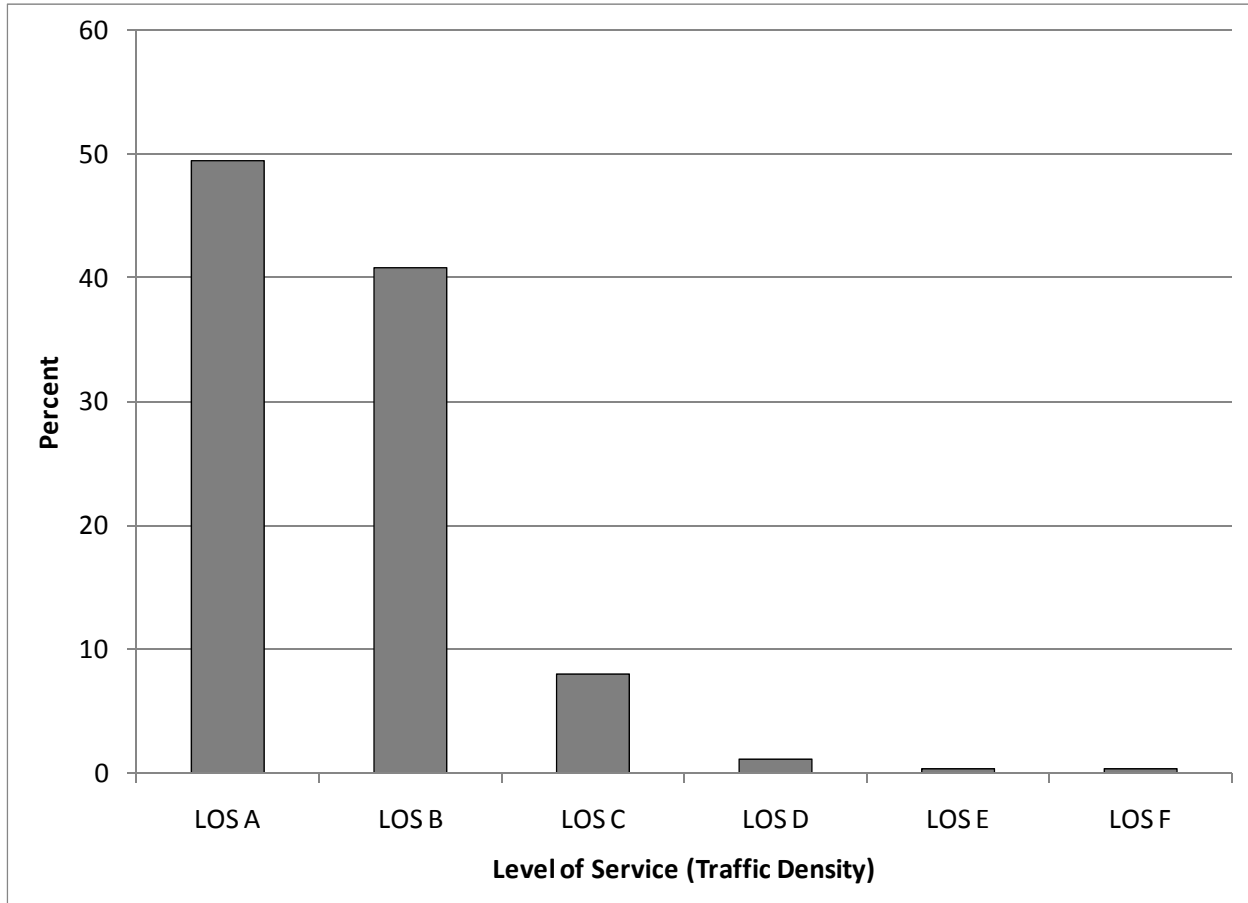


Figure 113. SCEs by Level of Service

Roadway Alignment

Figure 114 shows the percentage of SCEs that occurred on straight and curved roads. It can be seen that 70 percent of the SCEs occurred on straight roads, while 20 percent occurred when the road curved to the left.

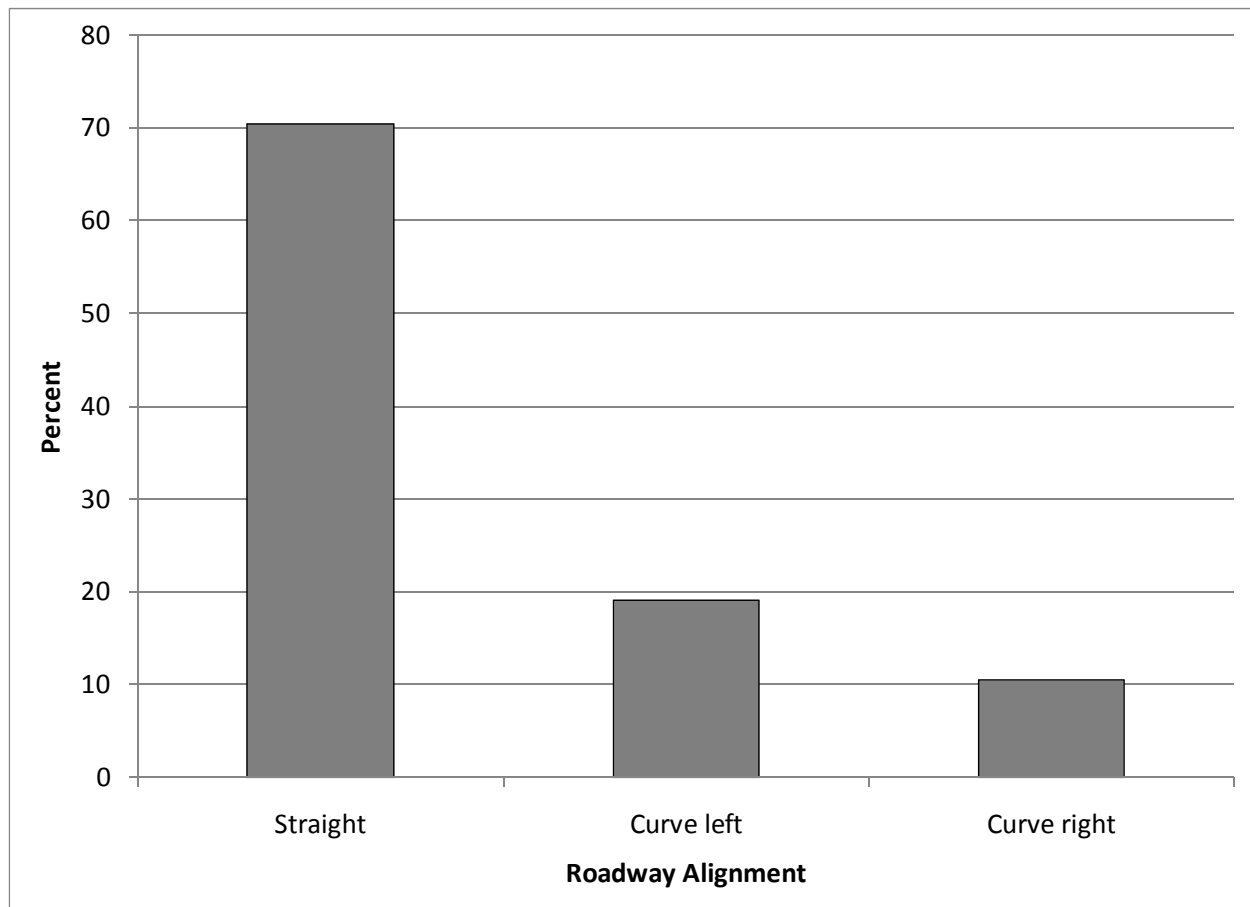


Figure 114. SCEs by Roadway Alignment

Time of Day

Figure 115 shows the percentage of SCEs that occurred in each hour of the day. Recall that participants' shifts began as early as 4 p.m. and as late as 1 a.m. Participants' shifts ended as early as 3:30 a.m. and as late as 11 a.m. It can be seen that the majority of the SCEs occurred between 11 p.m. and 3 a.m.

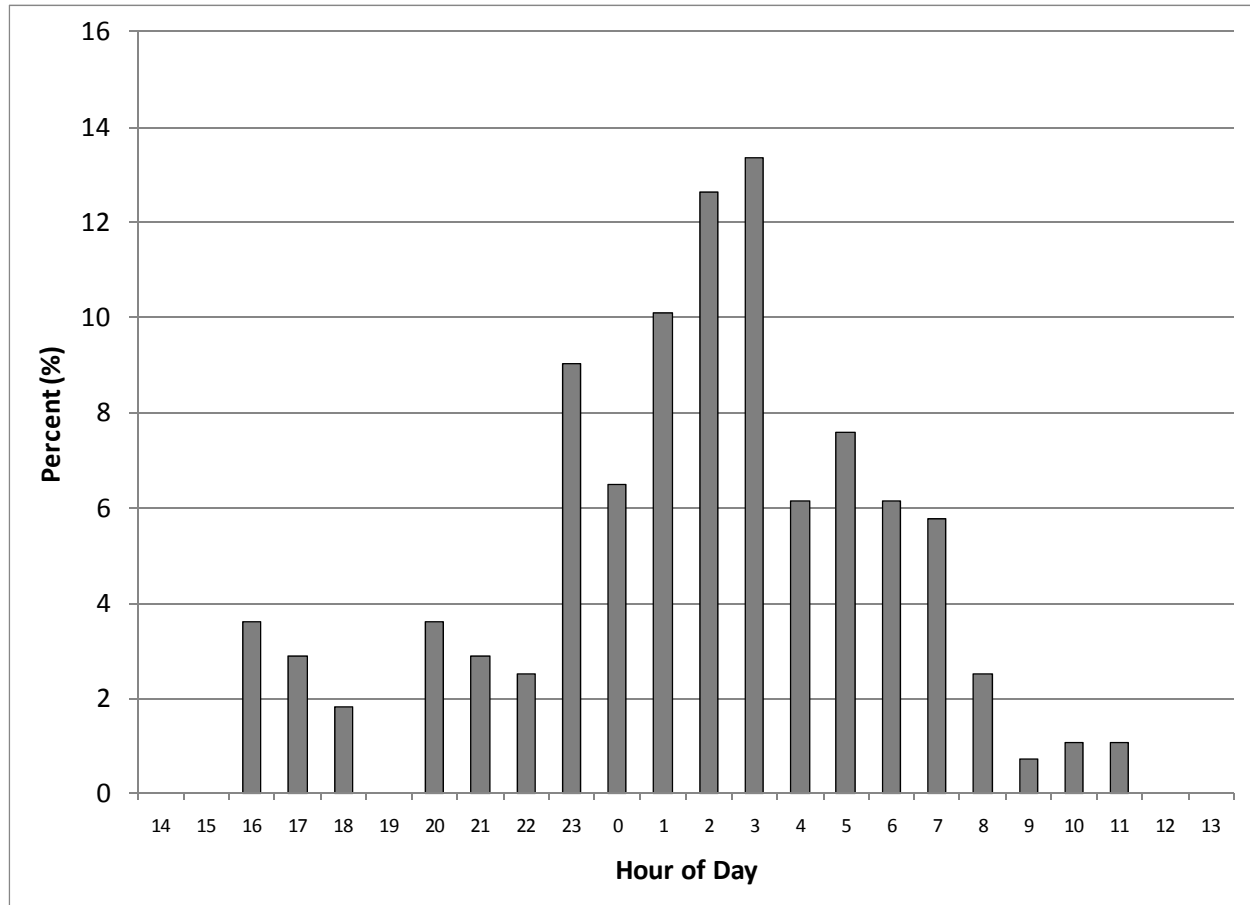


Figure 115. SCEs by Hour of Day

Table 27 shows the SCEs that occurred at each hour of the day by their severity. It can be seen that the majority of the SCEs were recorded between 11 p.m. and 8 a.m.

Table 27. SCE Severity by Hour of Occurrence

Hour	Crash	Curb Strike: Unavoidable	Curb Strike: Avoidable	Near Crash	Crash-Relevant Conflict	Illegal Maneuver	Total Row %
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.4	3.3	0.0	3.6
17	0.0	0.0	0.0	0.0	2.9	0.0	2.9
18	0.0	0.0	0.0	0.4	1.4	0.0	1.8
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	3.6	0.0	3.6
21	0.4	0.0	0.4	0.0	2.2	0.0	2.9
22	0.0	0.0	0.0	0.4	2.2	0.0	2.5
23	0.0	0.4	0.0	0.7	7.9	0.0	9.0
0	0.0	0.7	0.4	0.0	5.4	0.0	6.5
1	0.7	0.4	3.3	0.4	5.4	0.0	10.1
2	0.4	0.7	4.0	0.4	6.9	0.4	12.6
3	0.0	0.4	6.5	0.0	6.5	0.0	13.4
4	0.0	0.4	0.7	0.4	4.7	0.0	6.1
5	0.4	0.0	0.7	0.4	6.1	0.0	7.6
6	0.0	0.0	0.7	0.0	5.4	0.0	6.1
7	0.4	0.0	0.4	0.4	4.7	0.0	5.8
8	0.0	0.0	0.4	0.0	2.2	0.0	2.5
9	0.0	0.0	0.0	0.7	0.0	0.0	0.7
10	0.0	0.0	0.4	0.0	0.7	0.0	1.1
11	0.0	0.0	0.0	0.0	1.1	0.0	1.1
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Count	6	8	49	12	201	1	277
Total Column %	2.2	2.9	17.7	4.3	72.6	0.4	100.0

Seat Belt Compliance

Because the DAS emitted IR light to illuminate the driver's face at night, a reflective material was sewn onto the seat belt of the SV so that reductionists could identify when the driver was

wearing a seat belt during an SCE. It was found that drivers wore their seat belt during 69 percent of the 277 SCEs.

Analysis of Drivers' Safety-Critical Event Rate

Drivers' involvement in SCEs was used to assess how well drivers operated a CMV. The hypothesis here was that a C/VIS may allow drivers to monitor the areas around the tractor-trailer and reduce the number, and/or duration, of the glances to the existing mirror system. Since drivers looking at the monitors do not have to turn their head as far as they do when looking at the west coast mirrors, it was hypothesized that drivers using a C/VIS would spend more time looking at the forward roadway, be less likely to miss an unfolding conflict, and experience fewer SCEs. To properly account for drivers' exposure to the C/VIS when investigating their involvement in SCEs, an SCE rate was computed. Blanco et al. (2009) operationally defined the SCE rate as drivers' involvement in SCEs per 100 hours of driving. This definition was adopted by the TFD. The results of drivers' SCE rates are presented below.

A 2 (C/VIS) x 2 (Condition) Mixed Factors ANOVA was performed on the SCE rate dependent variable. The drivers' mean SCE rate of 5.2 in the Baseline condition (SE = 1.0, $n = 12$, min = 0.0, max = 10.7) was not found to be significantly different from their SCE rate of 5.2 in the Test condition (SE = 0.7, $n = 12$, min = 1.9, max = 8.9) ($F(1, 10) = 0.0$, $p = 0.9806$) (Figure 116).

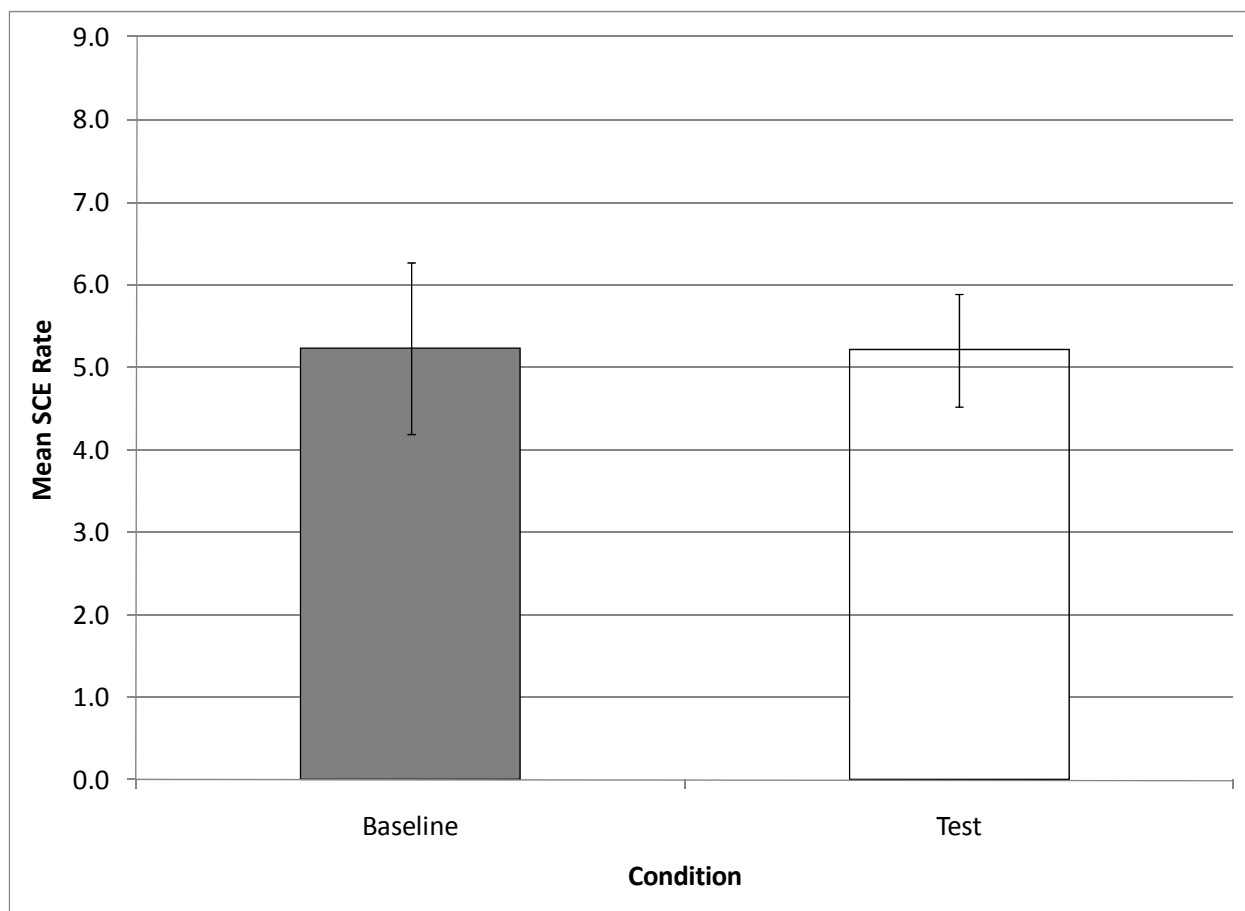


Figure 116. Drivers' Mean SCE Rates by Experimental Condition

To investigate whether the mean SCE rates for the drivers of the A-C/VIS-equipped and commercial C/VIS-equipped trucks changed when driving with a C/VIS, a C/VIS x Condition interaction was investigated but was not found ($F(1, 10) = 0.04, p = 0.8389$). The mean SCE rate for the drivers of the A-C/VIS-equipped trucks was 5.9 in the Baseline condition ($SE = 1.3, n = 6, \min = 1.9, \max = 9.2$) and 5.7 in the Test condition ($SE = 1.0, n = 6, \min = 2.2, \max = 8.9$) (Figure 117). The mean SCE rate for the drivers of the commercial C/VIS-equipped trucks was 4.5 in the Baseline condition ($SE = 1.7, n = 6, \min = 0.0, \max = 10.7$) and 4.7 in the Test condition ($SE = 1.0, n = 6, \min = 1.9, \max = 8.5$). The results indicate that the mean SCE rates for the drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks did not change significantly when driving with a C/VIS. Furthermore, the mean SCE rate exhibited by the drivers using the A-C/VIS was not significantly different from the mean SCE rate exhibited by the drivers using the commercially available C/VIS system.

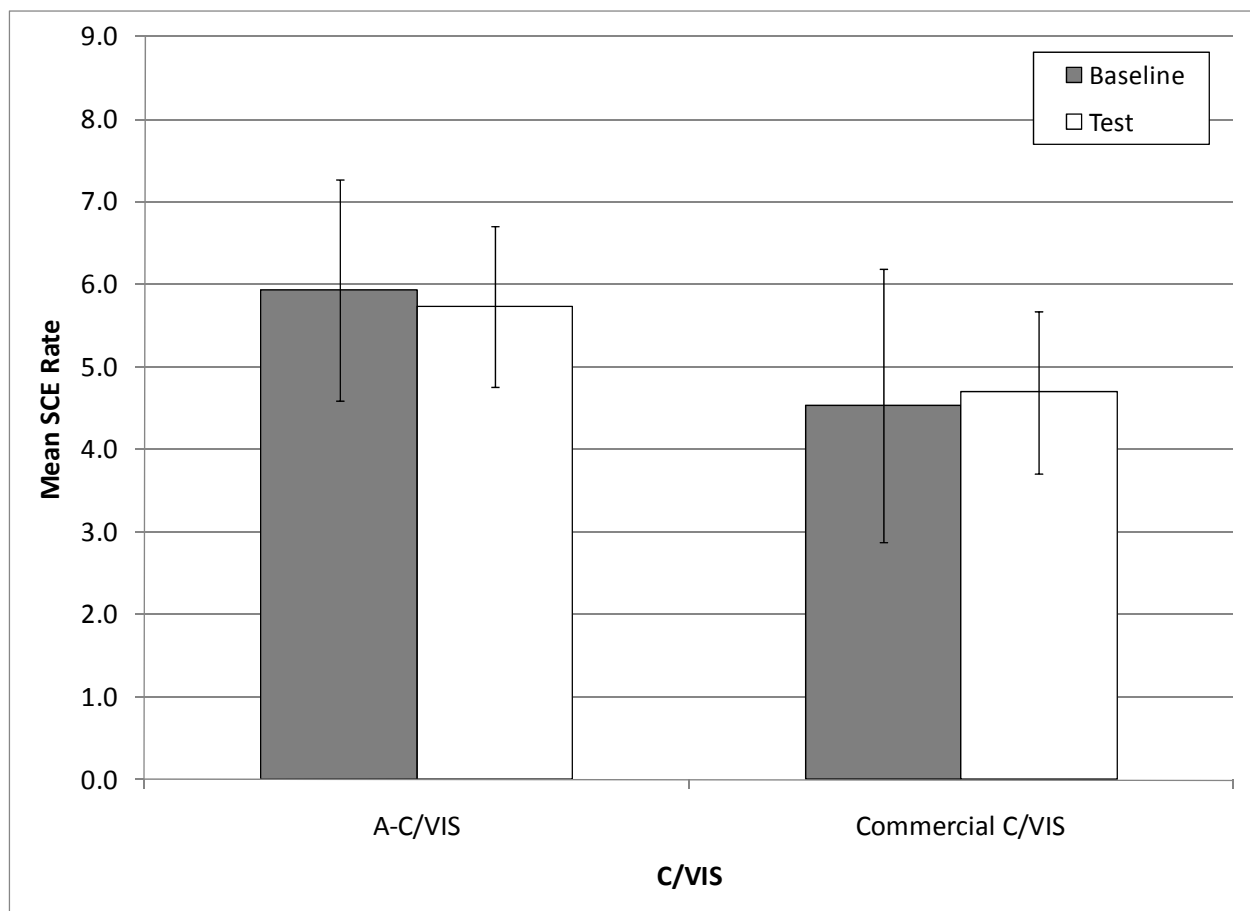


Figure 117. Drivers' Mean SCE Rates by C/VIS and Experimental Condition

Figure 118 shows the drivers' mean SCE rates for each month that they were in the study. A One-Way Repeated Measures ANOVA was performed on the SCE rate dependent variable using Month as the independent variable. A significant main effect was not found ($F(3, 32) = 0.02, p = 0.997$). The drivers' mean SCE rate in Month 1 (which encompassed the Baseline condition) was 5.2 ($SE = 1.0, n = 12, \min = 0.0, \max = 10.7$), in Month 2 it was 5.1 ($SE = 0.8, n = 12, \min = 0.0, \max = 9.7$), in Month 3 it was 5.3 ($SE = 1.1, n = 12, \min = 0.9, \max = 11.4$), and in Month 4 it

was 5.5 (SE = 1.1, n = 11, min = 0.8, max = 13.6). The Test condition encompassed Months 2, 3, and 4.

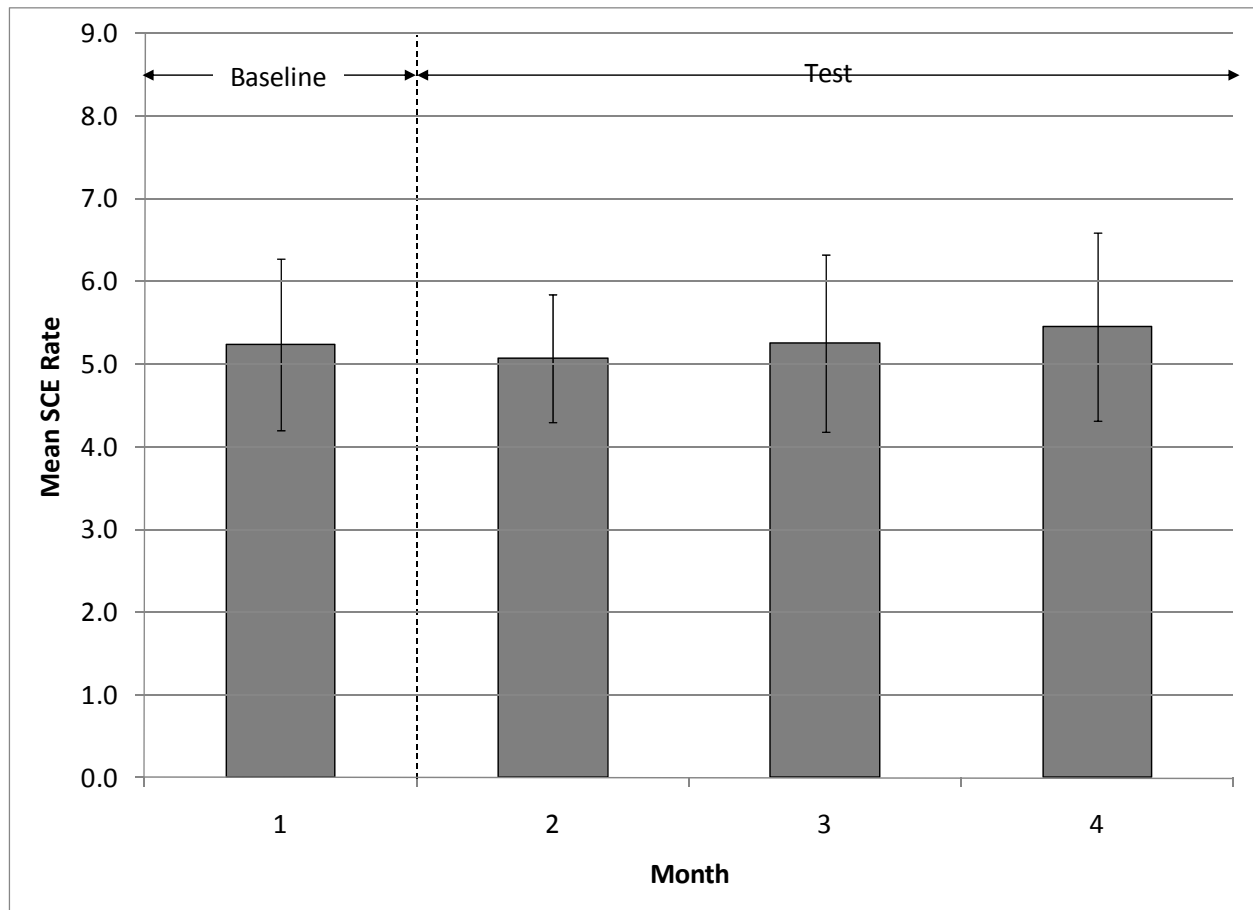


Figure 118. Drivers' Mean SCE Rates by Month in Study

Because the overall SCE rate comprises SCEs of various severity levels, an analysis was performed to determine whether the severity of the SCEs changed over the course of the study. The hypothesis here is that if a C/VIS does not reduce the occurrence of SCEs, then perhaps it may reduce the severity of the SCEs. Figure 119 shows drivers' mean SCE rates by month in study and SCE severity. A 4 (Month) x 6 (Severity) Mixed Factors ANOVA was performed on the SCE rate dependent variable. A Month x Severity interaction was not found ($F(15, 258) = 0.25, p = 0.9983$). Drivers' involvement in crashes, near-crashes, avoidable curb strikes, unavoidable curb strikes, crash-relevant conflicts, and illegal maneuvers did not significantly change across the four months in the study. Because the rate of near-crash SCEs appears to have decreased over the course of the four months, a one-way repeated measures ANOVA was performed on the near-crash SCE rate dependent variable using the Month in Study independent variable. The mean near-crash SCE rate was not found to significantly change by month in the study ($F(3, 43) = 1.72, p = 0.1777$).

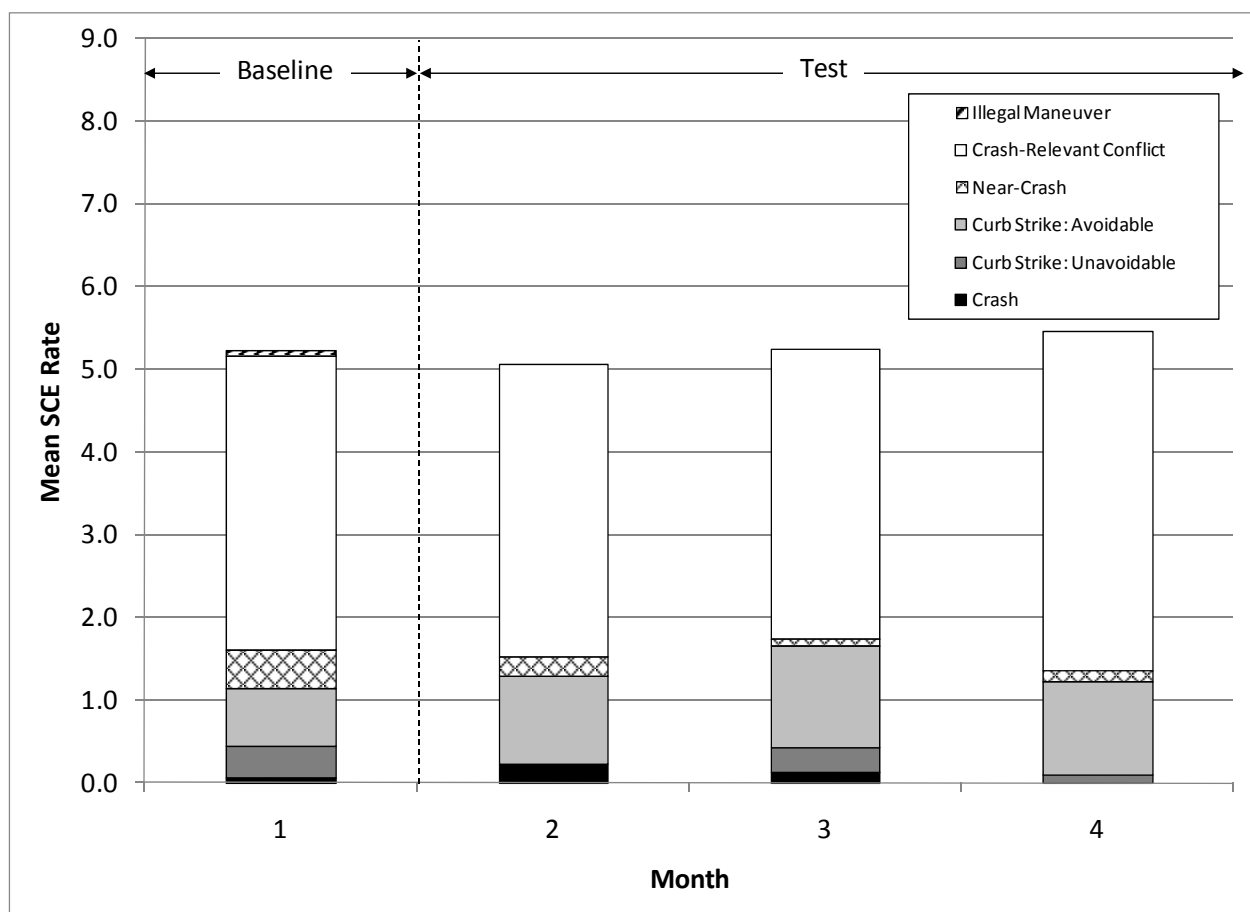


Figure 119. Drivers' Mean SCE Rates by Month in Study and SCE Severity

Because SCEs can occur due to the fault of the SV driver, or due to another vehicle driver, an animal, or inanimate objects appearing unexpectedly in the road, further analysis of the mean SCE rate was performed. Figure 120 shows drivers' mean SCE rates by month in study and fault assignment. The drivers' mean SCE rate for SCEs that were their fault was 1.9 in Month 1 (SE = 0.7, n = 12, Min = 0.0, Max = 6.9), 2.4 in Month 2 (SE = 0.7, n = 12, Min = 0.0, Max = 6.8), 2.0 in Month 3 (SE = 0.5, n = 12, Min = 0.0, Max = 4.4), and 2.5 in Month 4 (SE = 0.8, n = 11, Min = 0.0, Max = 7.4). A 4 (Month) x 3 (Fault) Mixed Factors ANOVA was performed and a Month x Fault interaction was not found ($F(6, 96) = 0.44, p = 0.849$). Drivers' involvement in at-fault SCEs did not significantly change across the four months in the study.

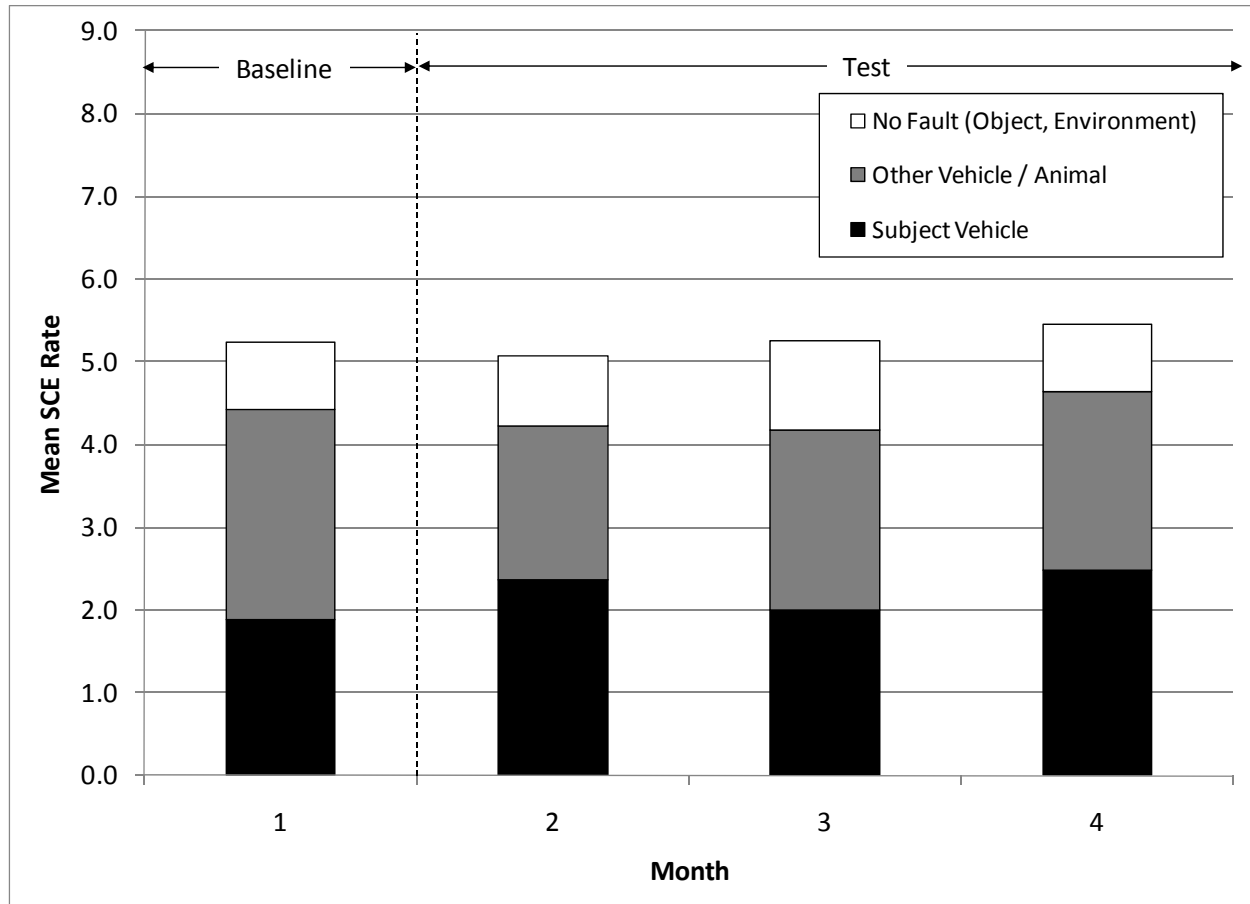


Figure 120. Drivers' Mean SCE Rates by Month in Study and Fault Assignment

Figure 121 shows the mean SCE rates for drivers in the A-C/VIS-equipped and commercial C/VIS-equipped trucks for each month that they were in the study. With regard to participants driving A-C/VIS-equipped trucks, their mean SCE rate in Month 1 was 5.9 (SE = 1.3, $n = 6$, min = 1.9, max = 9.2), in Month 2 it was 5.1 (SE = 0.2, $n = 6$, min = 4.4, max = 6.2), in Month 3 it was 6.0 (SE = 1.7, $n = 6$, min = 1.6, max = 11.4), and in Month 4 it was 6.3 (SE = 2.3, $n = 5$, min = 0.8, max = 13.6). With regard to participants driving trucks with the commercially available C/VIS, their mean SCE rate in Month 1 was 4.5 (SE = 1.7, $n = 6$, min = 0.0, max = 10.7), in Month 2 it was 5.0 (SE = 1.6, $n = 6$, min = 0.0, max = 9.7), in Month 3 it was 4.5 (SE = 1.4, $n = 6$, min = 0.9, max = 8.3), and in Month 4 it was 4.8 (SE = 1.0, $n = 6$, min = 2.0, max = 8.3). A 4 (Month) $\times$ 2 (C/VIS) Mixed Factors ANOVA was performed and a Month $\times$ C/VIS interaction was not found ($F(3, 29) = 0.13$, $p = 0.9395$). The mean SCE rates for the drivers of A-C/VIS-equipped trucks and commercial C/VIS-equipped trucks did not significantly change across the month in the study. Furthermore, the mean SCE rate of drivers using the A-C/VIS was not significantly different from the mean SCE rate of drivers using the commercially available C/VIS.

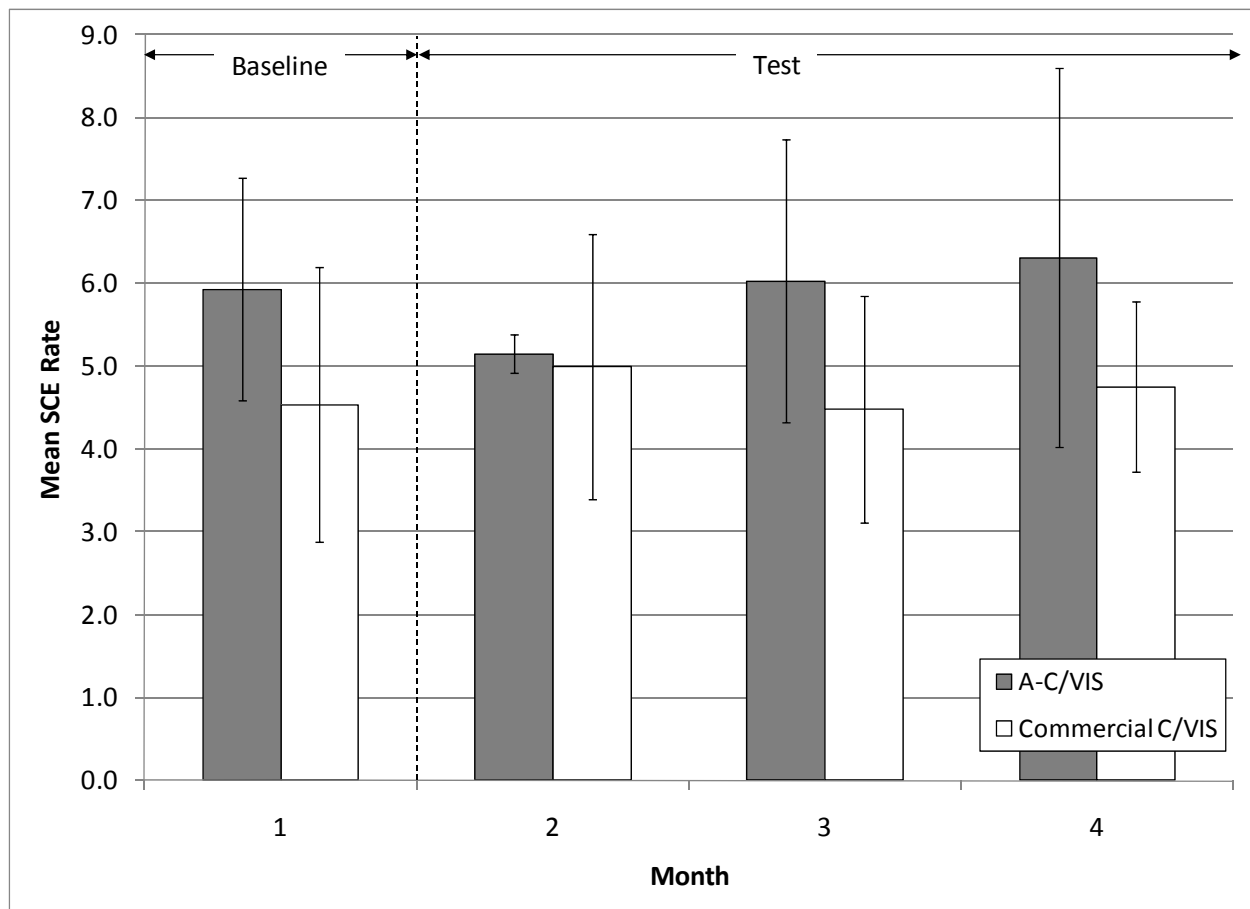


Figure 121. Drivers' Mean SCE Rates by Month in Study and Type of C/VIS

Figure 122 provides additional insight by showing each driver's SCE rate for each month in the study. Solid black lines delineate the SCE rates for drivers of A-C/VIS-equipped trucks, while dashed black lines delineate the SCE rates for drivers of commercial C/VIS-equipped trucks. The SCE rates varied tremendously by driver. For example, Driver 3, who drove an A-C/VIS-equipped truck, experienced more SCEs than Driver 7, who drove a commercial C/VIS-equipped truck and experienced no SCEs in Months 1 and 2 of the study.

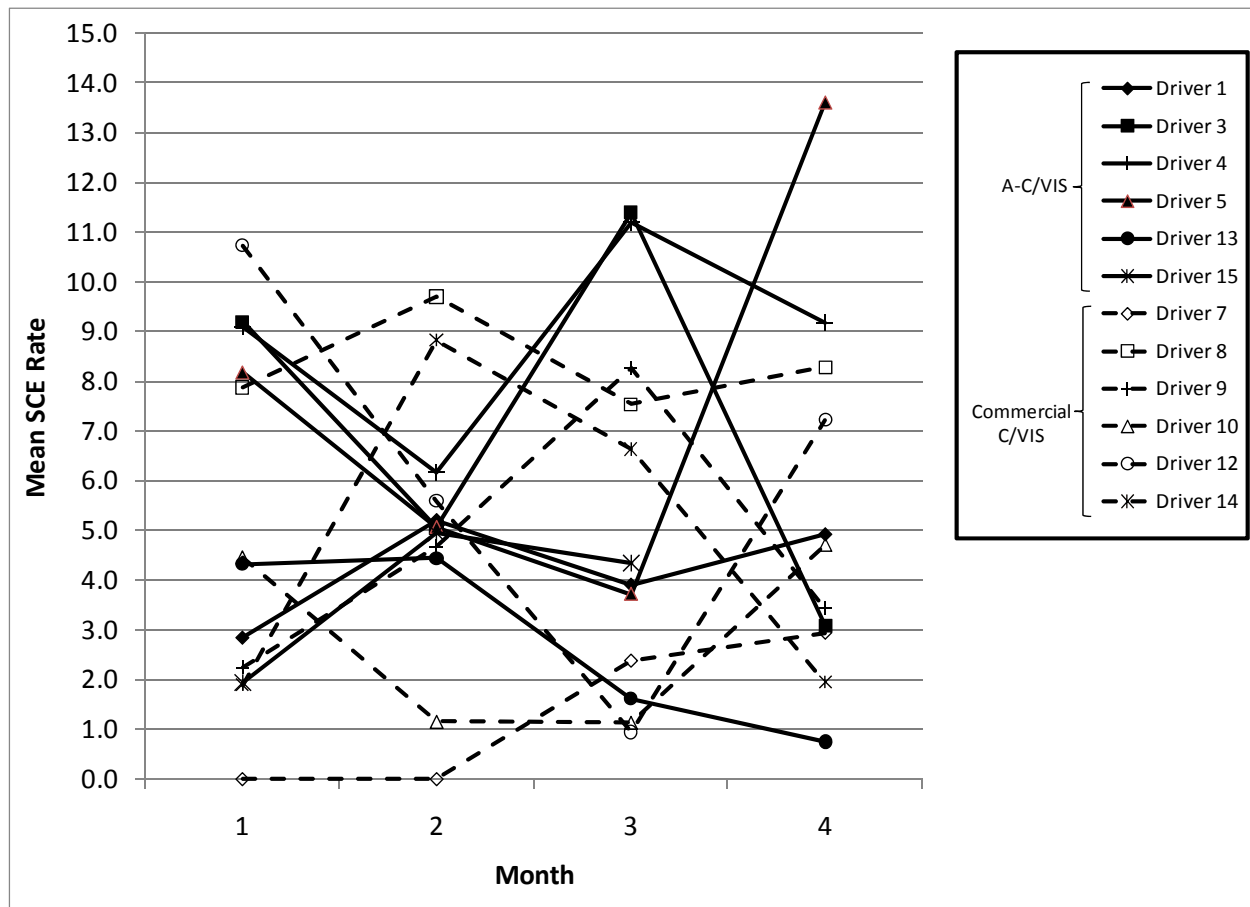


Figure 122. Each Driver's Mean SCE Rate by Month in Study

Figure 123 shows each driver's SCE rate for just the SCEs that were their fault across the month in the study. Again, solid black lines delineate the SCE rates for drivers of A-C/VIS-equipped trucks, while dashed black lines delineate the SCE rates for drivers of commercial C/VIS-equipped trucks. Again, it can be seen that some drivers experienced more SCEs than others over the course of the study. For instance, Driver 1, who drove an A-C/VIS-equipped truck, did not instigate any SCEs, while Driver 8, who drove a commercial C/VIS-equipped truck, instigated seven SCEs per 100 hours of driving in Months 1, 2, and 4.

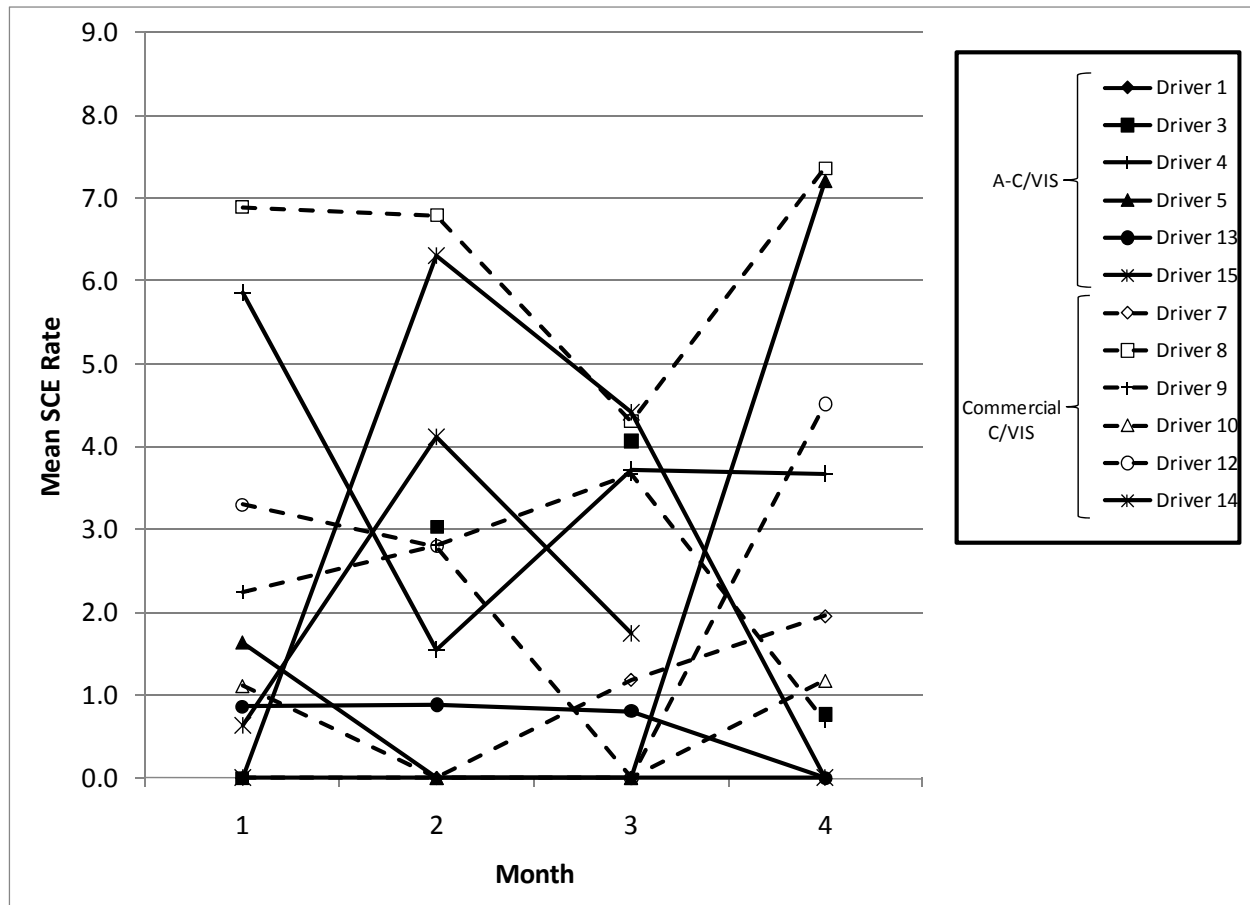


Figure 123. Each Drivers' Mean SCE Rate for SCEs that were their Fault, by Month in Study

Driver Visual Behavior Prior to Safety-Critical Events

Drivers' eye glance patterns prior to experiencing an SCE were investigated to determine whether their visual behavior changed when driving with a C/VIS. Recall that it was hypothesized that a C/VIS may allow drivers to monitor the areas around the tractor-trailer with fewer and shorter eye glances to the west coast mirrors and allow them to spend more time looking at the forward roadway. The analyses presented below are based on the eye glance patterns observed during the 8 s prior to experiencing an SCE. Eye glance reductions were possible on 265 of the 277 SCEs that were identified. Visual behavior during some SCEs could not be identified because the drivers' eyes were obscured (e.g., he was wearing sunglasses).

Eye Glance Probabilities

Figure 124 shows the mean probability that drivers looked in a specific location during the 8 seconds prior to an SCE in the Baseline and Test conditions. Drivers' mean probability of looking forward was 0.86 in the Baseline condition (SE = 0.03, n = 65, Min = 0.10, Max = 1.0) and 0.87 in the Test condition (SE = 0.01, n = 200, Min = 0.10, Max = 1.00). In performing a 2 (C/VIS) x 2 (Condition) Mixed Factors ANOVA on the forward location eye glance probability, these mean probabilities were not found to be significantly different ($F(1, 9) = 0.0, p = 0.9697$)².

The drivers' mean probability of looking at the left west coast/convex mirror of 0.05 in the Baseline condition (SE = 0.02, n = 65, Min = 0.00, Max = 0.58) was not found to be significantly different from their mean probability of looking at the left west coast/convex mirror of 0.04 in the Test condition (SE = 0.01, n = 200, Min = 0.00, Max = 0.64) ($F(1, 9) = 0.11, p = 0.7519$). The drivers' mean probability of looking at the right west coast/convex mirror of 0.02 in the Baseline condition (SE = 0.01, n = 65, Min = 0.00, Max = 0.28) was not found to be significantly different from their mean probability of looking at the right west coast/convex mirror of 0.02 in the Test condition (SE = 0.00, n = 200, Min = 0.00, Max = 0.59) ($F(1, 9) = 0.29, p = 0.6009$). The drivers' mean probability of looking at the right fender mirror of 0.01 in the Baseline condition (SE = 0.01, n = 65, Min = 0.00, Max = 0.22) was not found to be significantly different from their mean probability of looking at the right fender mirror of 0.00 in the Test condition (SE = 0.00, n = 200, Min = 0.00, Max = 0.25) ($F(1, 9) = 1.11, p = 0.3186$). In general, drivers did not decrease their likelihood of looking forward when driving with a C/VIS. The data indicate that the drivers' visual attention was not diverted from the forward roadway when driving with a C/VIS.

When driving with a C/VIS, drivers' mean probability of looking at the left monitor was 0.0014 and their mean probability of looking at the right monitor was 0.0023. These eye glance probabilities were computed using just the data from the Test condition. Furthermore, the drivers' mean probability of looking at the center monitor was 0.0023. This eye glance probability was computed using just the data from the A-C/VIS Test condition. The data indicate that drivers did not spend a large portion of time looking directly at the monitors during the 8 s prior to an SCE. It should be noted, however, that the analysis of drivers' eye glance patterns assumes that each eye glance location is independent (i.e., drivers only look at one location at a time). However, because the C/VIS monitors were positioned around the windshield, it may have been possible that drivers looked at them using their peripheral vision. The analysis of drivers' opinion data presented at the end of this chapter indicates that some drivers used the monitors in this fashion.

² The degrees of freedom associated with the denominator used to compute the F statistic have a value of 9 instead of an expected value of 10 [$2(2-1)(6-1) = 10$] because Driver 7 did not have any SCEs in his baseline condition. As a result, the Satterthwaite approximation was used in the analysis of variance performed on the unbalanced data, which adjusted the degrees of freedom to 9.

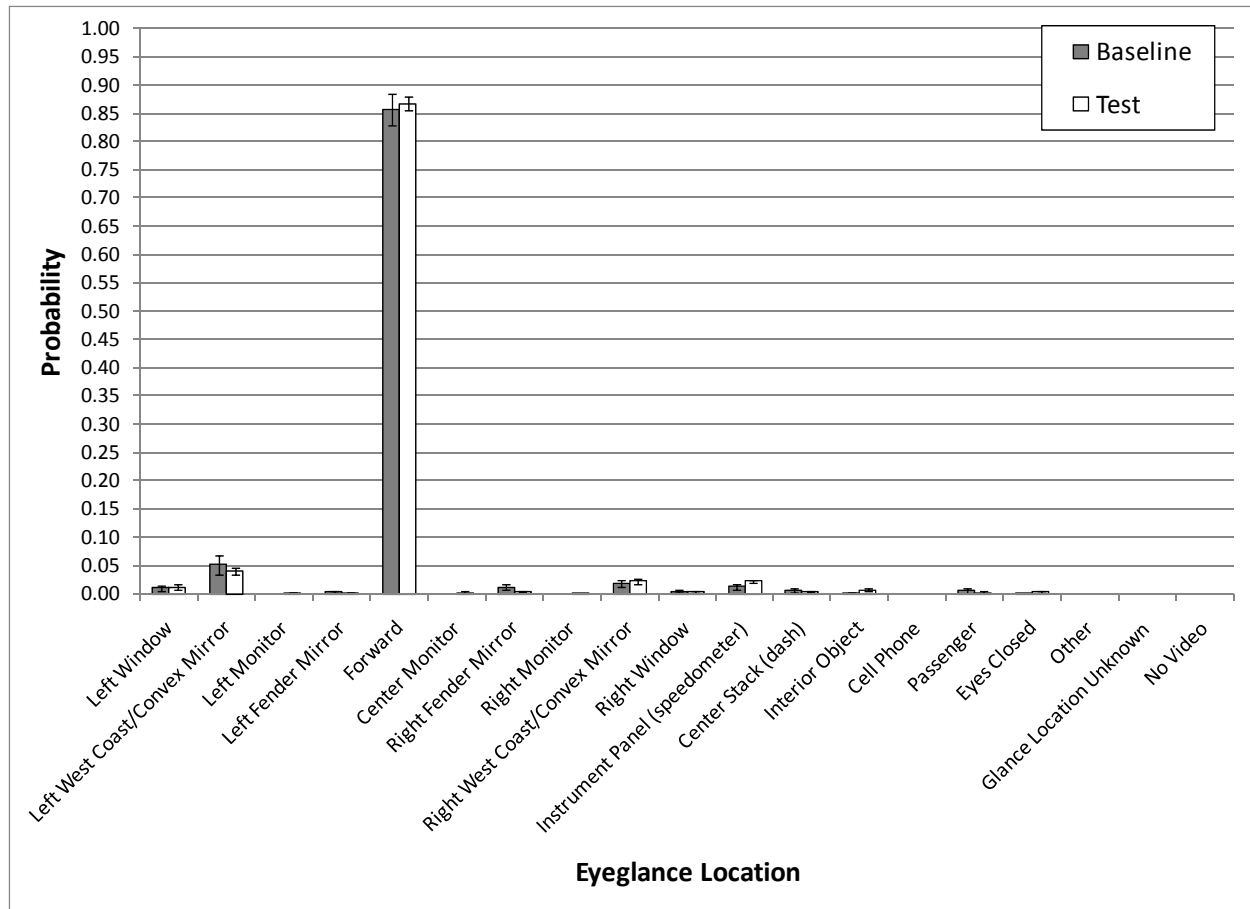


Figure 124. Mean Probability that Drivers Looked in a Location in the 8 s Prior to Experiencing an SCE by Experimental Condition

Figure 125 shows the mean probability that drivers of A-C/VIS-equipped trucks and commercial C/VIS-equipped trucks looked in a specific location by Experimental Condition. The mean probability of looking forward for drivers of A-C/VIS-equipped trucks was 0.88 in the Baseline condition (SE = 0.04, $n = 38$, Min = 0.15, Max = 1.00) and 0.88 in the Test condition (SE = 0.02, $n = 120$, Min = 0.00, Max = 1.00). The mean probability of looking forward for drivers of commercial C/VIS-equipped trucks was 0.82 in the Baseline condition (SE = 0.04, $n = 27$, Min = 0.10, Max = 1.00) and 0.85 in the Test condition (SE = 0.02, $n = 80$, Min = 0.14, Max = 1.00). In exploring a C/VIS x Condition interaction, these mean eye glance probabilities were not found to be significantly different ($F(1, 9) = 0.04$, $p = 0.8521$).

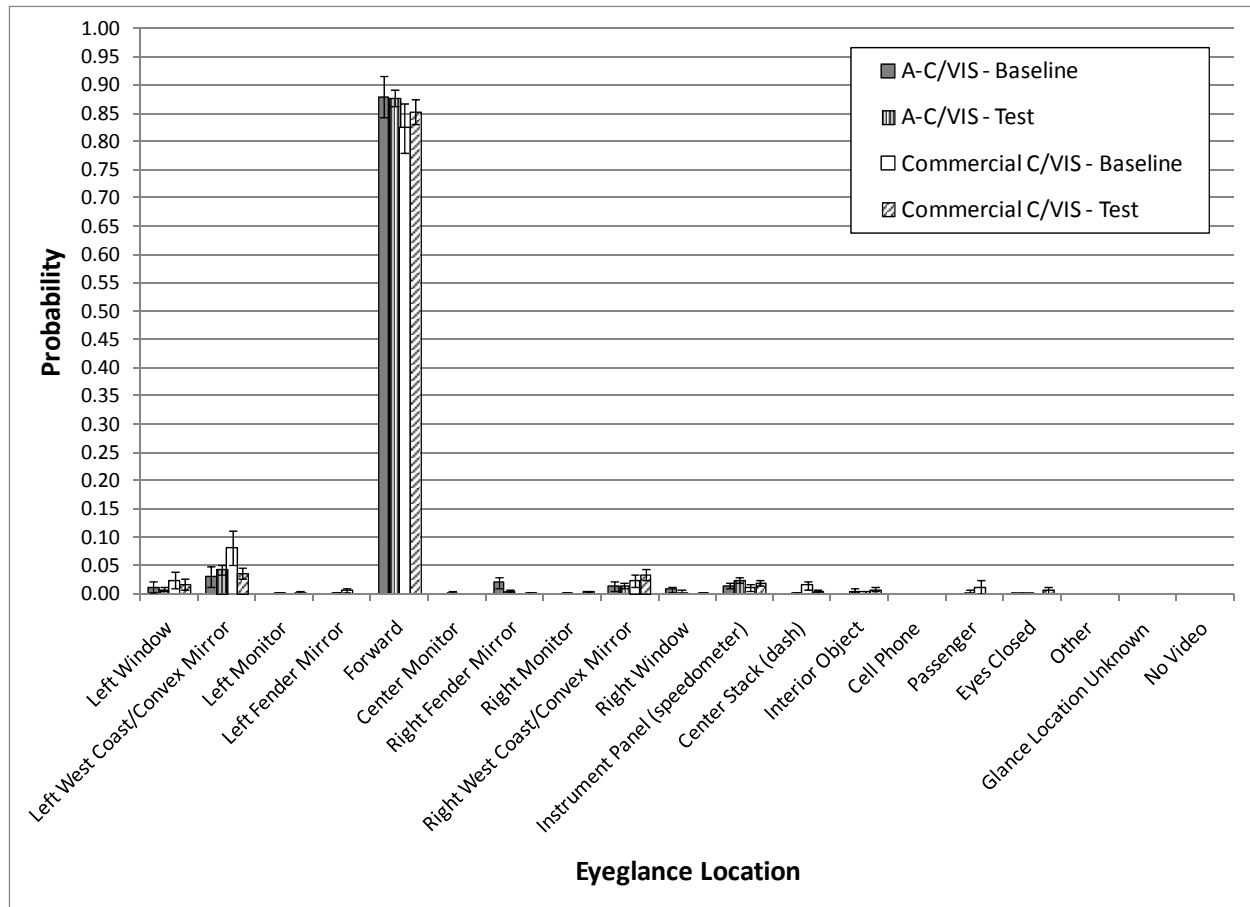


Figure 125. Mean Probability that Drivers Looked in a Location in the 8 s Prior to Experiencing an SCE Location by Experimental Condition and C/VIS

The mean probability of looking at the left west coast/convex mirror for drivers of A-C/VIS-equipped trucks was 0.03 in the Baseline condition (SE = 0.02, $n = 38$, Min = 0.00, Max = 0.52) and 0.04 in the Test condition (SE = 0.01, $n = 120$, Min = 0.00, Max = 0.64). The mean probability of looking at the left west coast/convex mirror for drivers of commercial C/VIS-equipped trucks was 0.08 in the Baseline condition (SE = 0.03, $n = 27$, Min = 0.00, Max = 0.58) and 0.04 in the Test condition (SE = 0.01, $n = 80$, Min = 0.00, Max = 0.46). In exploring a C/VIS x Condition interaction, these mean eye glance probabilities were not found to be significantly different ($F(1, 9) = 0.09$, $p = 0.7703$).

The mean probability of looking at the right west coast/convex mirror for drivers of A-C/VIS-equipped trucks was 0.01 in the Baseline condition (SE = 0.01, $n = 38$, Min = 0.00, Max = 0.28) and 0.01 in the Test condition (SE = 0.00, $n = 120$, Min = 0.00, Max = 0.32). The mean probability of looking at the right west coast/convex mirror for drivers of commercial C/VIS-equipped trucks was 0.02 in the Baseline condition (SE = 0.01, $n = 27$, Min = 0.00, Max = 0.19) and 0.03 in the Test condition (SE = 0.01, $n = 80$, Min = 0.00, Max = 0.59). In exploring a C/VIS x Condition interaction, these mean eye glance probabilities were not found to be significantly different ($F(1, 9) = 1.54$, $p = 0.2456$).

The mean probability of looking at the right fender mirror for drivers of A-C/VIS-equipped trucks was 0.02 in the Baseline condition (SE = 0.01, n = 38, Min = 0.00, Max = 0.22) and 0.00 in the Test condition (SE = 0.00, n = 120, Min = 0.00, Max = 0.25). The mean probability of looking at the right fender mirror for drivers of commercial C/VIS-equipped trucks was 0.00 in the Baseline condition (SE = 0.00, n = 27, Min = 0.00, Max = 0.00) and 0.00 in the Test condition (SE = 0.00, n = 80, Min = 0.00, Max = 0.09). In exploring a C/VIS x Condition interaction, these mean eye glance probabilities were not found to be significantly different ($F(1, 9) = 1.38, p = 0.2697$).

The mean probability that drivers of A-C/VIS-equipped trucks looked at the left monitor was 0.002 (SE = 0.00, n = 120, Min = 0.00, Max = 0.09), while the mean probability that drivers of commercial C/VIS-equipped trucks looked at the left monitor was 0.002 (SE = 0.00, n = 80, Min = 0.00, Max = 0.15). A One Way ANOVA did not find these means to be significantly different ($F(1, 10) = 1.87, p = 0.2016$). The mean probability that drivers of A-C/VIS-equipped trucks looked at the right monitor was 0.001 (SE = 0.00, n = 120, Min = 0.00, Max = 0.07), while the mean probability that drivers of commercial C/VIS-equipped trucks looked at the right monitor was 0.004 (SE = 0.00, n = 80, Min = 0.00, Max = 0.10). These means were not found to be significantly different ($F(1, 10) = 0.34, p = 0.5743$). The mean probability that drivers of A-C/VIS-equipped trucks looked at the center monitor was 0.002 (SE = 0.04, n = 120, Min = 0.00, Max = 0.27). These data indicate that drivers spent very little time directly looking at the monitors in the 8 s prior to experiencing an SCE.

Percentage of SCEs in which Drivers Looked at Least Once

In further developing an understanding of where drivers looked prior to experiencing an SCE, the number of SCEs in which drivers looked at least once in a given location was counted. For every recorded eye glance location, Figure 126 shows the percentage of SCEs in which drivers looked in that location at least once during the Baseline and Test conditions. Drivers looked forward at least once in all of the SCEs. Drivers looked at the left west coast/convex mirror in 23 percent of the SCEs in the Baseline condition (n = 65) and in 24 percent of the SCEs in the Test condition (n = 200). Drivers looked at the right west coast/convex mirror in 15 percent of the SCEs in the Baseline condition and in 15 percent of the SCEs in the Test condition. Drivers looked at the left and right monitors in 4.5 percent of the SCEs in the Test condition. Drivers of A-C/VIS-equipped trucks looked at the center monitor in 2 percent of the SCEs in the Test condition. Figure 127 shows the percentage of SCEs in which drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks looked in the recorded eye glance locations during the Baseline and Test conditions.

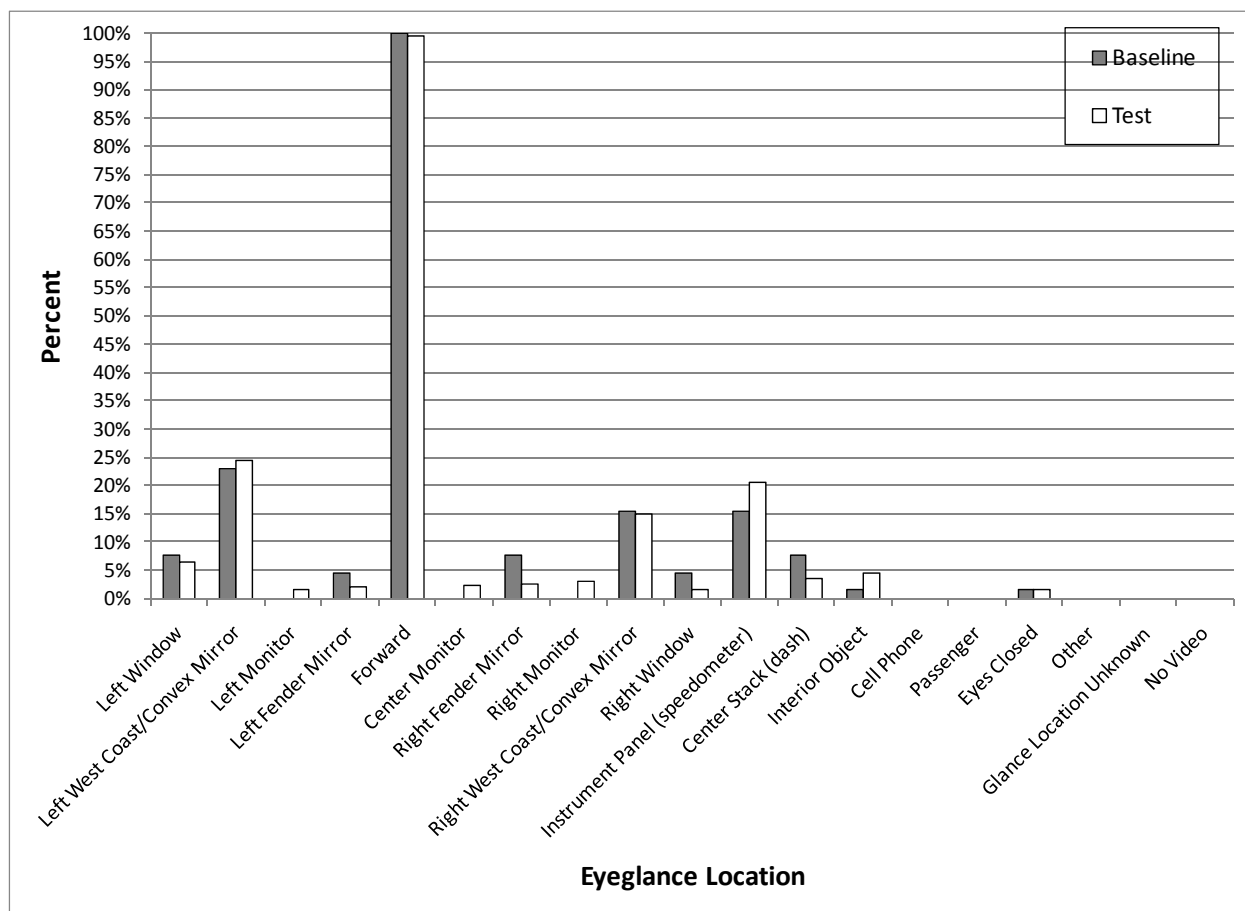


Figure 126. Percentage of SCEs in which Drivers Looked at Least Once to the Recorded Locations by Experimental Condition

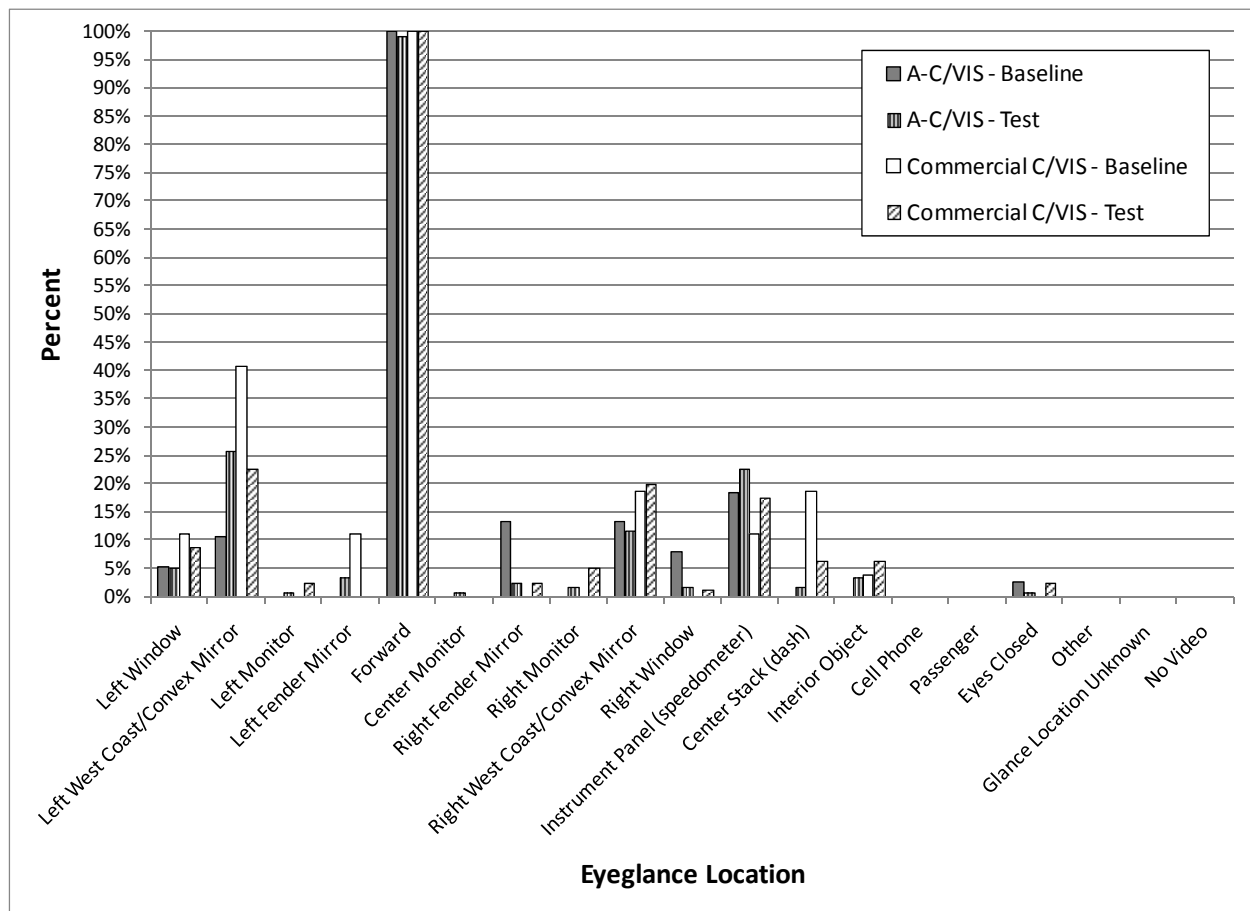


Figure 127. Percentage of SCEs in which Drivers Looked at Least Once at the Recorded Eye Glance Locations

Mean Number of Glances Prior to Experiencing an SCE

The mean number of times drivers looked at a recorded glance location in the 8 s prior to experiencing an SCE is shown in Figure 128 by experimental condition. It is important to clarify here that the mean number of glances to a location is an average of the number of glances made when that location was looked at (i.e., if a glance was not made to a specific location prior to an SCE, a value of zero was not used in computing the average for that location). It can be seen that in the Baseline condition, drivers looked at the forward location, on average, 1.71 times (SE = 0.11, n = 65, Min = 1.00, Max = 4.00), while they looked forward in the Test condition, on average, 1.89 times (SE = 0.07, n = 200, Min = 1.00, Max = 5.00). When considering the SCEs that occurred in the Test condition, the average number of glances made to the left monitor was 1.00 (SE = 0.00, n = 3, Min = 1.00, Max = 1.00), and the average number of glances made to the right monitor was 1.00 (SE = 0.00, n = 6, Min = 1.00, Max = 1.00). The center monitor was looked at three times by a driver prior to experiencing one SCE. Figure 129 shows the mean number of glances by C/VIS and experimental condition.

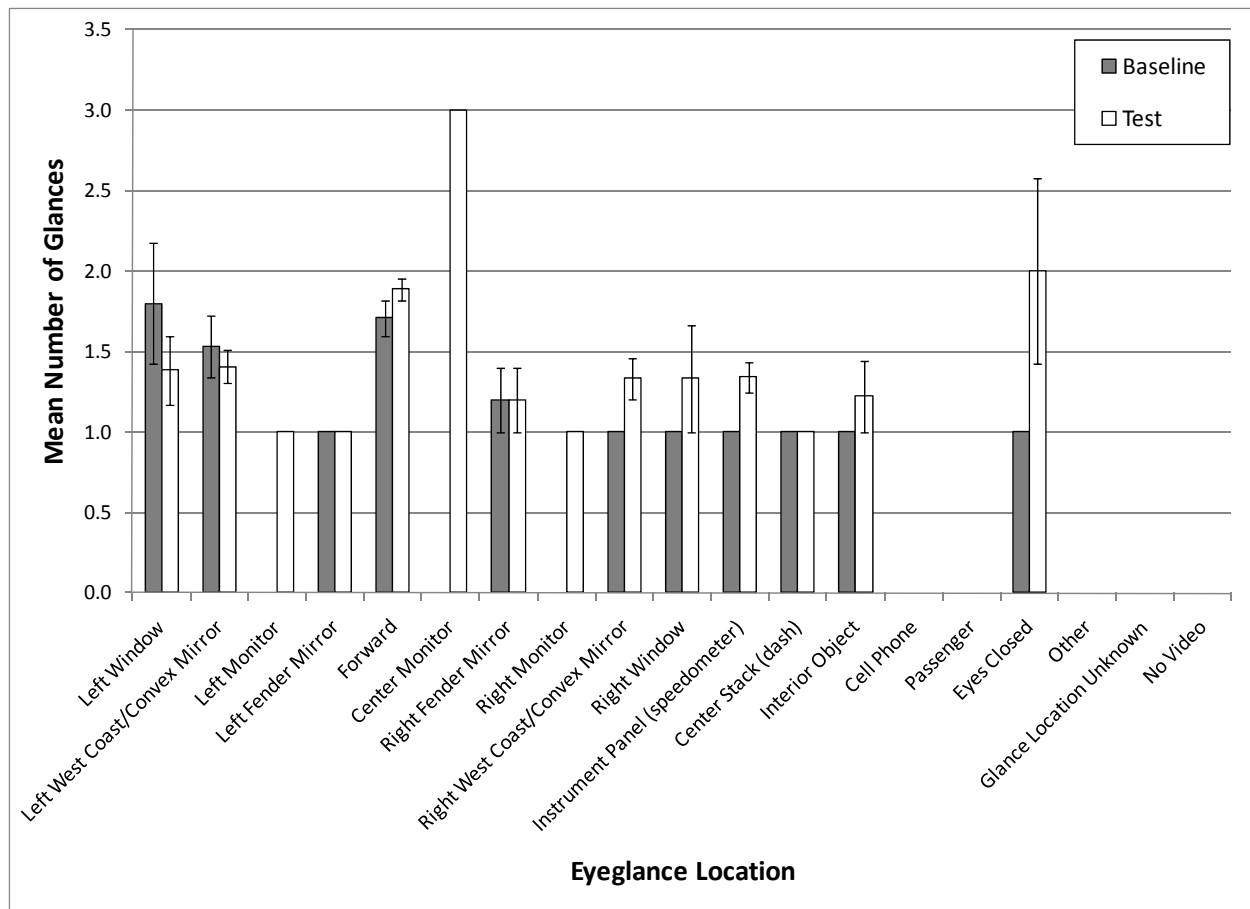


Figure 128. Mean Number of Glances Prior to an SCE by Experimental Condition

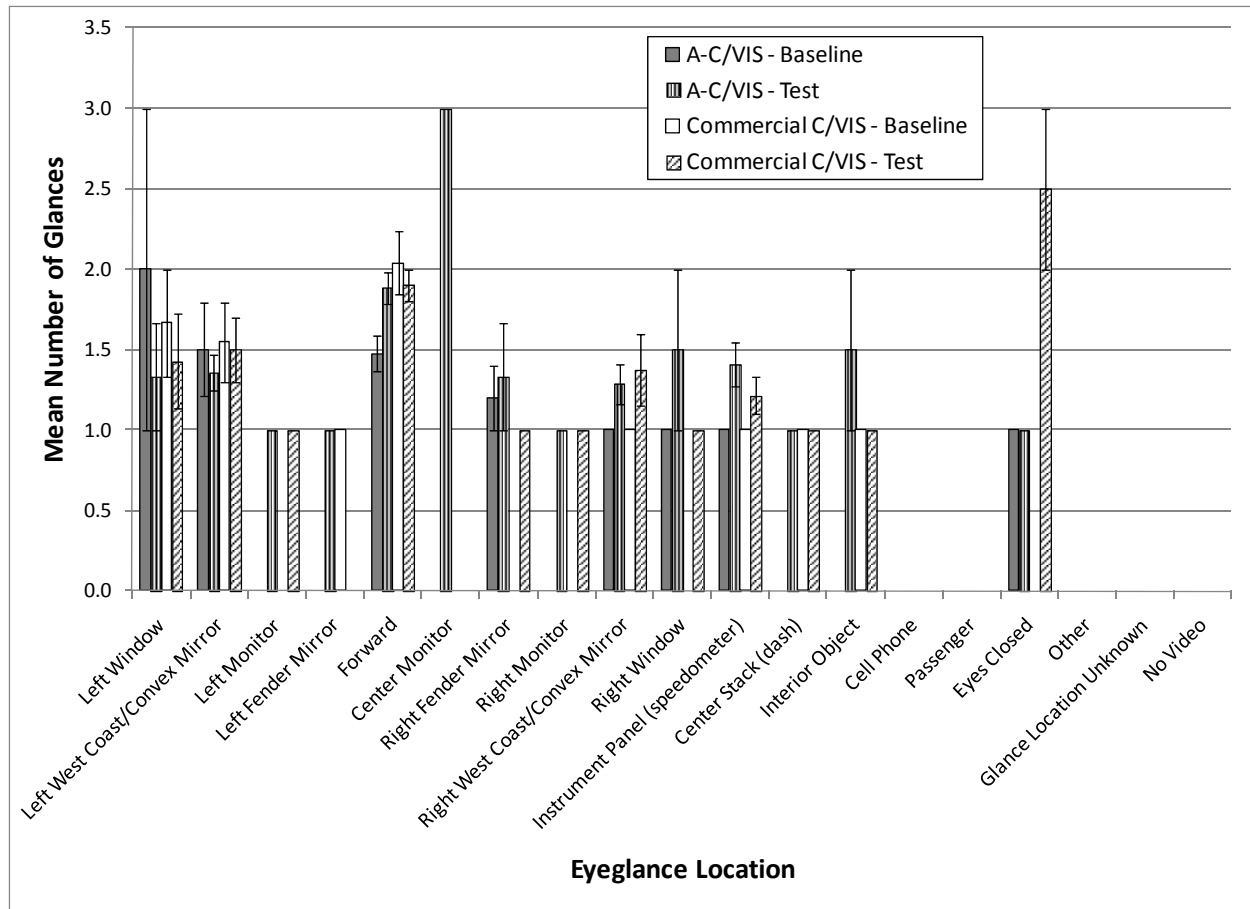


Figure 129. Mean Number of Glances Prior to an SCE by C/VIS and Experimental Condition

Mean Glance Duration Prior to Experiencing an SCE

The mean amount of time drivers spent looking in the recorded glance locations in the 8 s prior to experiencing an SCE is shown in Figure 130 by experimental condition. It can be seen that in the Baseline condition, drivers looked at the forward location, on average, for 5.18 s (SE = 0.40 s, n = 65, Min = 0.10 s, Max = 8.10 s), while their mean forward glance duration in the Test condition was 5.04 s (SE = 0.22 s, n = 200, Min = 0.20 s, Max = 8.10 s). It should be noted here that the duration of an eye glance was curtailed by the beginning and end of the 8-second data-reduction interval. When the monitors were viewed by drivers, the data indicate that drivers' glances were shorter than their glances to the mirrors. Figure 131 shows the mean glance duration for glances made prior to experiencing an SCE by C/VIS and experimental condition.

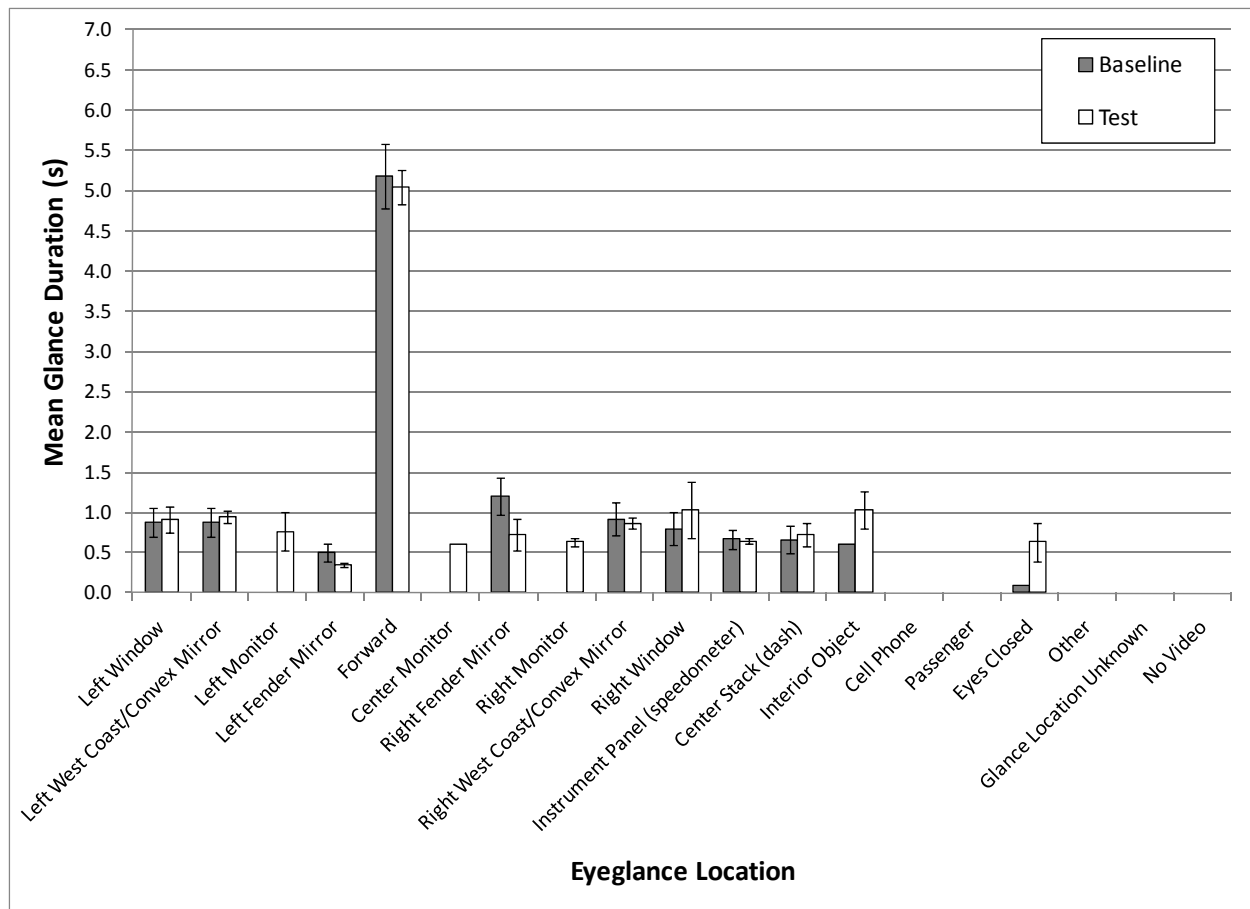


Figure 130. Mean Glance Duration Prior to an SCE by Experimental Condition

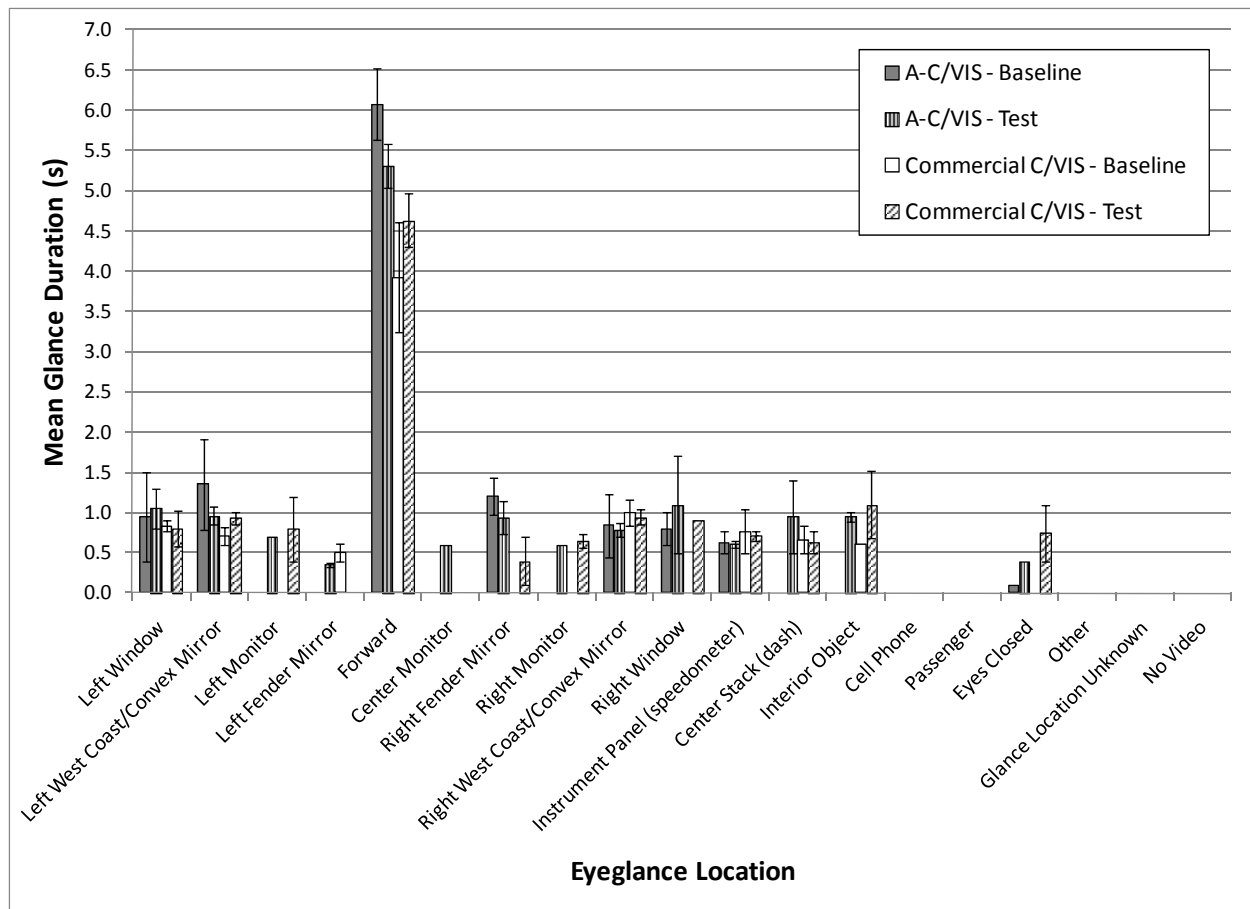


Figure 131. Mean Glance Duration Prior to an SCE by C/VIS and Experimental Condition

Lane-Change SCEs

Six of the 265 SCEs arose while the SV driver executed a lane change. This section brings attention to these events given their relevance to C/VISs.

Other Vehicle Passing on Right

One near-crash and one crash-relevant conflict arose from a trailing vehicle passing the SV on the right after the SV driver initiated a right lane change (Figure 132). In both cases, the SV driver could not see the other vehicle traveling behind the SV prior to changing lanes (both SCEs occurred during A-C/VIS Baseline driving conditions). Both SCEs occurred because the trailing vehicle exhibited aggressive driving behavior. Fortunately, the SV driver perceived the passing vehicle after initiating the lane change and aborted the lane-change maneuver.



Figure 132. Two Safety-Critical Events (Crash-Relevant Conflict Shown on Left, Near-Crash Shown on Right) Arising from a Trailing Vehicle Passing the SV on the Right during a Right Lane Change. It Should be Noted that the Right Lane is Shown in the Bottom Left Video Quadrant

Other Vehicle Simultaneously Merging into Subject Vehicle's Left Destination Lane

There were two crash-relevant conflicts that arose from a vehicle making a right lane change into the center lane as the SV executed a left lane change into the center lane. The SCEs occurred because the SV driver did not adequately scan the environment prior to changing lanes. Nevertheless, a crash was avoided because the SV driver perceived the other vehicle entering the destination lane and aborted the lane-change maneuver. For the SCE shown on the left in Figure 133, the other vehicle had to make a right lane change because its lane was ending and a substantial snow bank prevented travel on the shoulder of the road. For the SCE shown on the right side of Figure 133, the other vehicle aggressively moved into the center lane as the SV was changing lanes. Both SCEs occurred in the baseline driving condition for the commercially available C/VIS.



Figure 133. Crash-Relevant Conflicts Arising from an Adjacent Vehicle and the SV Moving Into a Common Destination Lane. It Should be Noted that the Left Lane is Shown in the Bottom Left Video Quadrant

SV Making a Left Lane Change in Front of a Rapidly Approaching Adjacent Vehicle in Left Lane

One Crash-Relevant Conflict arose from the SV driver inadequately scanning the environment prior to making a left lane change. In executing the lane change, the SV pulled out in front of a rapidly approaching vehicle in the left lane (Figure 134). A crash was avoided because the SV quickly returned to the right lane after the error was realized. This SCE occurred in the A-C/VIS Test mode.



Figure 134. Crash-Relevant Conflict from SV Making Left Lane Change in Front of Approaching Adjacent Vehicle

Lead Vehicle and SV Both Make a Left Lane Change into the Same Lane

The final Crash-Relevant Conflict occurred when a lead vehicle made a left lane change; the SV had begun a left lane change to enter this same lane. Because the SV was travelling at a faster rate, the SCE occurred as the lead vehicle forced the SV to brake (Figure 135). This SCE occurred in the A-C/VIS Test mode.



Figure 135. Crash-Relevant Conflict Arising from Lead Vehicle Changing into SV's Destination Lane while SV Executes a Lane Change

Summary

This section described the investigation into CMV drivers' performance when driving with a C/VIS. Drivers' mean SCE rate was 5.2 SCEs per 100 hours of driving in both the Baseline and Test conditions. The mean SCE rate for drivers of A-C/VIS-equipped trucks were reduced from 5.9 to 5.7 when driving with a C/VIS ($p = 0.8389$), while the mean SCE rate for drivers of commercial C/VIS-equipped trucks increased from 4.5 to 4.7 when driving with a C/VIS ($p = 0.8389$). Drivers' eye glance patterns prior to an SCE were also investigated. It was hypothesized that the C/VIS would allow drivers to make fewer mirror checks and spend more time looking forward. An analysis of drivers' eye glance probabilities, the percentage of SCEs in which a location was viewed at least once, the number of eye glances made to a location, and the duration of each eye glance did not reveal any significant differences in their visual behavior between the Baseline and Test conditions. Drivers' probability of looking forward increased slightly – from 0.86 to 0.87 – when driving with a C/VIS, indicating that the C/VISs did not detract drivers' visual attention away from the forward roadway.

DRIVERS' LANE-CHANGE PERFORMANCE

Various aspects of drivers' lane-change performance were investigated. The manner in which drivers executed left lane-change maneuvers was expected to differ from the manner in which they executed right lane-change maneuvers. As a result, a direction factor was incorporated into the ANOVAs performed on a number of lane-change performance variables, including the clearance between the tractor-trailer and an adjacent vehicle, the time taken to cross into the adjacent lane, and the time taken to complete a lane change.

Clearance between Tractor-Trailer and Adjacent Vehicle

A 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA was performed on the clearance-between-tractor-trailer-and-adjacent-vehicle dependent variable. Recall that clearance

was measured at the point in time in which the driver initiated the lane change, and not at the point in time that the lane markings were crossed. A Condition main effect was not found ($F(1, 10) = 0.45, p = 0.5176$). Drivers' mean clearance was 37.38 m in the Baseline condition ($SE = 1.14$ m, $n = 528$, $Min = -12.83$ m, $Max = 125.54$ m), while their mean clearance was 36.62 m in the Test condition ($SE = 0.66$ m, $n = 1484$, $Min = -9.86$ m, $Max = 123.26$ m) (Figure 136). Drivers' mean speed when initiating a lane change was 91.6 km/h, and their mean acceleration was 0.00 g.

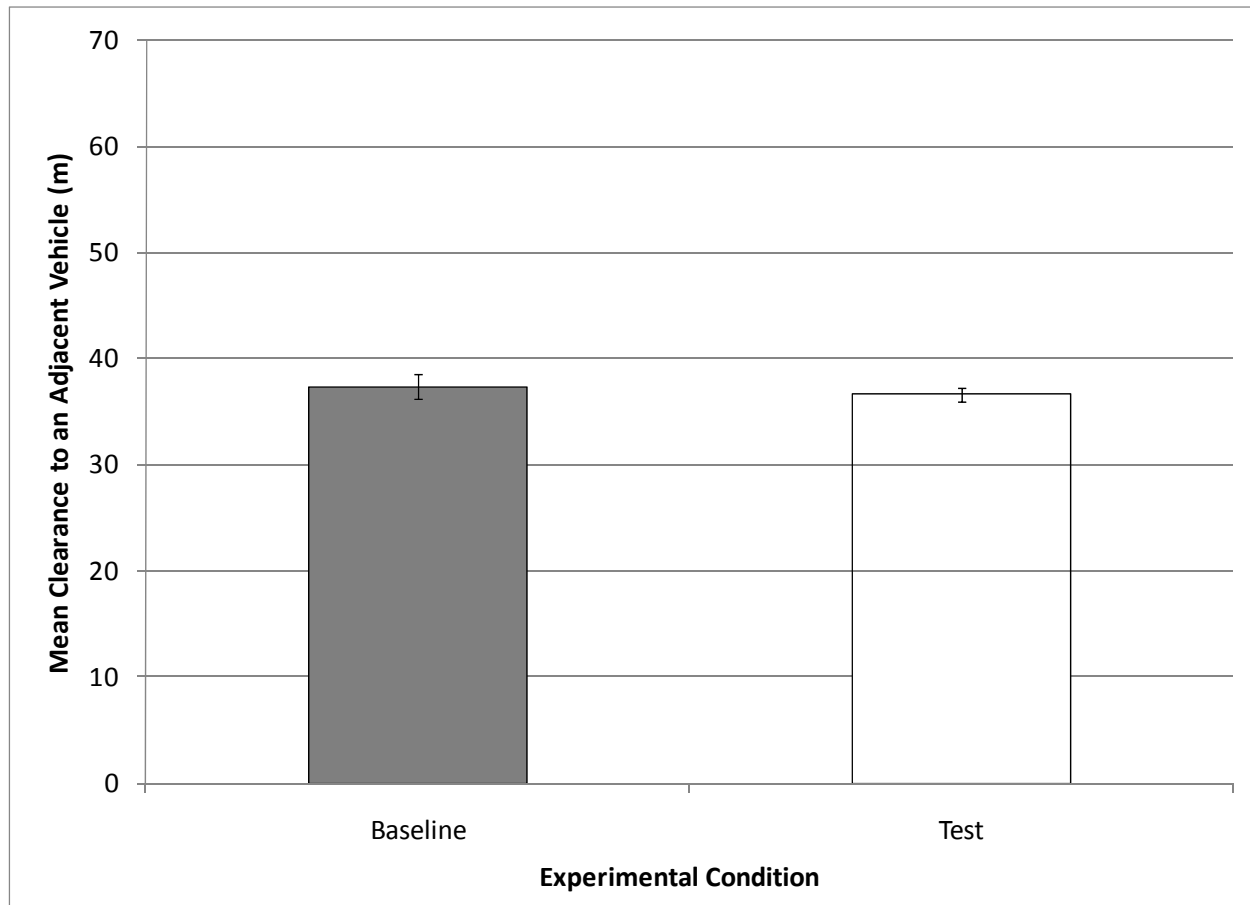


Figure 136. Drivers' Mean Clearance to an Adjacent Vehicle upon Initiating a Lane Change

Figure 137 shows drivers' mean clearance by month in study. Their mean clearance was 37.38 m in Month 1 ($SE = 1.14$ m, $n = 528$, $Min = -12.83$ m, $Max = 125.54$ m), 36.21 m in Month 2 ($SE = 1.10$ m, $n = 528$, $Min = 3.58$ m, $Max = 121.47$ m), 37.84 m in Month 3 ($SE = 1.21$ m, $n = 490$, $Min = -3.68$ m, $Max = 121.63$ m), and 35.79 m in Month 4 ($SE = 1.13$ m, $n = 466$, $Min = -9.86$ m, $Max = 123.26$ m). A 2 (C/VIS) x 4 (Month) Mixed Factors ANOVA was also performed on the clearance dependent variable. A significant Month effect was not found ($F(3, 29) = 0.2, p = 0.8982$).

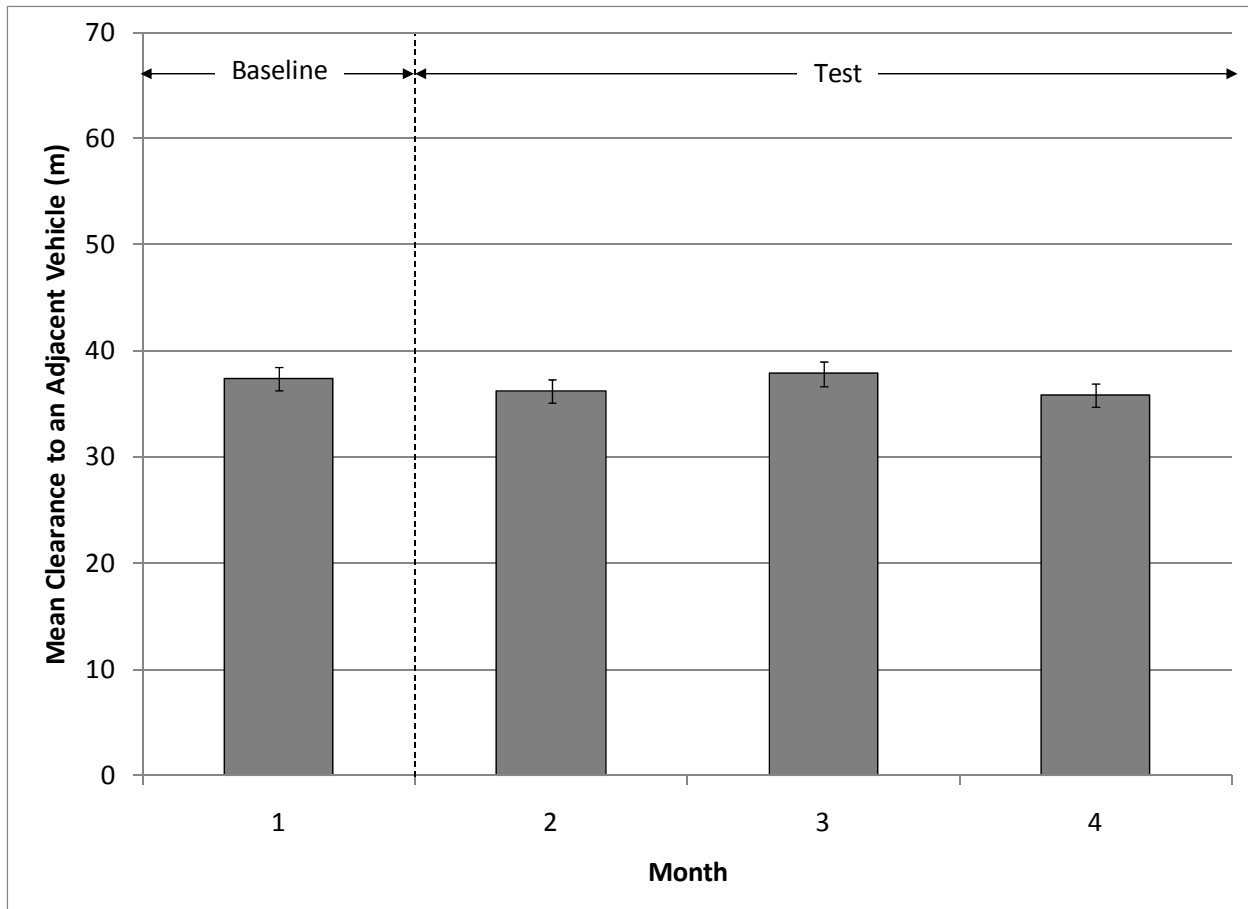


Figure 137. Drivers' Mean Clearance to an Adjacent Vehicle by Month in Study

With respect to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA that was performed, a C/VIS x Condition interaction was investigated to determine whether the clearance adopted by drivers of A-C/VIS-equipped trucks or commercial C/VIS-equipped trucks differed across experimental condition. A C/VIS x Condition interaction was not found ($F(1, 10) = 0.3, p = 0.5971$). The mean clearance to an adjacent vehicle for drivers of A-C/VIS-equipped trucks was 36.91 m in the Baseline condition (SE = 1.55 m, $n = 264$, Min = -12.83 m, Max = 120.51 m) and 35.81 m in the Test condition (SE = 0.91 m, $n = 692$, Min = -9.86 m, Max = 119.10 m) (Figure 138). The mean clearance to an adjacent vehicle for drivers of commercial C/VIS-equipped trucks was 37.86 m in the Baseline condition (SE = 1.67 m, $n = 264$, Min = -3.87 m, Max = 125.54 m) and 37.32 m in the Test condition (SE = 0.95 m, $n = 792$, Min = -0.77 m, Max = 123.26 m). The lack of an interaction also means that the mean clearance adopted by drivers of A-C/VIS-equipped trucks in Test mode was not found to be significantly different from the mean clearance adopted by drivers of commercial C/VIS-equipped trucks in Test mode.

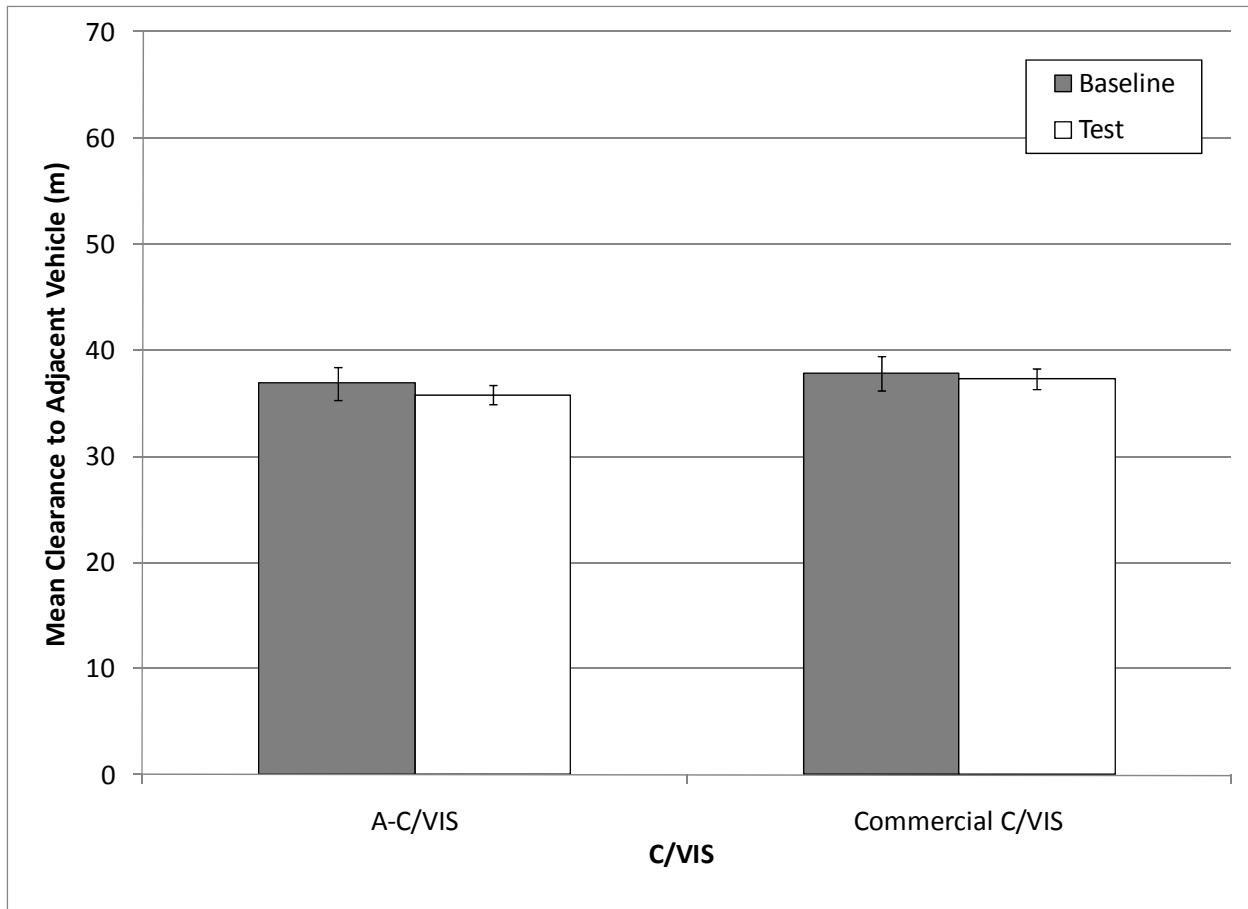


Figure 138. Drivers' Mean Clearance to an Adjacent Vehicle by C/VIS and Experimental Condition

Figure 139 shows the mean clearance for drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks by month in study. With respect to the 2 (C/VIS) x 4 (Month) Mixed Factors ANOVA that was performed, a C/VIS x Month interaction was not found ($F(3, 29) = 1.28$, $p = 0.2982$). Table 28 presents the clearance values for the reader's convenience.

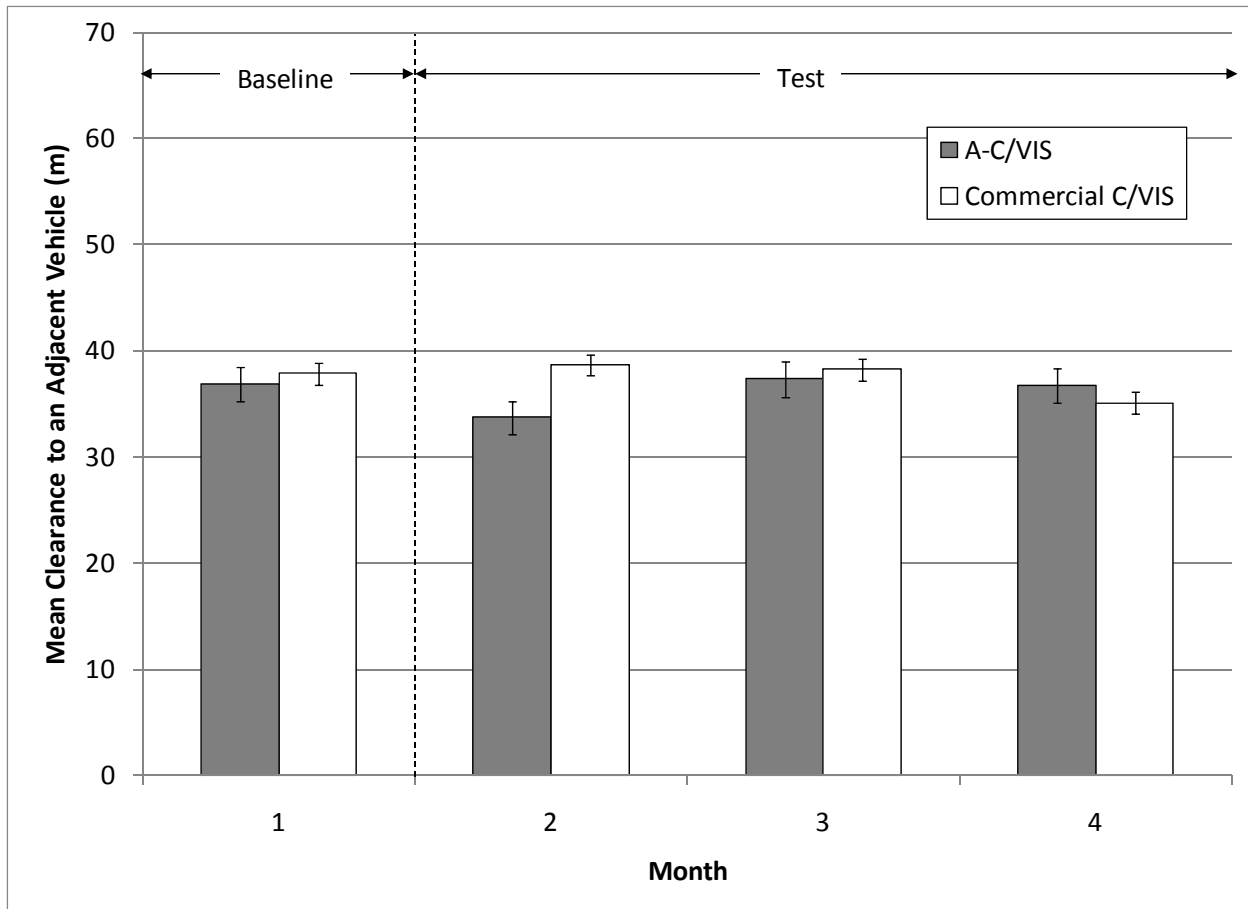


Figure 139. Drivers' Mean Clearance to an Adjacent Vehicle by C/VIS and Month in Study

Table 28. Drivers' Mean Clearance to an Adjacent Vehicle by C/VIS and Month in Study

C/VIS	Month	M (m)	SE (m)	n	Min (m)	Max (m)
A-C/VIS	1	36.91	1.55	264	-12.83	120.51
	2	33.77	1.47	264	4.42	119.10
	3	37.39	1.61	226	-3.68	118.62
	4	36.72	1.66	202	-9.86	114.02
Commercial C/VIS	1	37.86	1.67	264	-3.87	125.54
	2	38.66	1.61	264	3.58	121.47
	3	38.22	1.77	264	-0.77	121.63
	4	35.09	1.54	264	-0.38	123.26

Drivers' clearances were also binned into one of five categories: 1) overlapping, 2) less than 6 m away from the trailer, 3) less than 12 m away from the trailer, 4) less than 18 m away from the trailer, and 5) greater than or equal to 18 m away from the trailer. Figure 140 shows the percentage of lane changes that fell into each category. A 2 (Condition) x 2 (C/VIS) x 2 (Direction) Multinomial Logistic Regression was performed on the Clearance categorical dependent variable to investigate whether the experimental condition, and C/VIS used, had an

effect on the relative frequency of lane changes in each clearance category. A Condition main effect was not found ($\chi^2(1) = 0.4, p = 0.5256$).

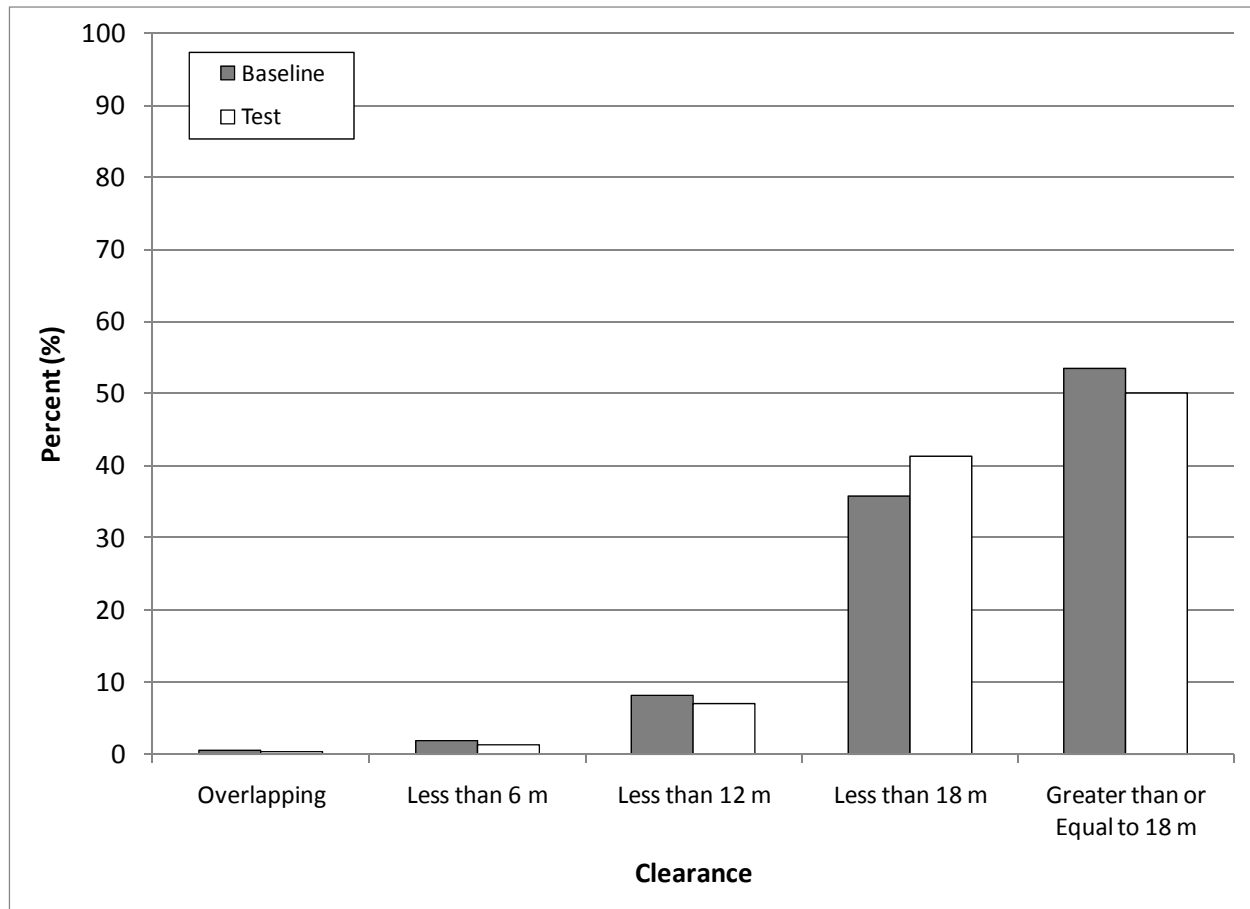


Figure 140. Percentage of Lane Changes for the Clearance Groupings

With regard to the Multinomial Logistic Regression that was performed on the Clearance categorical dependent variable, a C/VIS x Condition interaction was not found ($\chi^2(1) = 1.23, p = 0.2676$). The distribution of clearances for drivers of both A-C/VIS-equipped and commercial C/VIS-equipped trucks did not significantly change between the Baseline and Test conditions. Furthermore, the distribution of clearances for drivers of A-C/VIS-equipped trucks in the Test condition was not significantly different from the distribution of clearances for drivers of commercial C/VIS-equipped trucks in the Test condition. Figure 141 shows the percentage of lane changes that fell into each clearance category for each C/VIS and experimental condition.

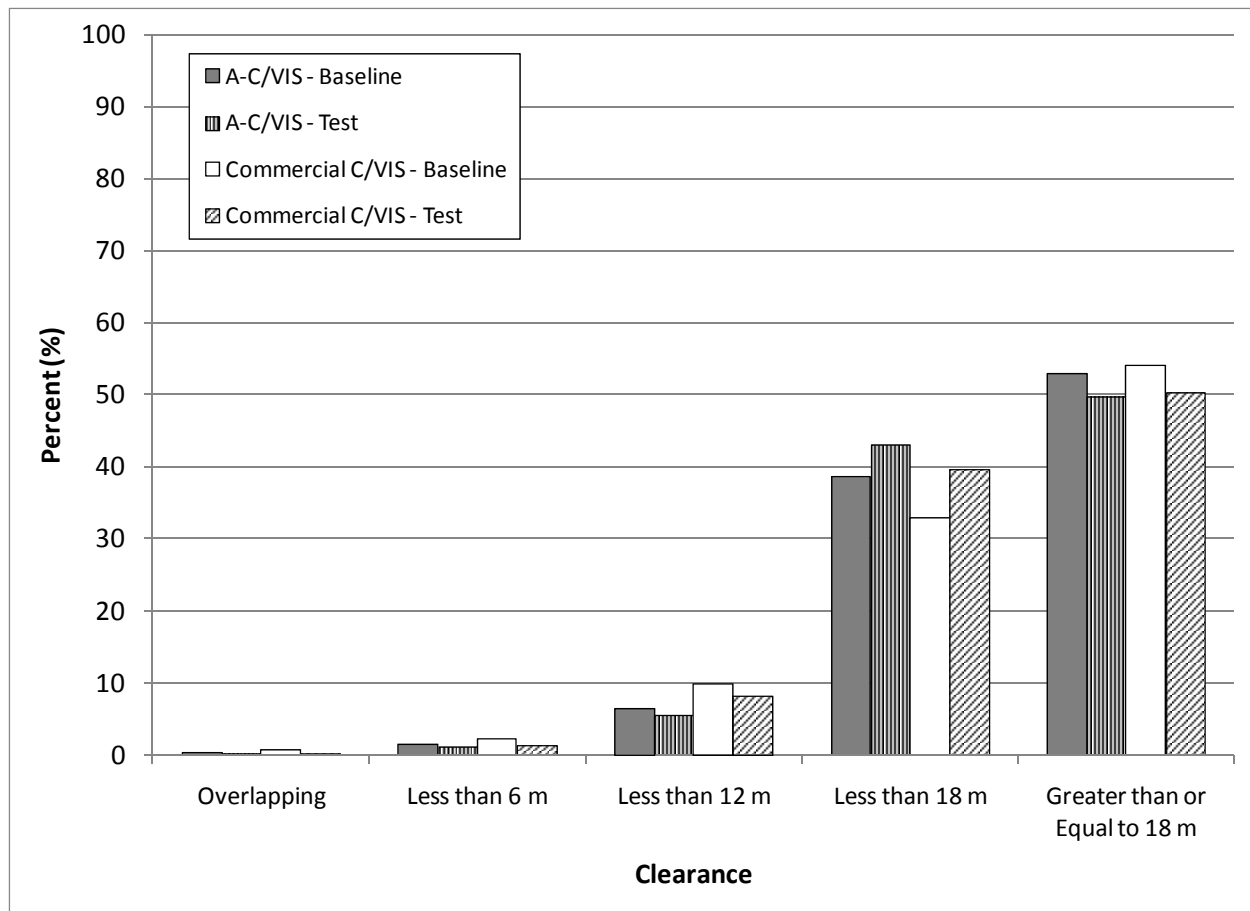


Figure 141. Percentage of Lane Changes for the Five Clearance Groupings by C/VIS and Experimental Condition

With regard to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors Analysis of Variance that was performed, a Direction main effect was found ($F(1, 10) = 60.61, p < 0.0001$). Drivers' mean clearance to an adjacent vehicle was 53.31 m when making left lane changes ($SE = 1.46$ m, $n = 483$, $Min = -12.83$ m, $Max = 129.02$ m), while it was 31.63 m when making right lane changes ($SE = 0.53$ m, $n = 1529$, $Min = -3.87$ m, $Max = 121.47$ m) (Figure 142). Table 29 categorizes the sampled left and right lane changes by type. It can be seen that the majority of left lane changes arose from drivers initiating a pass of a slow lead vehicle, while the majority of right lane changes were drivers returning to the right lane after passing a lead vehicle.

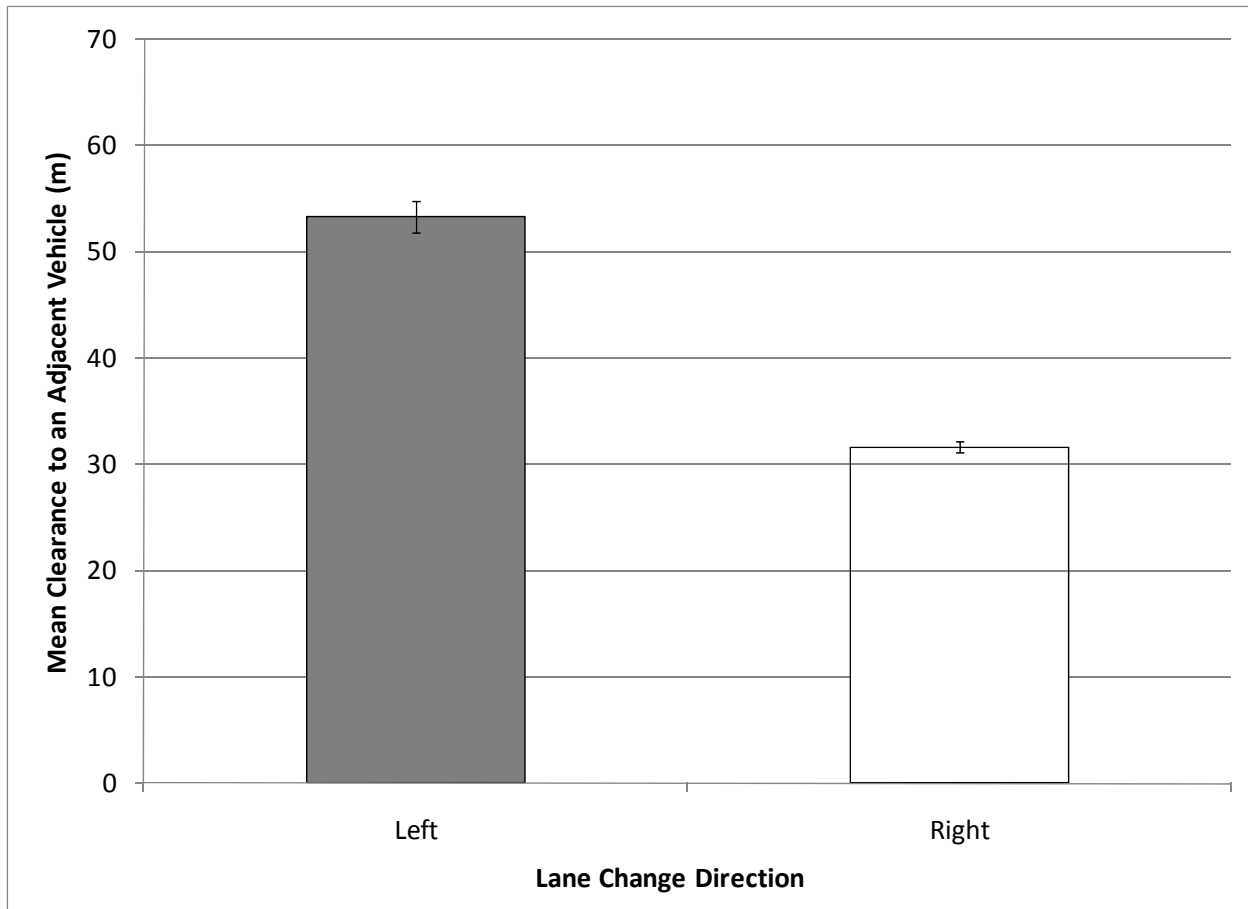


Figure 142. Drivers' Mean Clearance to an Adjacent Vehicle by Lane-Change Direction

Table 29. Drivers' Mean Clearance to an Adjacent Vehicle by Lane-Change Direction

Lane-Change Type	Left	Right
Added Lane	0%	1%
Enter	11%	1%
Exit/Prep Exit	9%	2%
Lane Drop	10%	0%
Merging Vehicle (LC to let Vehicle Enter Highway)	8%	0%
Other	17%	1%
Return	2%	94%
Rough/Obstacle Avoid	6%	0%
Slow Lead Vehicle	36%	1%
Total	100%	100%

Using the same ANOVA, a Condition x Direction interaction was tested to explore whether drivers' mean clearance when making left or right lane changes differed between the Baseline and Test conditions. A Condition x Direction interaction was not found ($F(1, 10) = 0.41, p = 0.5348$). A C/VIS x Condition x Direction interaction was also tested, but was not found to be

significant ($F(1, 10) = 2.12, p = 0.1764$). Drivers' mean clearances by C/VIS, Experimental Condition, and Lane-Change Direction are depicted in Figure 143 and shown in Table 30.

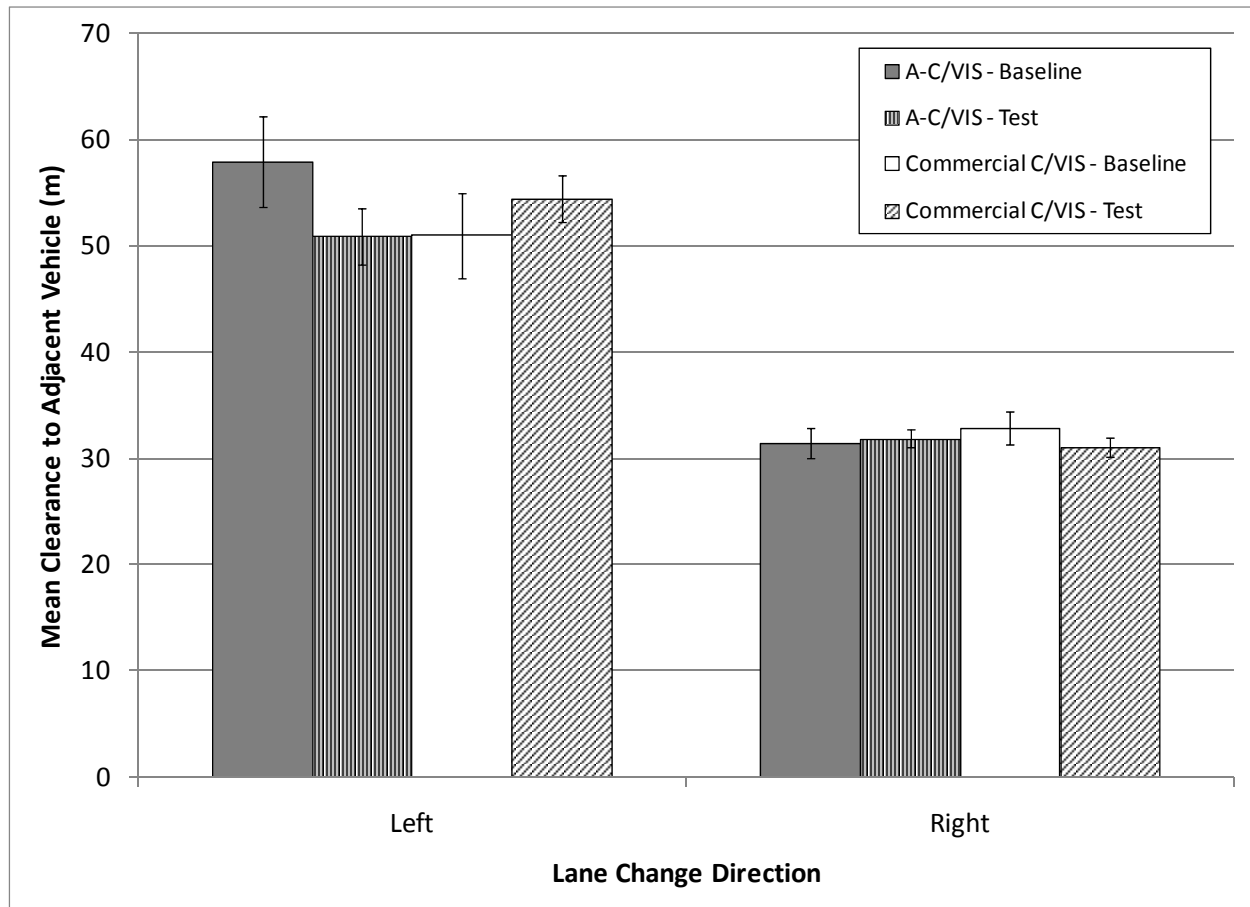


Figure 143. Drivers' Mean Clearance to an Adjacent Vehicle by C/VIS, Experimental Condition, and Lane-Change Direction

Table 30. Drivers' Mean Clearance to an Adjacent Vehicle by C/VIS, Experimental Condition, and Lane-Change Direction

Lane-Change Direction	C/VIS	Experimental Condition	M (m)	SE (m)	n (m)	Min (m)	Max (m)
Left	A-C/VIS	Baseline	57.22	4.04	56	-12.83	119.30
		Test	51.00	2.63	142	-9.86	118.62
	Commercial C/VIS	Baseline	50.97	4.01	73	3.33	125.54
		Test	54.50	2.19	212	3.58	123.26
Right	A-C/VIS	Baseline	31.44	1.43	208	0.19	120.51
		Test	31.89	0.84	550	-3.68	119.10
	Commercial C/VIS	Baseline	32.84	1.59	191	-3.87	115.71
		Test	31.04	0.89	580	-0.77	121.47

Figure 144 shows the percentage of left lane changes that fell into each clearance category. With regard to the Multinomial Logistic Regression that was performed on the clearance categorical dependent variable, a C/VIS x Direction interaction was not found ($\chi^2(1) = 0.44, p = 0.5078$). The relative frequency of left lane changes in each clearance category did not significantly change when participants drove with a C/VIS.

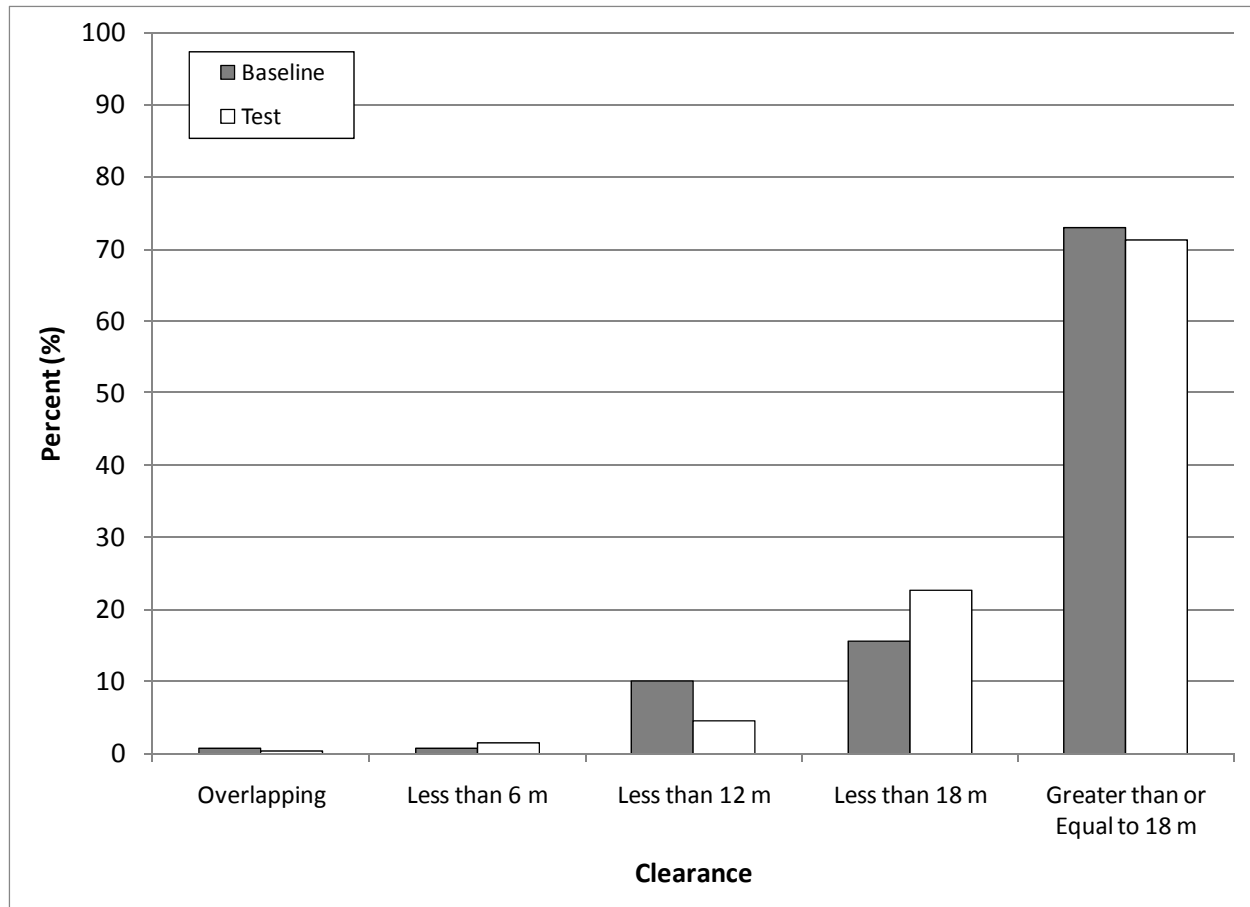


Figure 144. Percentage of Left Lane Changes per Clearance Category

Figure 145 shows the percentage of left lane changes that fell into each category for each C/VIS and Experimental Condition. With regard to the Multinomial Logistic Regression that was performed on the Clearance categorical dependent variable, a Condition x C/VIS x Direction interaction was not found ($\chi^2(1) = 2.54, p = 0.111$).

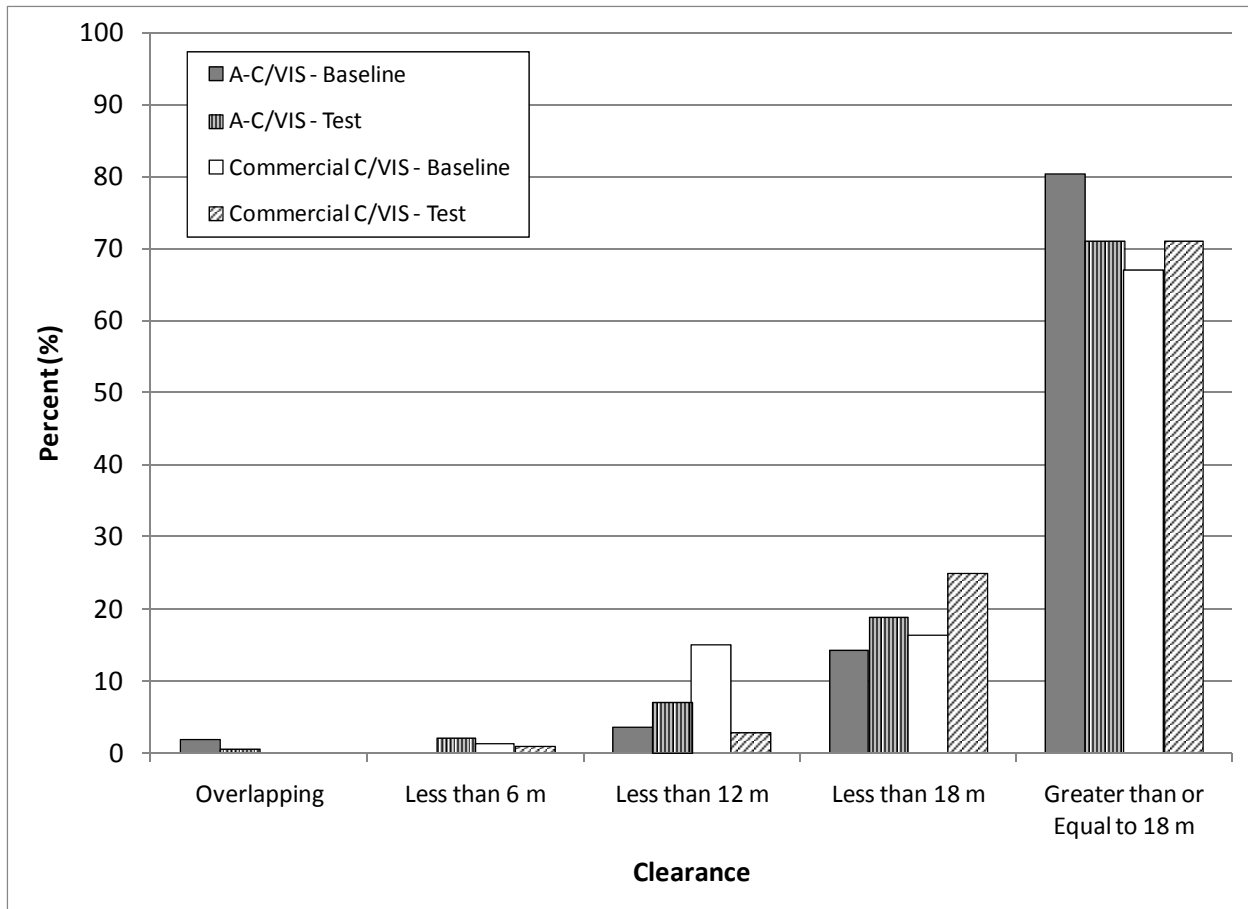


Figure 145. Percentage of Left Lane Changes for the Clearance Groupings by C/VIS and Experimental Condition

Figure 146 shows the percentage of right lane changes that fell into each category for each C/VIS. Because a C/VIS x Direction interaction was not found when performing the Multinomial Logistic Regression ($\chi^2(1) = 0.44, p = 0.5078$), the relative frequency of right lane changes in each clearance category was not found to change when driving with a C/VIS.

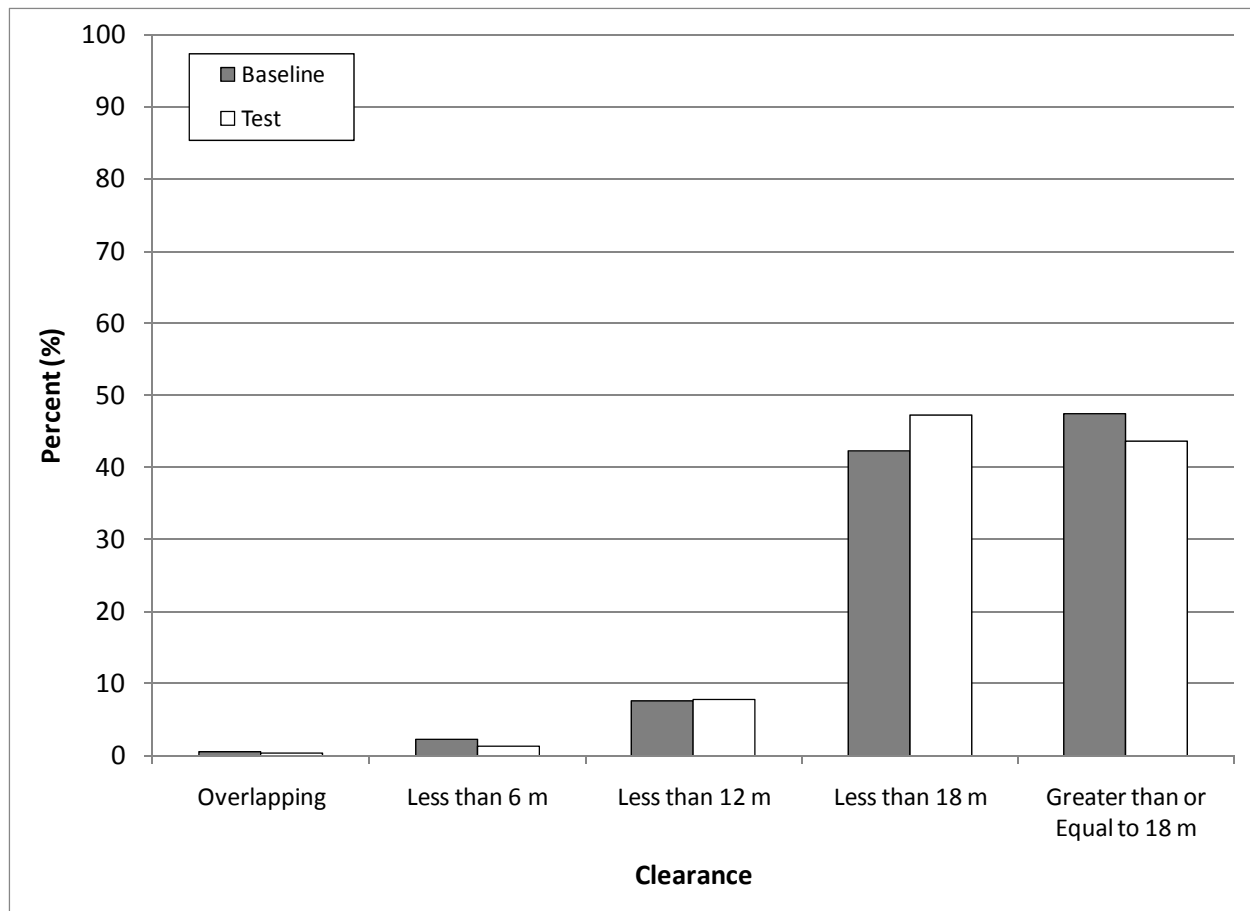


Figure 146. Percentage of Right Lane Changes for the Clearance Groupings

Figure 147 shows the percentage of right lane changes that fell into each category for each C/VIS and Experimental Condition. Because a Condition x C/VIS x Direction interaction was not found when performing the Multinomial Logistic Regression ($\chi^2(1) = 2.54, p = 0.111$), the relative frequency of right lane changes in each clearance category was not found to change for drivers of either A-C/VIS-equipped or commercial C/VIS-equipped trucks when driving with a C/VIS.

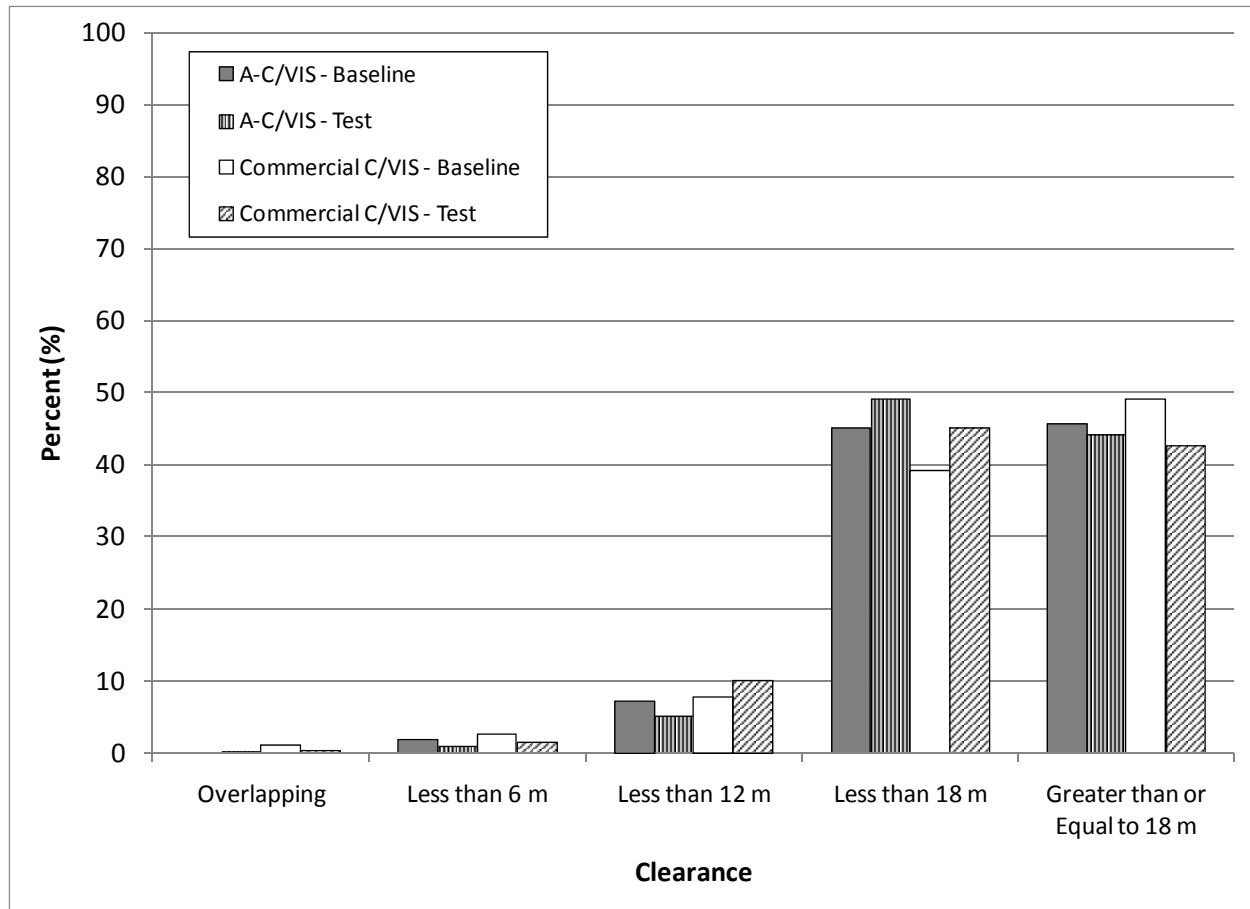


Figure 147. Percentage of Right Lane Changes for the Clearance Groupings by C/VIS and Experimental Condition

Since daylight and weather affect drivers' visibility, additional analyses were performed to investigate whether drivers' mean clearance when making left lane changes varies across various environmental conditions. Table 31 shows the percentage of observed left lane changes that were made in four environmental conditions.

Table 31. Distribution of Sampled Left Lane Changes by Environmental Condition

Environmental Condition	Frequency	Percent
Clear Day	196	41
Clear Night	230	48
Inclement Day	25	5
Inclement Night	32	7
Total	483	100

Figure 148 shows drivers' mean clearance during left lane changes by Environmental Condition. A 2 (Condition) x 2 (C/VIS) x 4 (Environmental Condition) Mixed Factors ANOVA was performed on the clearance dependent variable. An Environment main effect was not found ($F(3, 21) = 0.66, p = 0.5834$). The drivers' mean clearance was 47.47 m during clear daytime

conditions (SE = 2.29 m, n = 196, Min = -12.83 m, Max = 116.42 m), 57.32 m during clear nighttime conditions (SE = 2.09 m, n = 230, Min = 4.42 m, Max = 123.26 m), 54.60 m during inclement daytime conditions (SE = 5.72 m, n = 25, Min = 9.22 m, Max = 107.33 m), and 58.39 m during inclement nighttime conditions (SE = 5.48 m, n = 32, Min = 11.30 m, Max = 125.54 m).

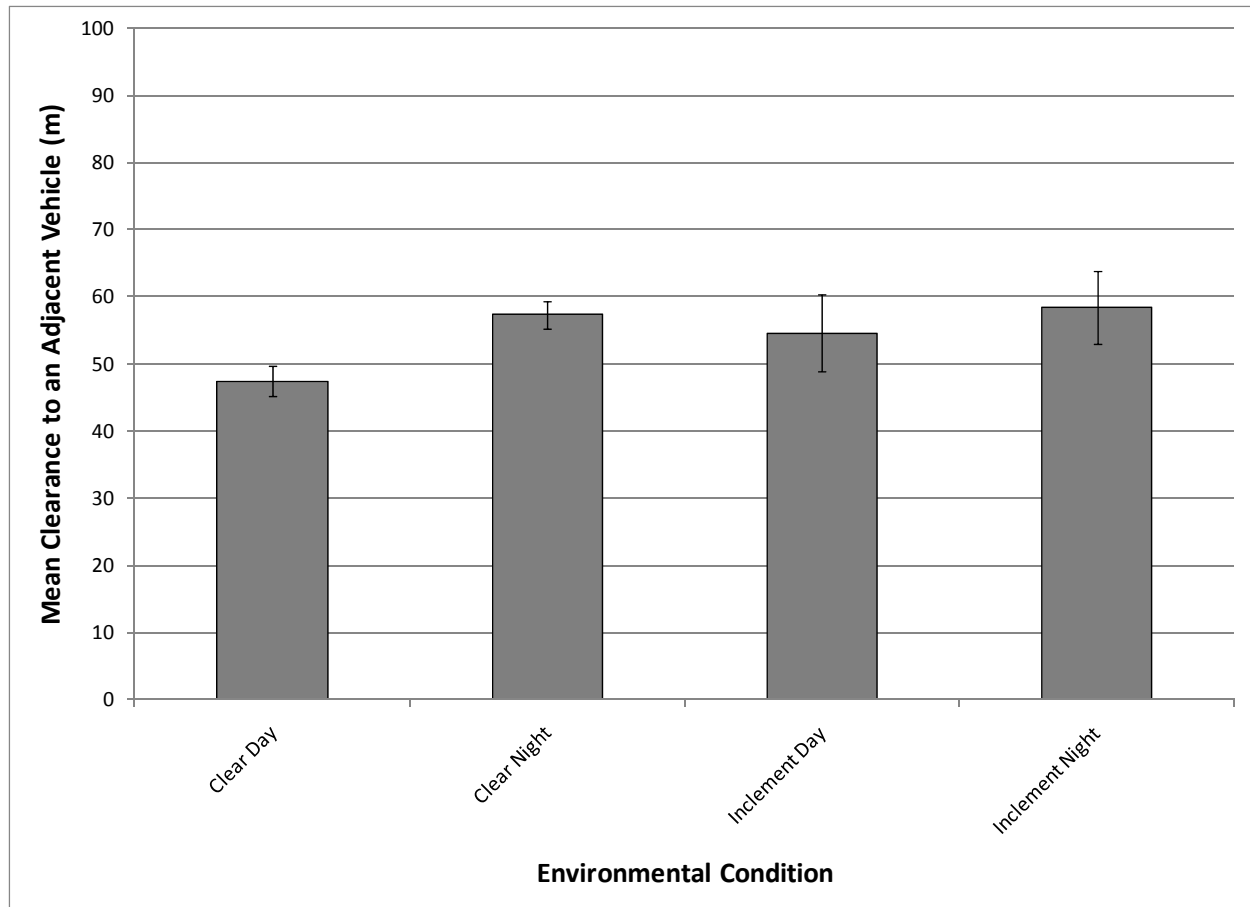


Figure 148. Drivers' Mean Clearance during Left Lane Changes by Environmental Condition

An Experimental Condition x Environmental Condition interaction was also not found ($F(3, 11) = 0.97, p = 0.4422$). Figure 149 and Table 32 show the drivers' mean clearance by Experimental Condition and Environmental Condition.

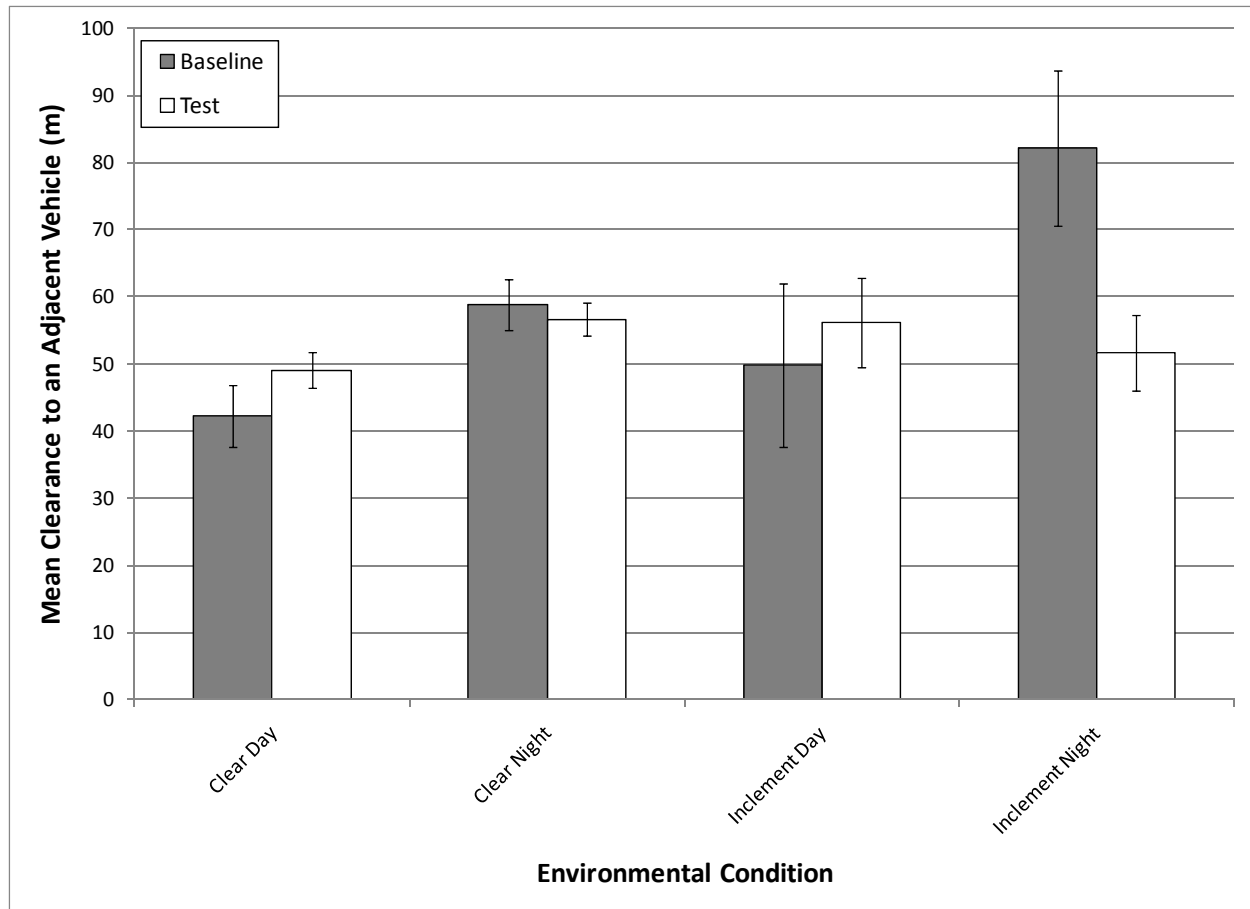


Figure 149. Drivers' Mean Clearance during Left Lane Changes by Experimental Condition and Environmental Condition

Table 32. Drivers' Clearance during Left Lane Changes by Experimental Condition and Environmental Condition

Environmental Condition	Experimental Condition	Mean (m)	SE (m)	n	Min (m)	Max (m)
Clear Day	Baseline	42.26	4.55	47	-12.83	115.33
	Test	49.12	2.64	149	-9.86	116.42
Clear Night	Baseline	58.91	3.79	69	7.68	119.30
	Test	56.64	2.51	161	4.42	123.26
Inclement Day	Baseline	49.77	12.21	6	9.22	89.02
	Test	56.13	6.62	19	13.60	107.33
Inclement Night	Baseline	82.23	11.60	7	39.55	125.54
	Test	51.71	5.63	25	11.30	106.34

An Experimental Condition x Environmental Condition x C/VIS interaction was also not found ($F(3, 11) = 0.78, p = 0.5292$). Drivers' mean clearances by Environmental Condition, C/VIS, and Experimental Condition are depicted in Figure 150 and shown in Table 33. The particularly large

variance pertaining to drivers' mean clearances in the inclement daytime and nighttime conditions is because of the few lane changes that were observed in these environmental conditions.

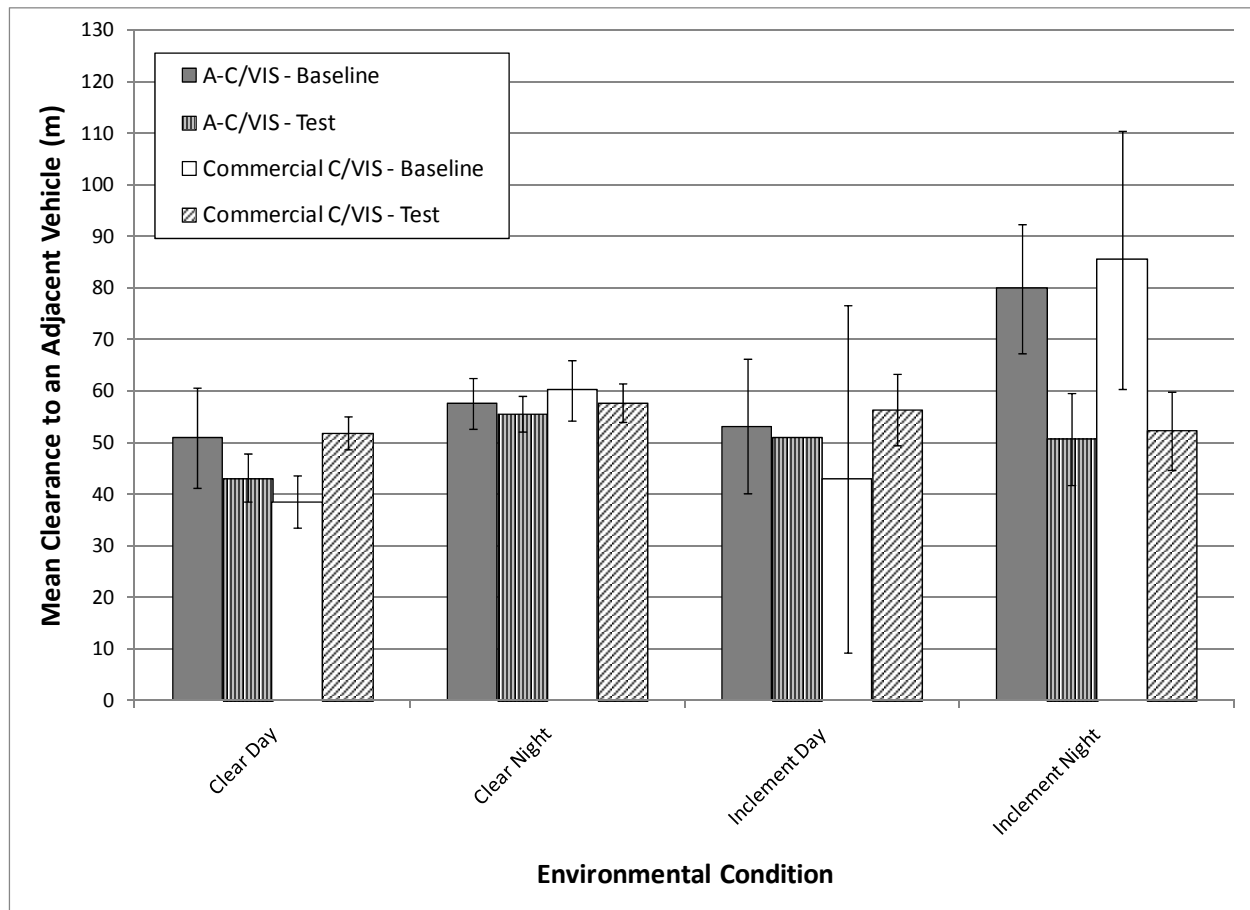


Figure 150. Drivers' Mean Clearance during Left Lane Changes by C/VIS, Experimental Condition, and Environmental Condition

Table 33. Drivers' Mean Clearance during Left Lane Changes by C/VIS, Experimental Condition, and Environmental Condition

Environmental Condition	C/VIS	Experimental Condition	Mean (m)	SE (m)	n	Min (m)	Max (m)
Clear Day	A-C/VIS	Baseline	51.01	9.71	14	-12.83	115.33
		Test	43.17	4.68	48	-9.86	116.42
	Commercial C/VIS	Baseline	38.55	4.97	33	3.33	106.98
		Test	51.94	3.17	101	3.58	113.63
Clear Night	A-C/VIS	Baseline	57.59	4.87	34	9.38	119.30
		Test	55.56	3.37	83	4.42	118.62
	Commercial C/VIS	Baseline	60.18	5.84	35	7.68	118.88
		Test	57.80	3.74	78	10.18	123.26
Inclement Day	A-C/VIS	Baseline	53.18	13.09	4	29.18	89.02
		Test	51.20	.	1	51.20	51.20
	Commercial C/VIS	Baseline	42.95	33.73	2	9.22	76.67
		Test	56.40	6.99	18	13.60	107.33
Inclement Night	A-C/VIS	Baseline	79.85	12.43	4	47.23	102.43
		Test	50.79	8.93	10	11.30	91.78
	Commercial C/VIS	Baseline	85.42	24.99	3	39.55	125.54
		Test	52.32	7.51	15	15.97	106.34

Drivers' mean clearance when making right lane changes under various environmental conditions was also explored. Table 34 shows the percentage of observed right lane changes that were made in the four environmental conditions.

Table 34. Distribution of Sampled Right Lane Changes by Environmental Condition

Environmental Condition	Frequency	Percent
Clear Day	477	31
Clear Night	878	57
Inclement Day	66	4
Inclement Night	108	7
Total	1529	100

Figure 151 shows the drivers' mean clearance during right lane changes by Environmental Condition. A 2 (Condition) x 2 (C/VIS) x 4 (Environmental Condition) Mixed Factors ANOVA was performed on the clearance dependent variable. An Environment main effect was found ($F(3, 28) = 4.4, p = 0.0117$). The drivers' mean clearance was 28.77 m during clear daytime conditions ($SE = 0.93$ m, $n = 477$, $Min = -0.77$ m, $Max = 119.10$ m), 33.50 m during clear nighttime conditions ($SE = 0.71$ m, $n = 878$, $Min = -3.68$ m, $Max = 121.47$ m), 30.95 m during inclement daytime conditions ($SE = 3.18$ m, $n = 66$, $Min = -3.87$ m, $Max = 113.31$ m), and

29.39 m during inclement nighttime conditions (SE = 1.59 m, n = 108, Min = 3.84 m, Max = 85.25 m). A Tukey Honestly Significant Difference (HSD) multiple comparisons test revealed that drivers' mean clearance in clear daytime conditions was significantly shorter than their mean clearance in clear nighttime conditions.

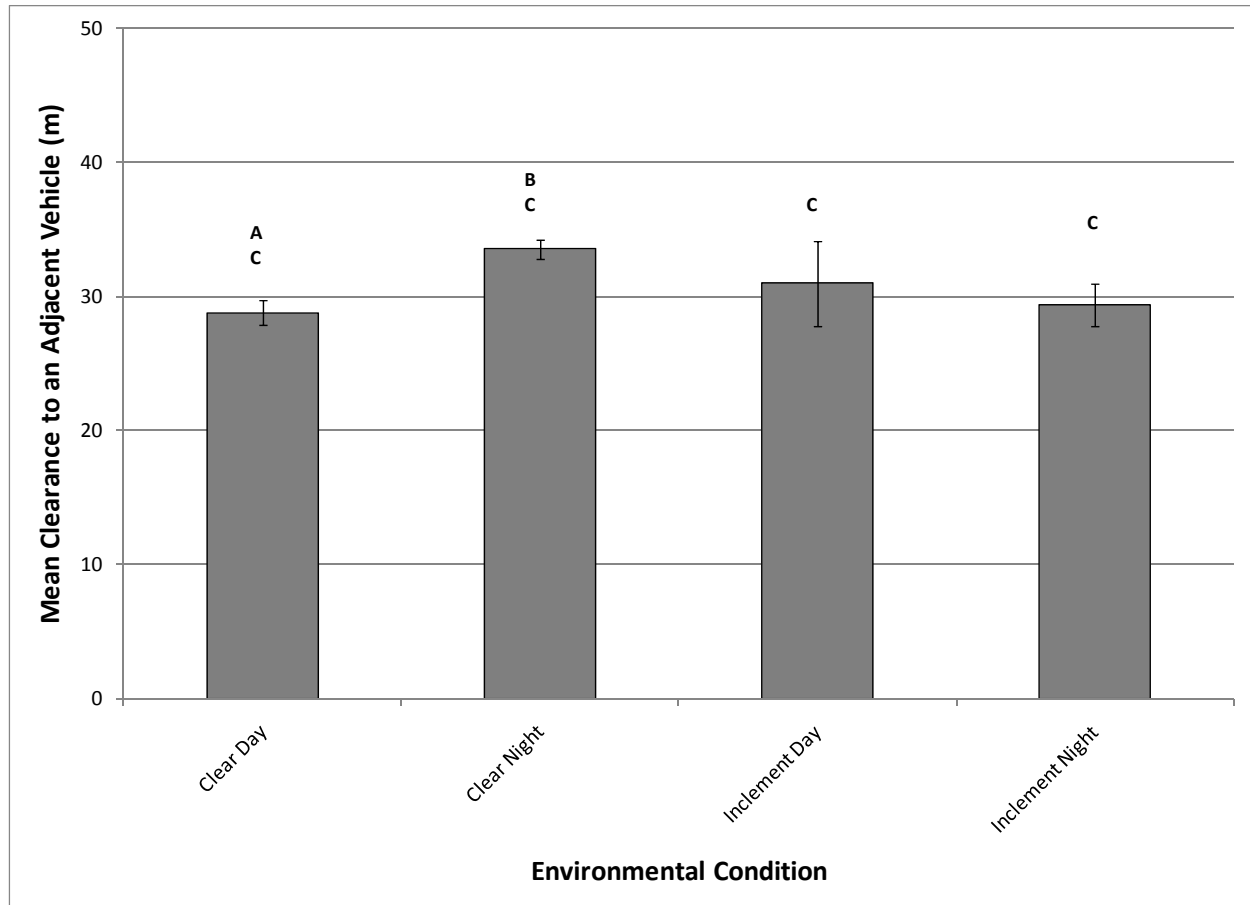


Figure 151. Drivers' Mean Clearance during Right Lane Changes by Environmental Condition

An Experimental Condition x Environmental Condition interaction was not found ($F(3, 18) = 0.16, p = 0.9235$). Figure 152 and Table 35 show drivers' mean clearance during right lane changes by Experimental Condition and Environmental Condition. Across the environmental conditions examined, drivers did not change their clearance to an adjacent vehicle when driving with a C/VIS.

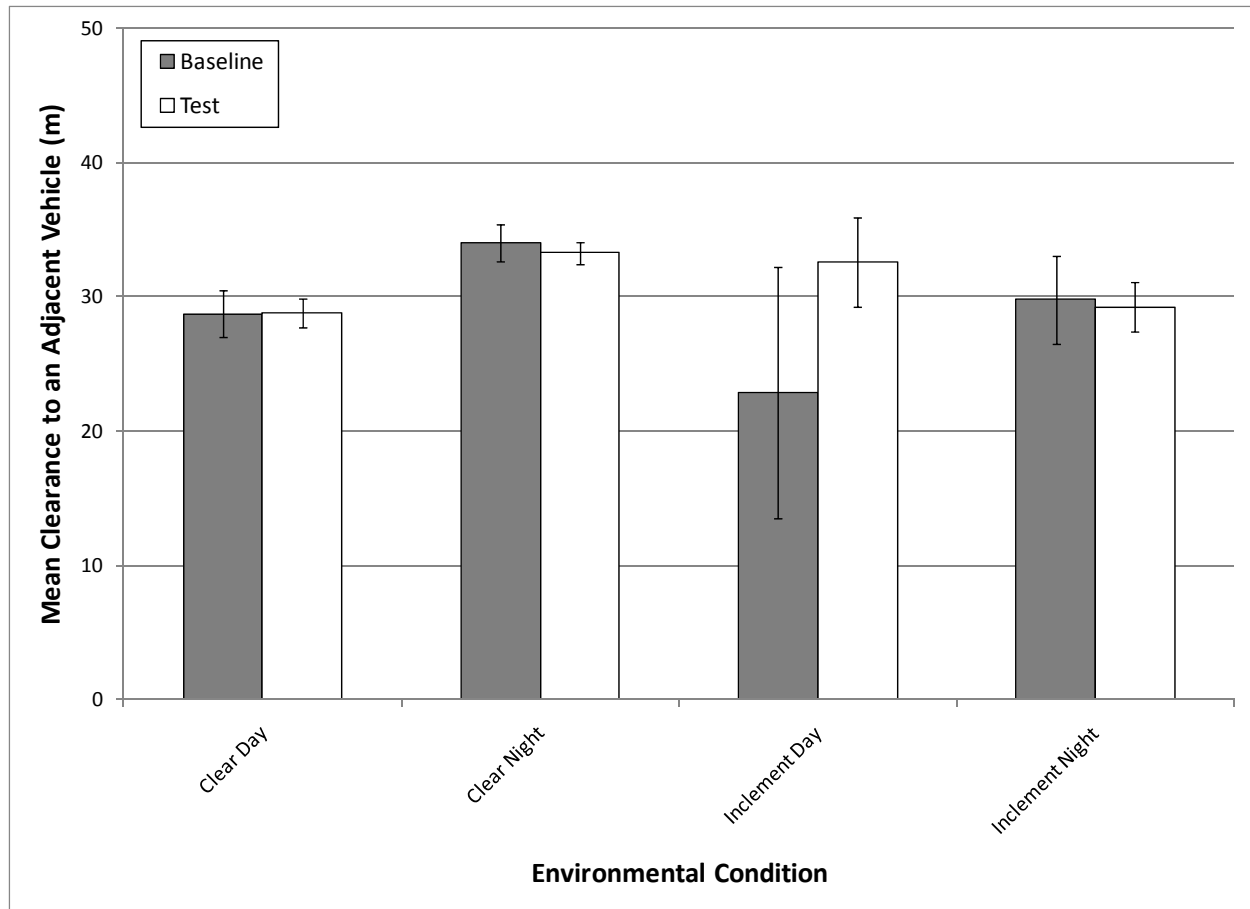


Figure 152. Drivers' Mean Clearance during Right Lane Changes by Experimental Condition and Environmental Condition

Table 35. Drivers' Clearance during Right Lane Changes by Experimental Condition and Environmental Condition

Environmental Condition	Experimental Condition	Mean (m)	SE (m)	n	Min (m)	Max (m)
Clear Day	Baseline	28.73	1.73	100	3.94	100.19
	Test	28.78	1.08	377	-0.77	119.10
Clear Night	Baseline	34.04	1.38	261	0.19	120.51
	Test	33.28	0.82	617	-3.68	121.47
Inclement Day	Baseline	22.89	9.38	11	-3.87	110.21
	Test	32.56	3.32	55	7.52	113.31
Inclement Night	Baseline	29.78	3.23	27	12.13	80.32
	Test	29.26	1.84	81	3.84	85.25

An Experimental Condition x Environmental Condition x C/VIS interaction was not found ($F(3, 18) = 0.11, p = 0.9549$). Drivers' mean clearances during right lane changes by Environmental Condition, C/VIS, and Experimental Condition are depicted in Figure 153 and shown in Table

36. There is a particularly large variance pertaining to drivers' mean clearances in the inclement daytime condition because of the few lane changes that were observed in this environmental condition.

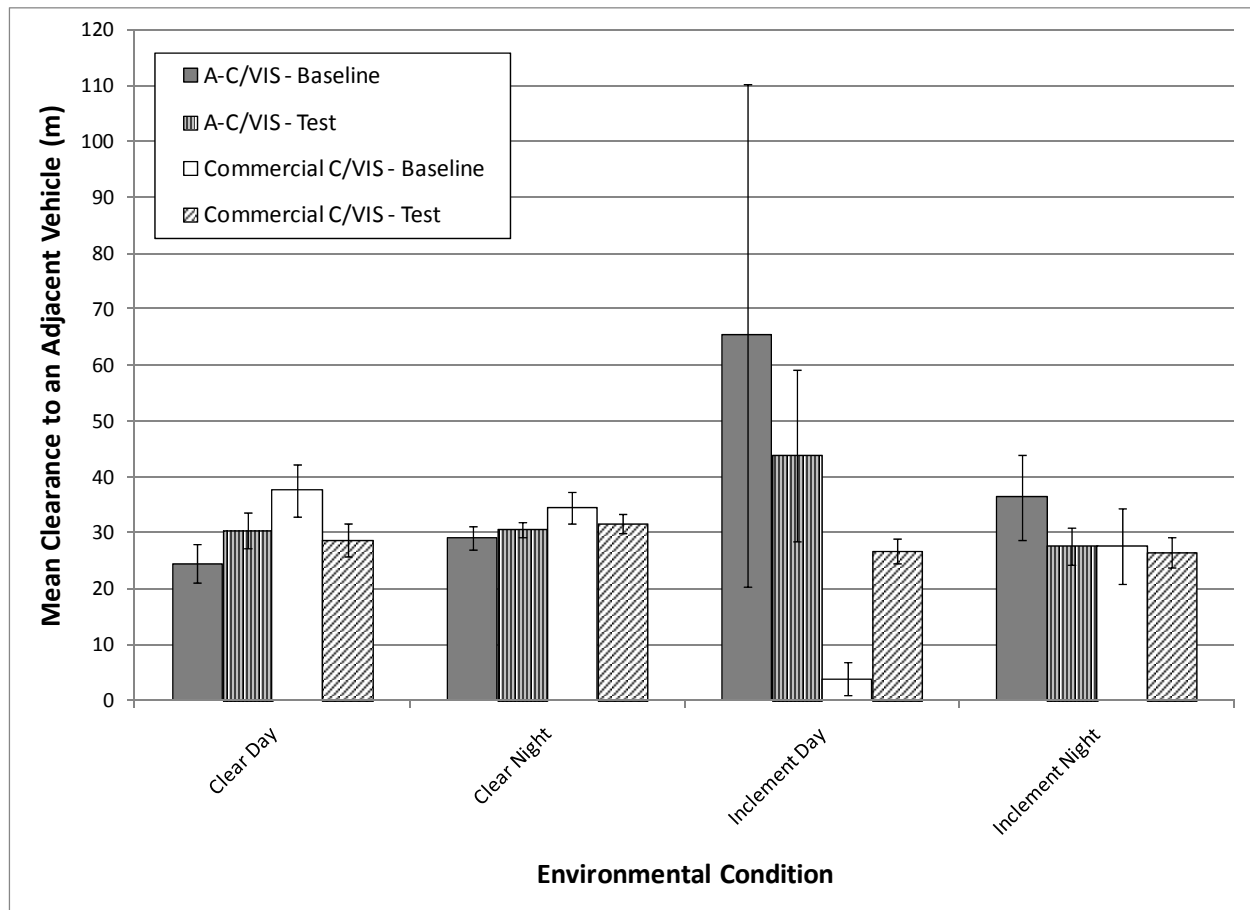


Figure 153. Drivers' Mean Clearance during Right Lane Changes by C/VIS, Experimental Condition, and Environmental Condition

Table 36. Drivers' Mean Clearance during Right Lane Changes by C/VIS, Experimental Condition, and Environmental Condition

Environmental Condition	C/VIS	Experimental Condition	Mean (m)	SE (m)	n	Min (m)	Max (m)
Clear Day	A-C/VIS	Baseline	26.75	2.24	52	5.15	83.23
		Test	27.53	1.50	166	3.52	119.10
	Commercial C/VIS	Baseline	30.87	2.65	48	3.94	100.19
		Test	29.77	1.52	211	-0.77	119.07
Clear Night	A-C/VIS	Baseline	33.00	1.80	140	0.19	120.51
		Test	33.78	1.04	323	-3.68	105.22
	Commercial C/VIS	Baseline	35.25	2.14	121	0.38	115.71
		Test	32.73	1.29	294	-0.38	121.47
Inclement Day	A-C/VIS	Baseline	44.19	22.02	4	20.45	110.21
		Test	41.81	8.39	18	9.60	113.31
	Commercial C/VIS	Baseline	10.72	4.87	7	-3.87	28.70
		Test	28.07	2.58	37	7.52	84.00
Inclement Night	A-C/VIS	Baseline	29.37	5.04	12	12.13	60.06
		Test	30.39	2.76	43	3.84	85.25
	Commercial C/VIS	Baseline	30.11	4.36	15	14.05	80.32
		Test	27.98	2.38	38	9.63	72.86

Drivers' Visual Behavior when Changing Lanes

Drivers' visual behavior when changing lanes was investigated. There was a particular interest in determining whether drivers' eye glance patterns changed when driving with a C/VIS. Drivers' eye glance patterns during the interval of time spanning 8 s prior to initiating a lane change and 5 s after initiating a lane change were analyzed. Because drivers' eye glance patterns were expected to differ according to the direction of the lane-change maneuver, the analyses were performed separately for left and right lane changes.

Eye Glance Probabilities for Left Lane Changes

Figure 154 shows the mean probability that drivers looked in a specific location during the Baseline and Test conditions. Drivers' mean probability of looking forward was 0.66 in both the Baseline and Test conditions. This suggests that the C/VISs did not divert drivers' visual attention away from the forward roadway.

Drivers' mean probability of looking at the left west coast/convex mirror was 0.27 in the Baseline condition, and 0.26 in the Test condition. A 2 (C/VIS) x 2 (Condition) Mixed Factors ANOVA was performed on the left west coast/convex mirror eye glance probability. The mean

probability of looking at the left west coast/convex mirror was not found to be significantly different when driving with a C/VIS ($F(1, 10) = 1.23, p = 0.2942$).

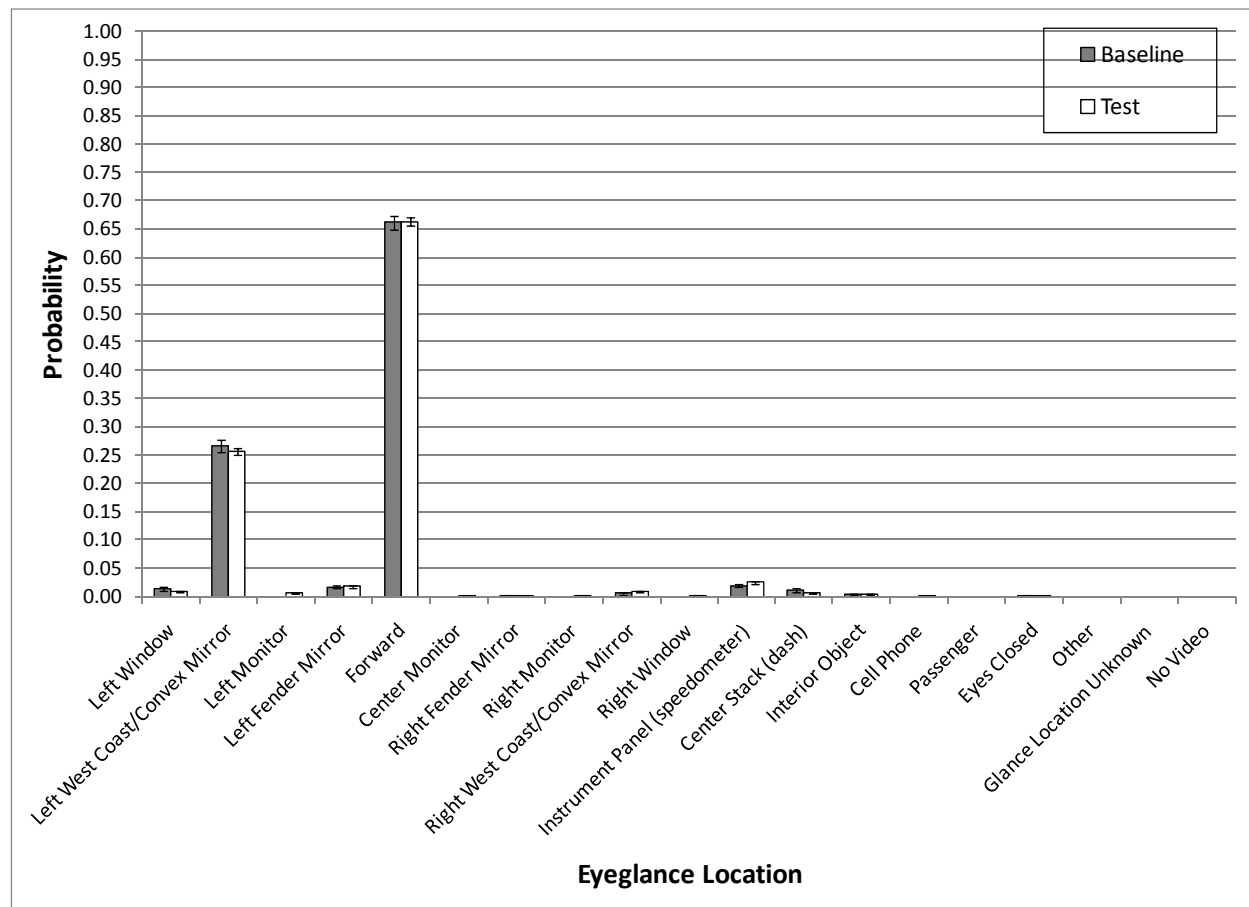


Figure 154. Mean Probability that Drivers Looked in a Location when Making a Left Lane Change by Experimental Condition

Figure 155 shows the mean probability that drivers looked in a specific location by Experimental Condition and C/VIS. The mean probability of looking forward for drivers of A-C/VIS-equipped trucks was 0.68 in the Baseline condition and 0.70 in the Test condition. The mean probability of looking forward for drivers of commercial C/VIS-equipped trucks was 0.64 in both the Baseline and Test conditions. A Condition x C/VIS interaction was not found ($F(1, 10) = 0.05, p = 0.822$). Neither the A-C/VIS nor the commercially available C/VIS was found to divert drivers' visual attention away from the forward roadway.

The mean probability of looking at the left west coast/convex mirror for drivers of A-C/VIS-equipped trucks was 0.25 in the Baseline condition and 0.21 in the Test condition. The mean probability of looking at the left west coast/convex mirror for drivers of commercial C/VIS-equipped trucks was 0.28 in the Baseline condition, and 0.29 in the Test condition. A Condition x C/VIS interaction pertaining to the probability of looking at the left west coast/convex mirror was not found ($F(1, 10) = 1.83, p = 0.2058$).

The probability that drivers of A-C/VIS-equipped trucks looked at the left monitor was 0.0056, while the probability that drivers of commercial C/VIS-equipped trucks looked at the left monitor was 0.0065. A One Way ANOVA did not find these means to be significantly different ($F(1, 10) = 1.18, p = 0.3029$). The probability that drivers of A-C/VIS-equipped trucks looked at the right monitor was 0.0015, while the probability that drivers of commercial C/VIS-equipped trucks looked at the right monitor was 0.0015. The probability that drivers of A-C/VIS-equipped trucks looked at the center monitor was 0.0021. These data indicate that drivers spent very little time directly looking at the monitors when changing lanes.

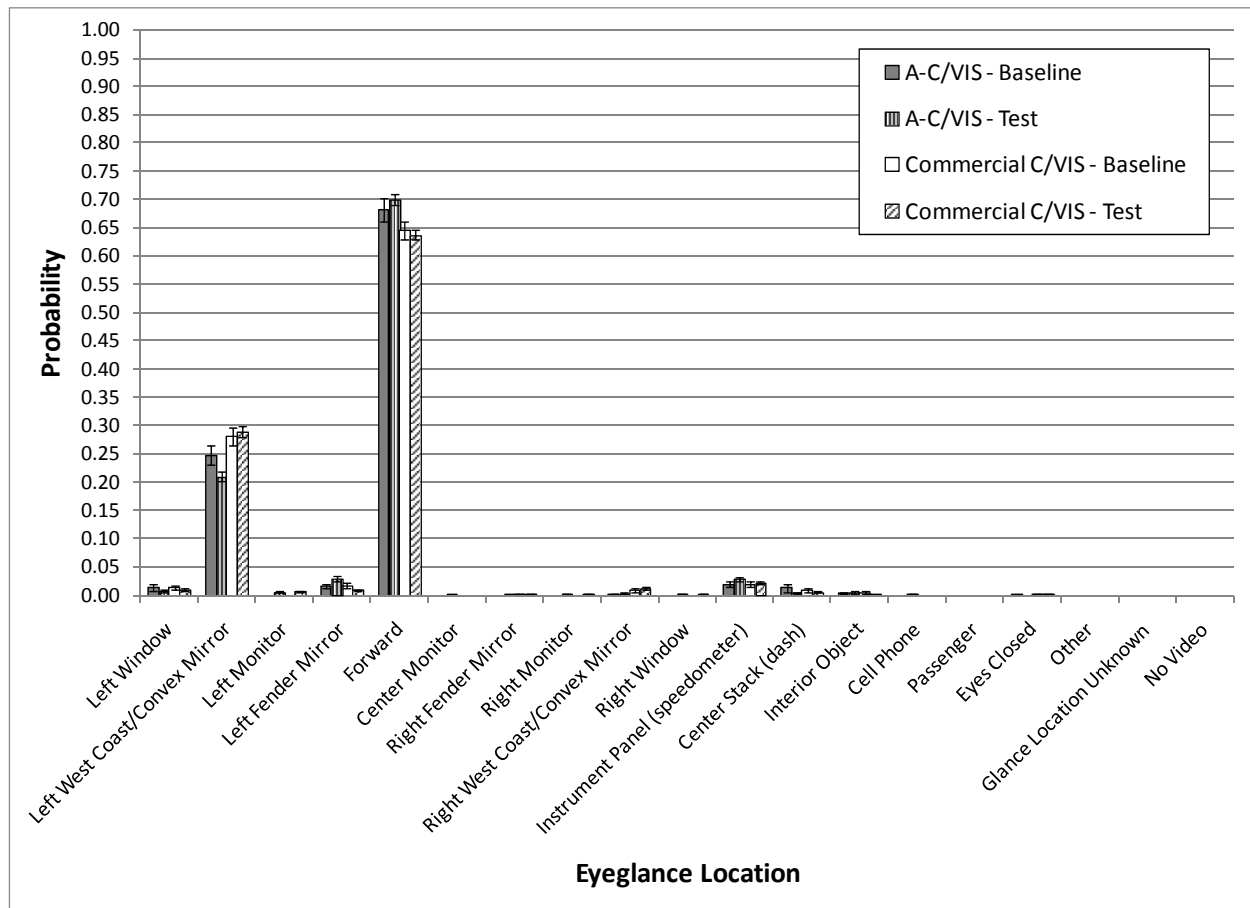


Figure 155. Mean Probability that Drivers Looked in a Location when Making a Left Lane Change by Experimental Condition and C/VIS

Percentage of Left Lane Changes that Drivers Looked at least Once

The percentage of left lane changes in which drivers looked at least once in a given location was examined. Figure 156 shows the percentage of lane changes in which drivers looked in the recorded eye glance locations during the Baseline and Test conditions. With respect to the Baseline condition, all drivers looked forward and at the left west coast/convex mirror at least once. They also looked at the left fender mirror in 29 percent of the left lane changes. In the Test condition, all drivers looked forward at least once, they looked at the left west coast/convex mirror in 98 percent of the lane changes, and they looked at the left fender mirror in 23 percent of the lane changes. A Cochran-Mantel-Haenszel test did not find the percentage of lane changes

in which drivers looked at the left fender mirror to significantly differ between the Baseline and Test conditions ($\chi^2_{CMH}(1) = 2.4234$, $p = 0.1195$). Drivers looked at the left monitor in 11 percent of the lane changes, at the right monitor in 2 percent of the lane changes, and at the center monitor in 5 percent of the lane changes.

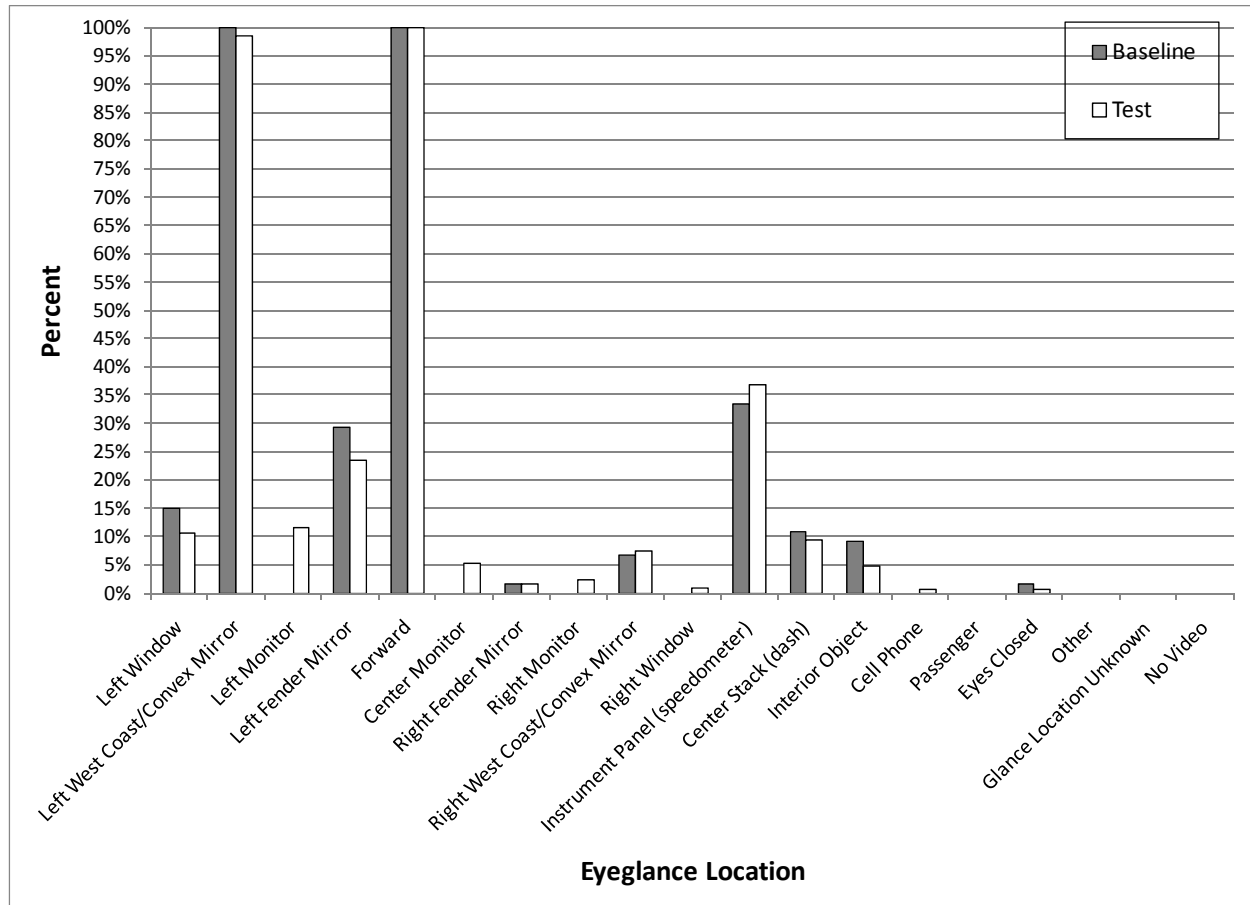


Figure 156. Percentage of Left Lane Changes in which Drivers Looked at Least Once to the Recorded Locations by Experimental Condition

Figure 157 shows the percentage of left lane changes in which drivers looked in the recorded eye glance locations by C/VIS and Experimental Condition. Drivers of commercial C/VIS-equipped trucks were found to look at the left fender mirror less frequently when driving with a C/VIS ($\chi^2_{CMH}(1) = 6.6614$, $p = 0.0099$). Drivers of A-C/VIS-equipped trucks looked at the left monitor in 8 percent of the left lane changes, at the center monitor in 5 percent of the left lane changes, and at the right monitor in 3 percent of the left lane changes. Drivers of commercial C/VIS-equipped trucks looked at the left monitor in 14 percent of the left lane changes, and at the right monitor in 3 percent of the left lane changes.

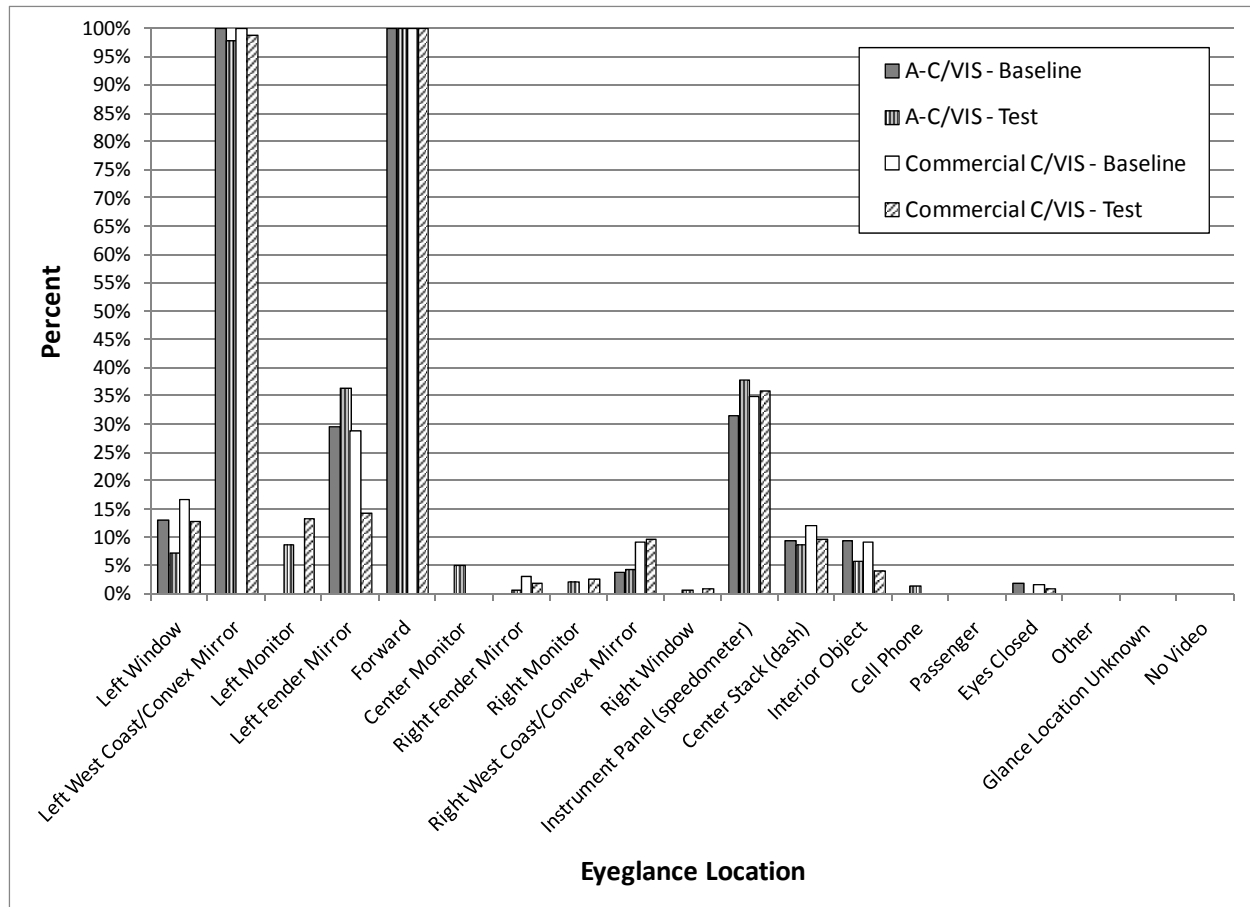


Figure 157. Percentage of Left Lane Changes in Which Drivers Looked at Least Once at a Given Location

Mean Number of Glances When Making Left Lane Changes

The mean number of times drivers looked at a recorded glance location when making a left lane change is shown in Figure 158 by experimental condition. It can be seen that in the Baseline condition, drivers looked at the forward location, on average, 4.67 times (SE = 0.12, n = 120, Min = 2.00, Max = 8.00) while they looked forward in the Test condition, on average, 4.65 times (SE = 0.07, n = 332, Min = 2.00, Max = 10.00). In the Baseline condition, drivers looked at the left west coast/convex mirror, on average, 3.08 times (SE = 0.02, n = 120, Min = 1.00, Max = 7.00) while they looked at the left west coast/convex mirror in the Test condition, on average, 2.96 times (SE = 0.06, n = 327, Min = 1.00, Max = 7.00). Drivers looked at the left monitor, on average, 1.18 times (SE = 0.07, n = 38, Min = 1.00, Max = 3.00), at the right monitor 1.13 times (SE = 0.13, n = 8, Min = 1.00, Max = 2.00), and at the center monitor 1.00 times (SE = 0.00, n = 7, Min = 1.00, Max = 1.00).

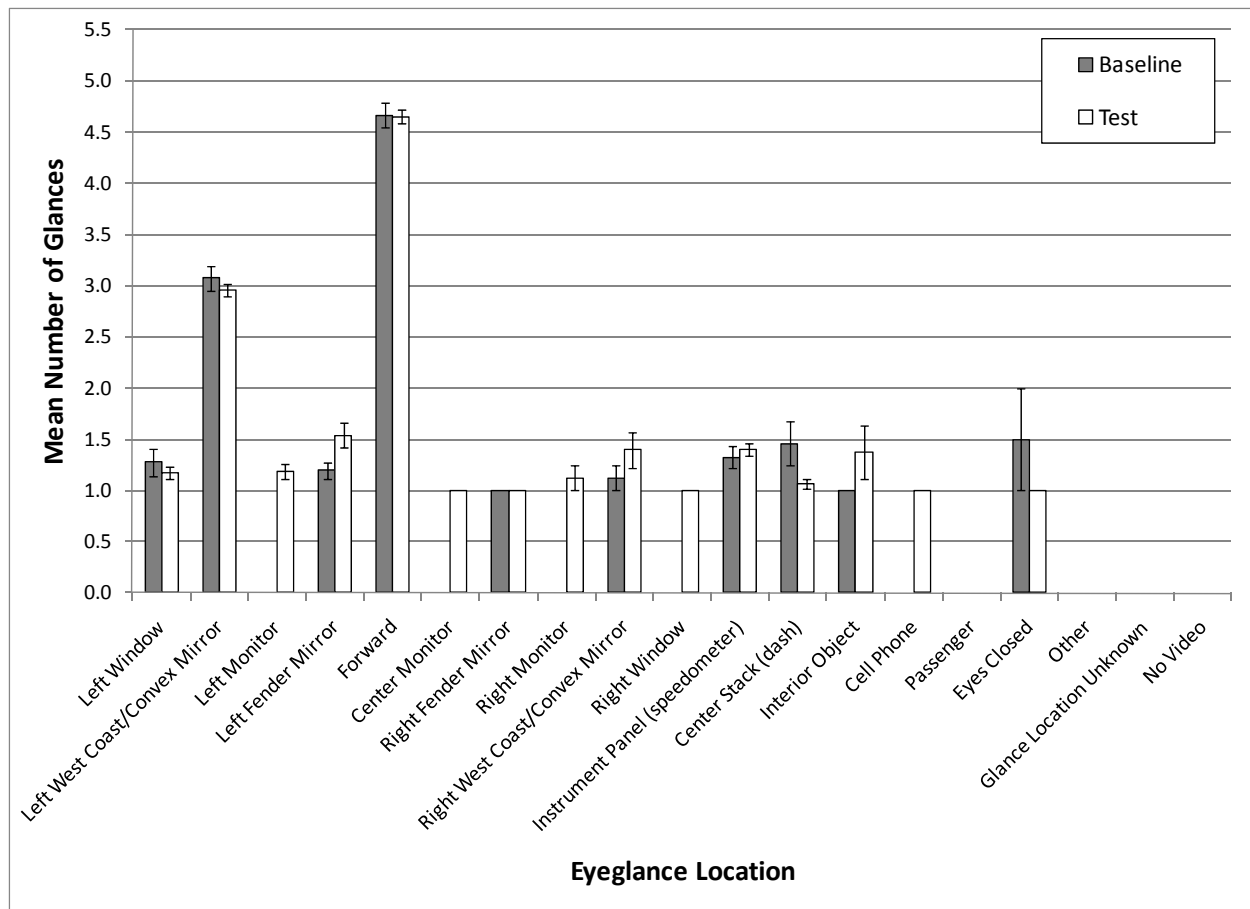


Figure 158. Mean Number of Glances when Making a Left Lane Change by Experimental Condition

The mean number of times drivers looked at a recorded glance location when making a left lane change is shown in Figure 159 by C/VIS and Experimental Condition. Again, it can be seen that drivers looked at the left west coast/convex mirror more times than either of the C/VIS monitors.

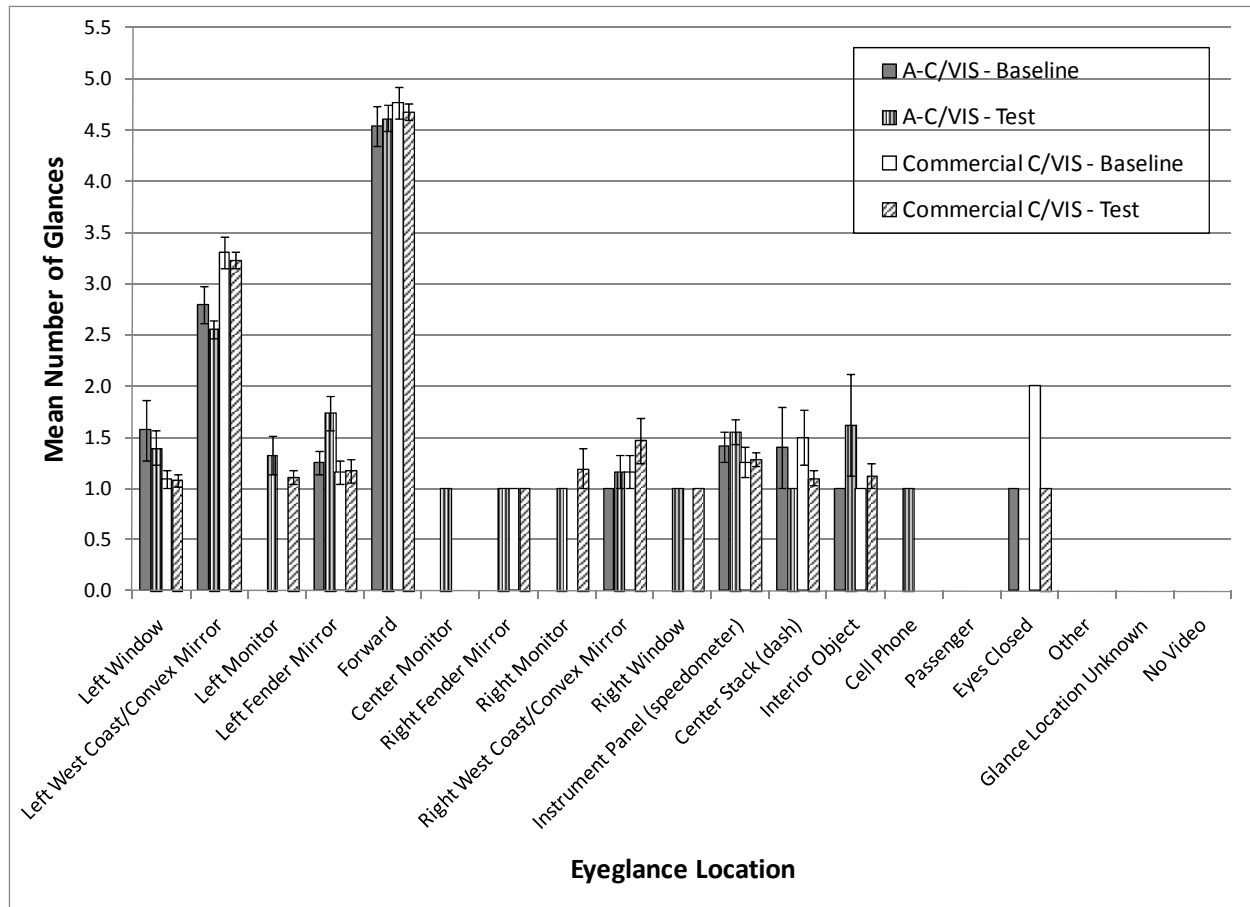


Figure 159. Mean Number of Glances when Making a Left Lane Change by C/VIS and Experimental Condition

Mean Glance Duration When Making Left Lane Changes

The mean amount of time drivers spent looking in the recorded glance locations when making a left lane change is shown in Figure 160 by experimental condition. It can be seen that drivers looked at the forward location, on average, 2.82 s in the Baseline condition (SE = 0.20 s, n = 120, Min = 0.10 s, Max = 8.50 s), while their mean forward glance duration was 2.81 s in the Test condition (SE = 0.12 s, n = 332, Min = 0.10 s, Max = 10.30 s). Drivers looked at the left west coast/convex mirror, on average, 0.98 s in the Baseline condition (SE = 0.04 s, n = 120, Min = 0.20 s, Max = 2.70 s), while their mean left west coast/convex mirror glance duration was 1.04 s in the Test condition (SE = 0.02 s, n = 327, Min = 0.20 s, Max = 3.00 s). Drivers' mean glance duration to the left monitor was 0.60 s (SE = 0.03 s, n = 38, Min = 0.30 s, Max = 1.20 s), their mean glance duration to the right monitor was 0.71 s (SE = 0.09 s, n = 8, Min = 0.50 s, Max = 1.30 s), and their mean glance duration to the center monitor was 0.53 s (SE = 0.04 s, n = 7, Min = 0.40 s, Max = 0.70 s).

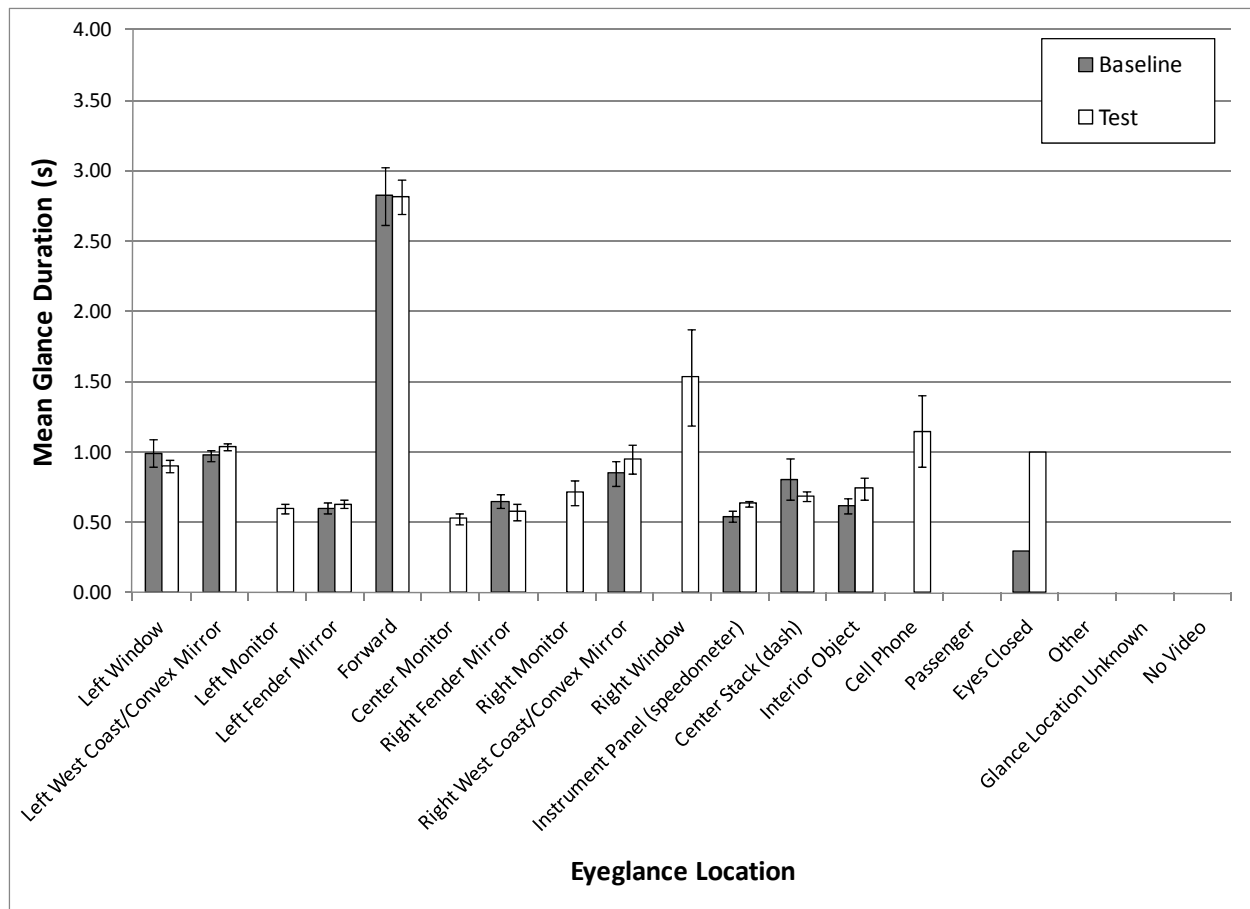


Figure 160. Mean Glance Duration Prior to Left Lane Change by Experimental Condition

The mean amount of time drivers spent looking in the recorded glance locations when making a left lane change is shown in Figure 161 by C/VIS and Experimental Condition. It can be seen that drivers spent more time looking at the left west coast/convex mirror than they did looking at the left monitor. Also, drivers spent the same amount of time looking at the left monitor as they did looking at the left fender mirror.

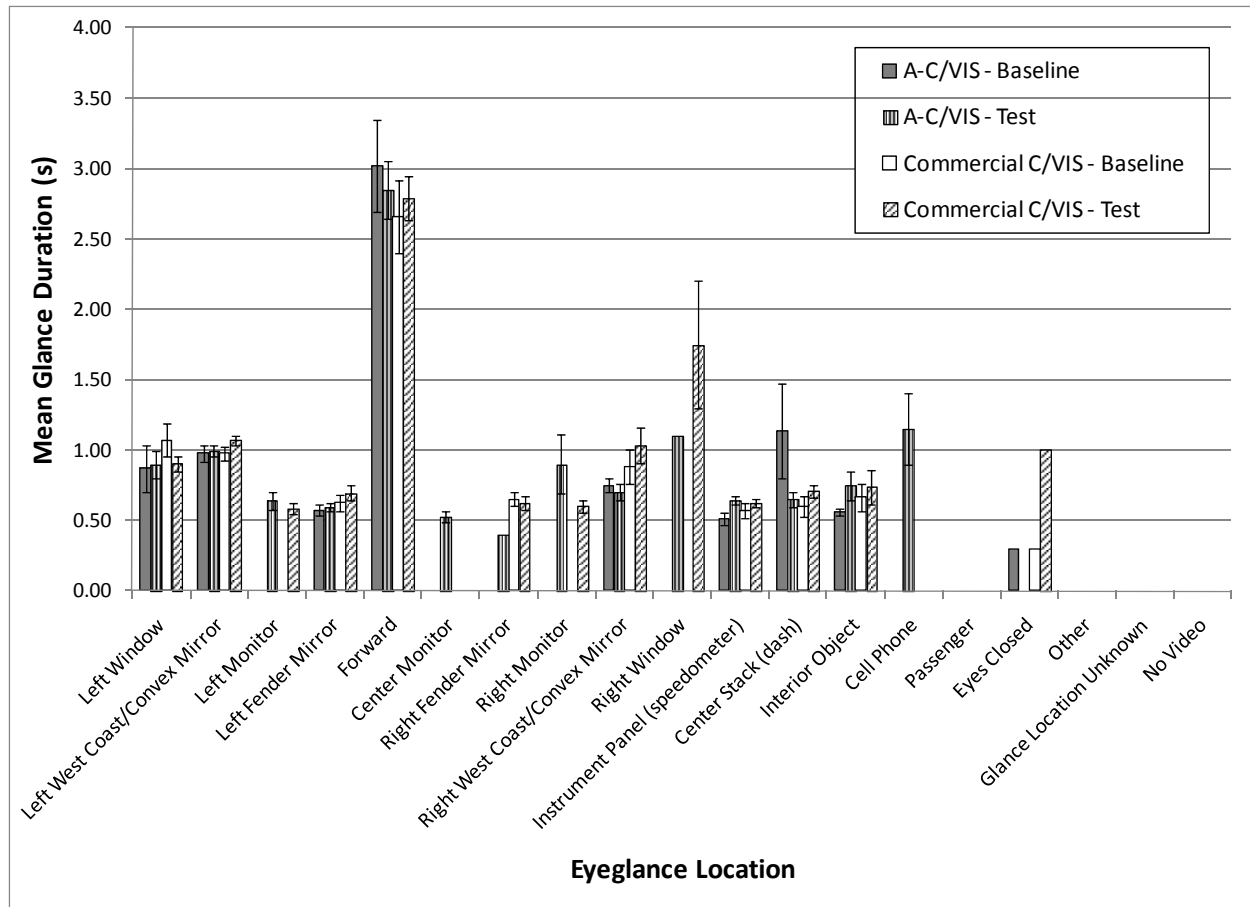


Figure 161. Mean Glance Duration when Making a Left Lane Change by C/VIS and Experimental Condition

Glance Probabilities for Right Lane Changes

Figure 162 shows the mean probability that drivers looked in a specific location during the Baseline and Test conditions. Drivers' mean probability of looking forward was 0.67 in the Baseline condition, while it was 0.66 in the Test condition. A 2 (C/VIS) x 2 (Condition) Mixed Factors ANOVA was performed on the forward eye glance probability dependent variable. These means were not found to be significantly different ($F(1, 10) = 0.72, p = 0.4173$).

Drivers' mean probability of looking at the right west coast/convex mirror was 0.25 in the Baseline condition, and 0.24 in the Test condition. These means were not found to be significantly different ($F(1, 10) = 0.38, p = 0.5526$).

Drivers' mean probability of looking at the right fender mirror was 0.04 in the Baseline condition, and 0.03 in the Test condition. These means were not found to be significantly different ($F(1, 10) = 1.01, p = 0.3395$).

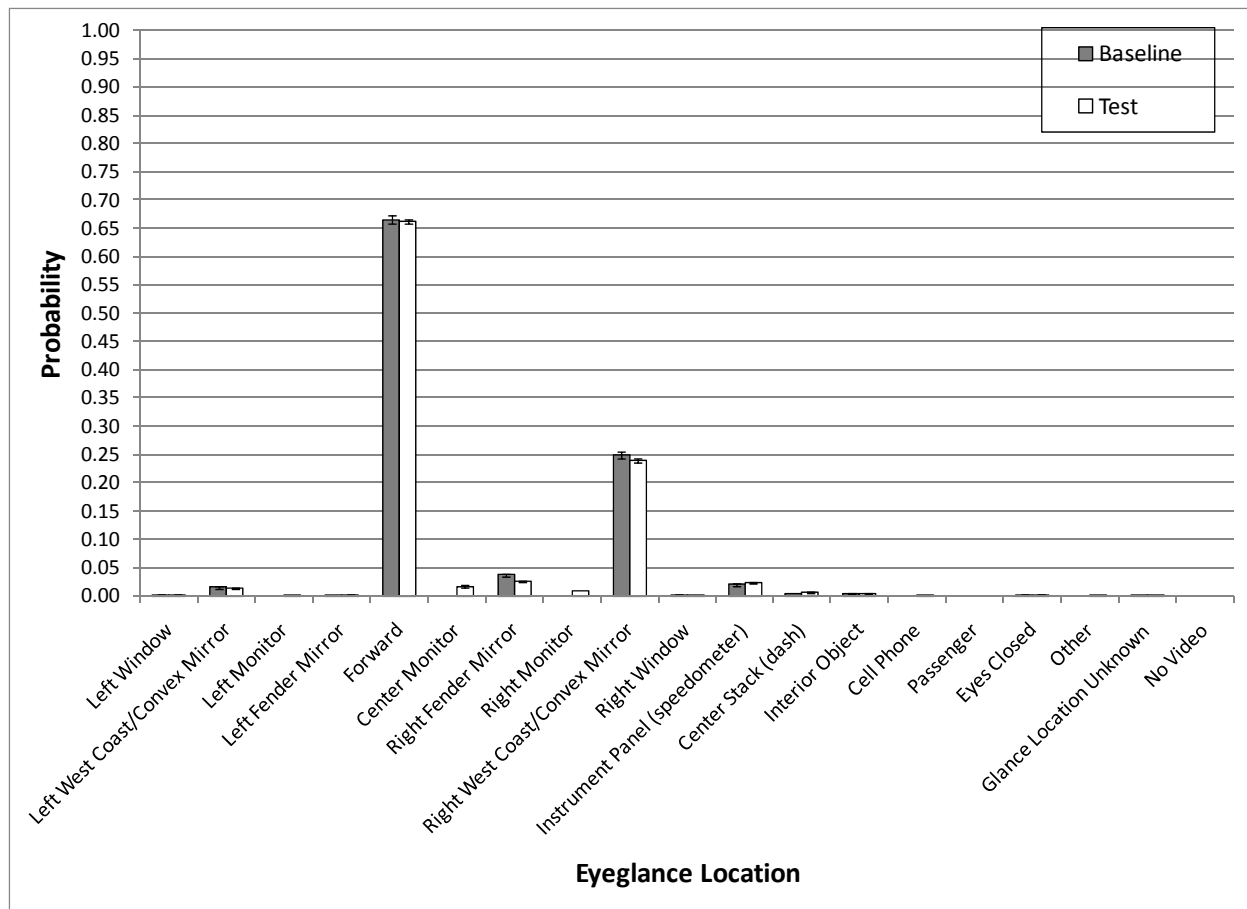


Figure 162. Mean Probability that Drivers Looked in a Location when Making a Right Lane Change by Experimental Condition

Figure 163 shows the mean probability that drivers looked in a specific location by Experimental Condition and C/VIS. The mean probability of looking forward for drivers of A-C/VIS-equipped trucks was 0.68 in both the Baseline and Test conditions. The mean probability of looking forward for drivers of commercial C/VIS-equipped trucks was 0.65 in both the Baseline and Test conditions. Driving with either C/VIS was not found to increase drivers' likelihood of looking forward, suggesting that the C/VISs do not divert drivers' visual attention away from the forward roadway.

The mean probability of looking at the right west coast/convex mirror for drivers of A-C/VIS-equipped trucks was 0.24 in the Baseline condition and 0.22 in the Test condition. The mean probability of looking at the right west coast/convex mirror for drivers of commercial C/VIS-equipped trucks was 0.26 in both the Baseline and Test conditions. A Condition x C/VIS interaction was not found ($F(1, 10) = 1.18, p = 0.3027$).

The probability that drivers of A-C/VIS-equipped trucks looked at the right monitor was 0.0067, while the probability that drivers of commercial C/VIS-equipped trucks looked at the right monitor was 0.0128. A One Way ANOVA did not find these means to be significantly different ($F(1, 10) = 0.08, p = 0.7802$). The probability that drivers of A-C/VIS-equipped trucks looked at the left monitor was 0.0011, while the probability that drivers of commercial C/VIS-equipped

trucks looked at the left monitor was 0.0008. The probability that drivers of A-C/VIS-equipped trucks looked at the center monitor was 0.0169. These data indicate that drivers spent very little time directly looking at the monitors when changing lanes.

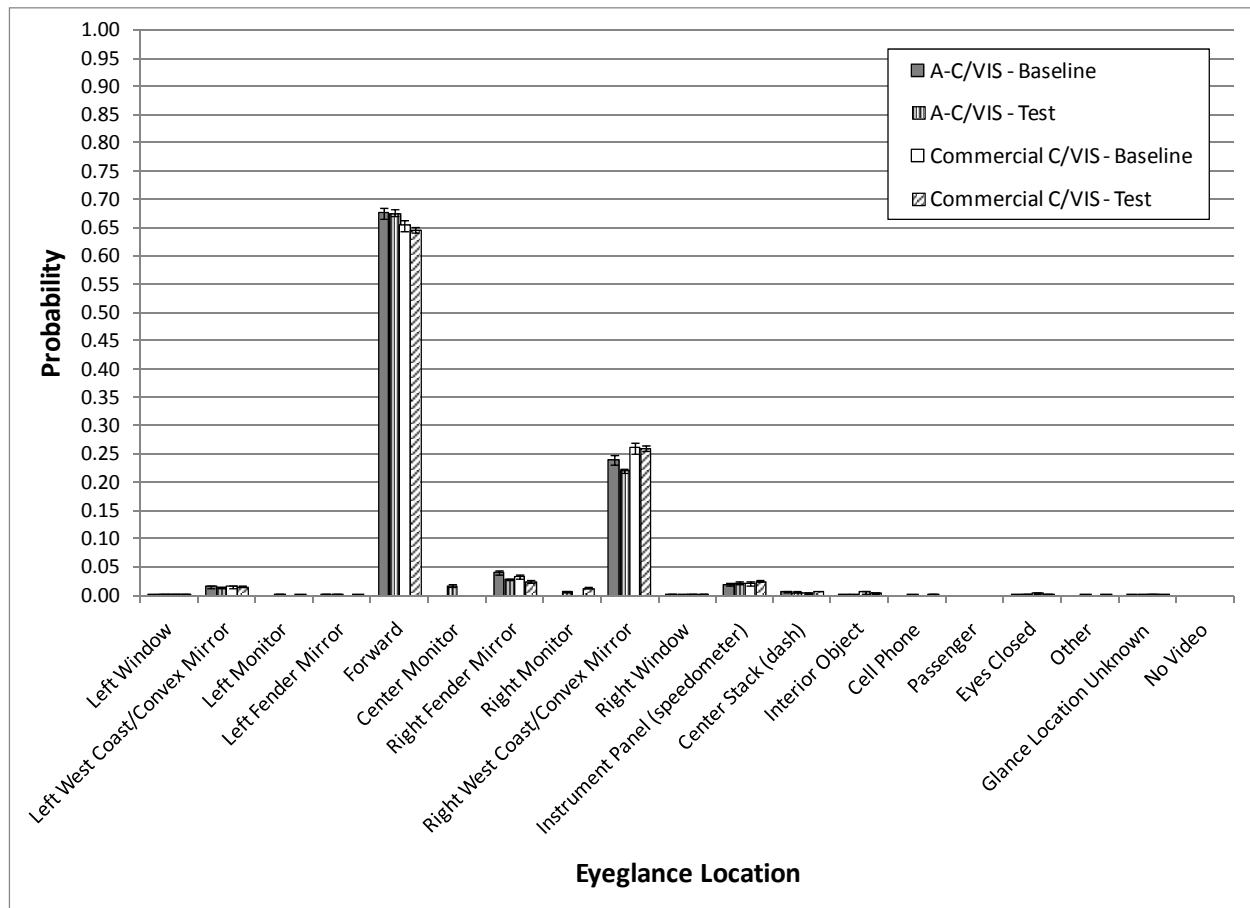


Figure 163. Mean Probability that Drivers Looked in a Location when Making a Right Lane Change by Experimental Condition and C/VIS

Percentage of Right Lane Changes that Drivers Looked at least Once

The frequency of right lane changes in which drivers looked at least once in a given location was evaluated. Figure 164 shows the percentage of lane changes in which drivers looked in the recorded eye glance locations during the Baseline and Test conditions.

Drivers looked forward at least once in every lane change made in the Baseline and Test conditions. Drivers looked at the right west coast/convex mirror in all of the lane changes made in the Baseline condition, and 99 percent of the lane changes made in the Test condition. Drivers looked at the right fender mirror in 51 percent of the lane changes made in the Baseline condition, and 39 percent of the lane changes made in the Test condition. Drivers looked at the right fender mirror less frequently when driving with a C/VIS ($\chi^2_{CMH}(1) = 17.6676, p < 0.0001$).

Drivers looked at the right monitor in 15 percent of the lane changes made in the Test condition, at the center monitor in 20 percent of the lane changes made in the Test condition, and at the left monitor in 2 percent of the lane changes made in the Test condition.

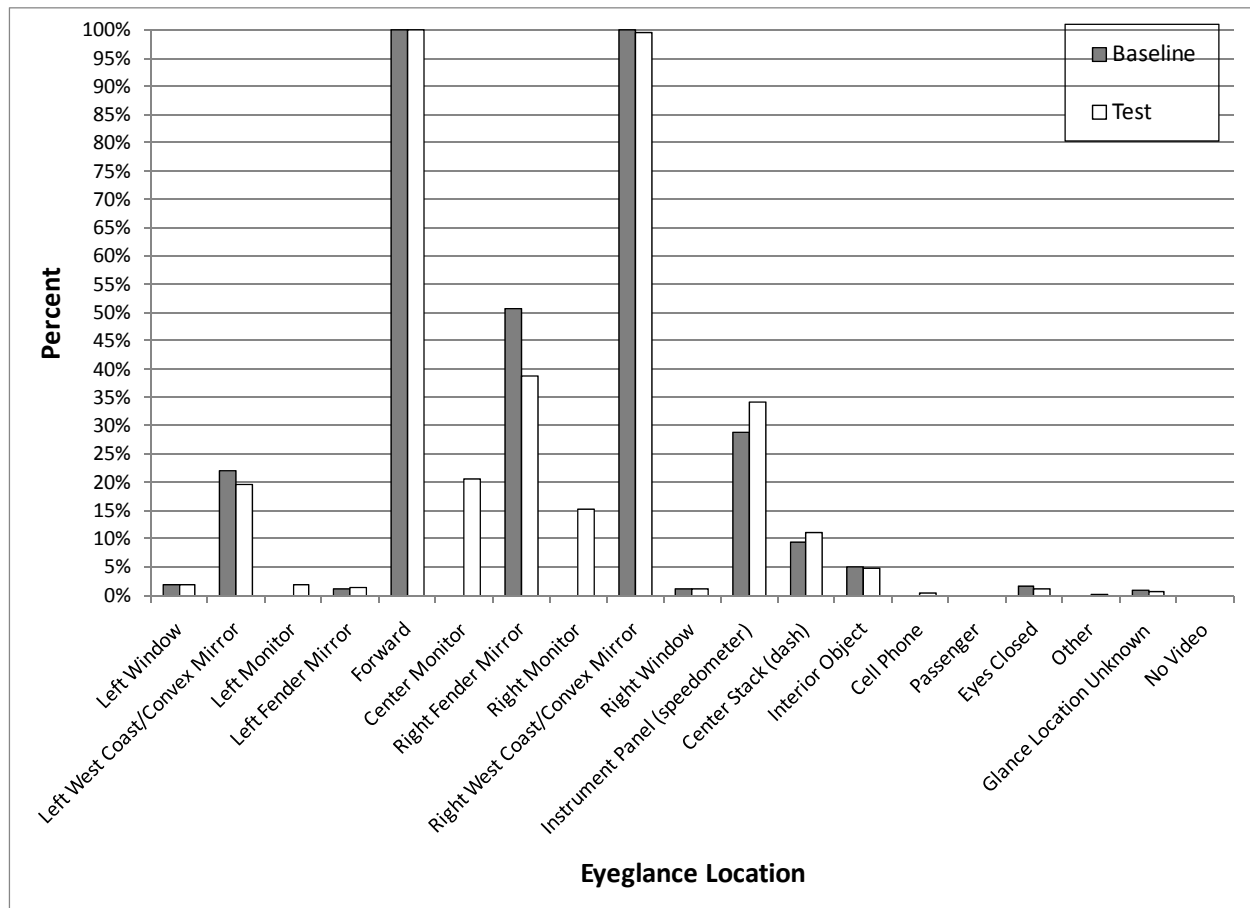


Figure 164. Percentage of Right Lane Changes in which Drivers Looked at Least Once to the Recorded Locations by Experimental Condition

Figure 165 shows the percentage of right lane changes in which drivers looked in the recorded eye glance locations by C/VIS and Experimental Condition. Drivers of A-C/VIS-equipped trucks significantly reduced their use of the right fender mirror when driving with a C/VIS ($\chi^2_{CMH(1)} = 16.8268, p < 0.0001$). Drivers of A-C/VIS-equipped trucks looked at the right monitor in 11 percent of the lane changes made in the Test condition, at the center monitor in 20 percent of the lane changes made in the Test condition, and at the left monitor in 2 percent of the lane changes made in the Test condition. Drivers of commercial C/VIS-equipped trucks looked at the right monitor in 20 percent of the lane changes made in the Test condition, and at the left monitor in 2 percent of the lane changes made in the Test condition. These data suggest that drivers used the C/VISs when making right lane changes, perhaps owing to the large blind spots that exist along the right side of the truck.

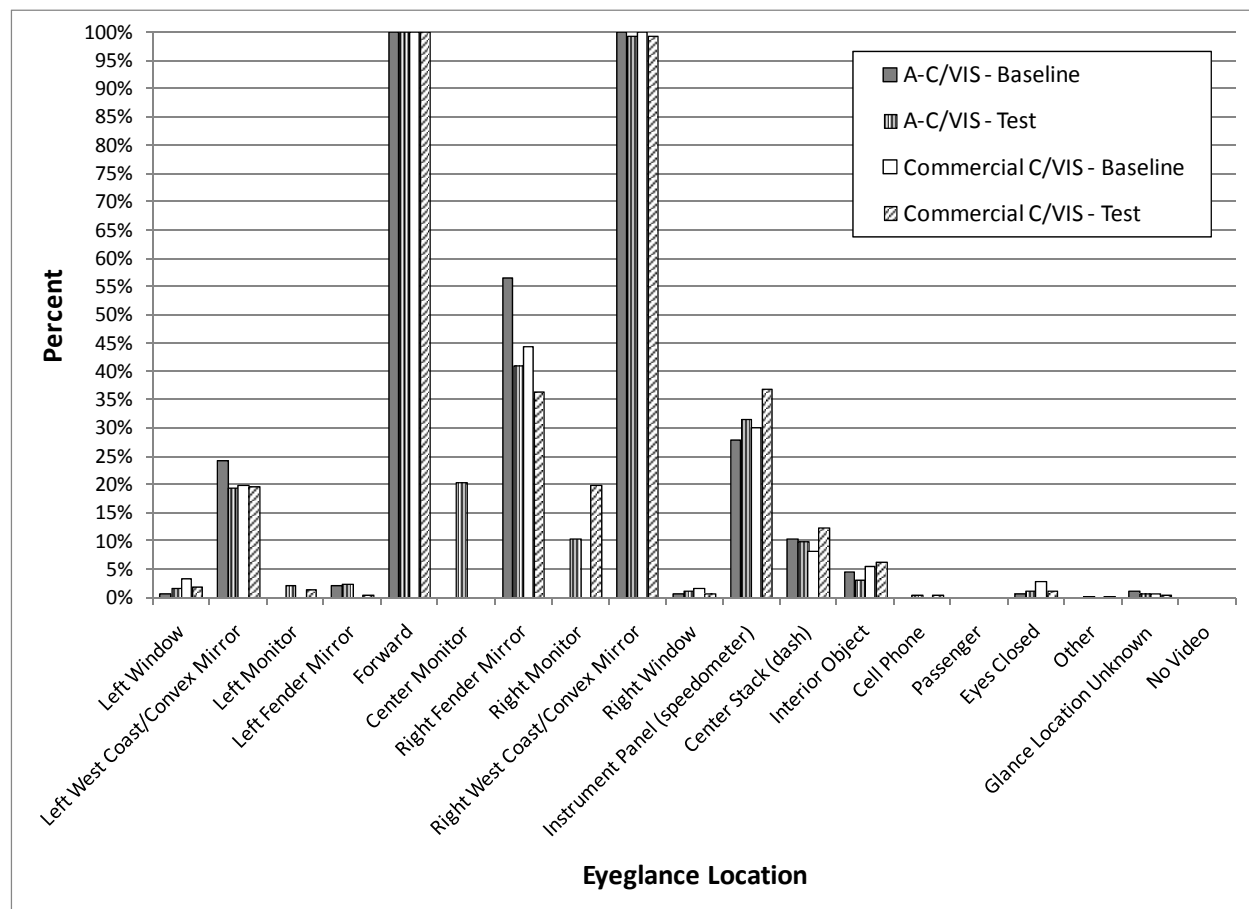


Figure 165. Percentage of Right Lane Changes in Which Drivers Looked at Least Once at a Given Location

Mean Number of Glances Prior to Right Lane Changes

The mean number of times drivers looked at a recorded glance location when making a right lane change is shown in Figure 166 by experimental condition. It can be seen that in the Baseline condition, drivers looked at the forward location, on average, 4.39 times (SE = 0.06, n = 389, Min = 2.00, Max = 9.00) while they looked forward in the Test condition, on average, 4.46 times (SE = 0.04, n = 1086, Min = 1.00, Max = 9.00). In the Baseline condition, drivers looked at the

right west coast/convex mirror, on average, 2.63 times (SE = 0.05, n = 389, Min = 1.00, Max = 7.00) while they looked at the right west coast/convex mirror in the Test condition, on average, 2.57 times (SE = 0.03, n = 1080, Min = 1.00, Max = 6.00).

Drivers looked at the right monitor, on average, 1.15 times (SE = 0.04, n = 165, Min = 1.00, Max = 5.00), at the center monitor, on average, 1.37 times (SE = 0.07, n = 111, Min = 1.00, Max = 5.00), and the left monitor, on average, 1.05 times (SE = 0.05, n = 20, Min = 1.00, Max = 2.00).

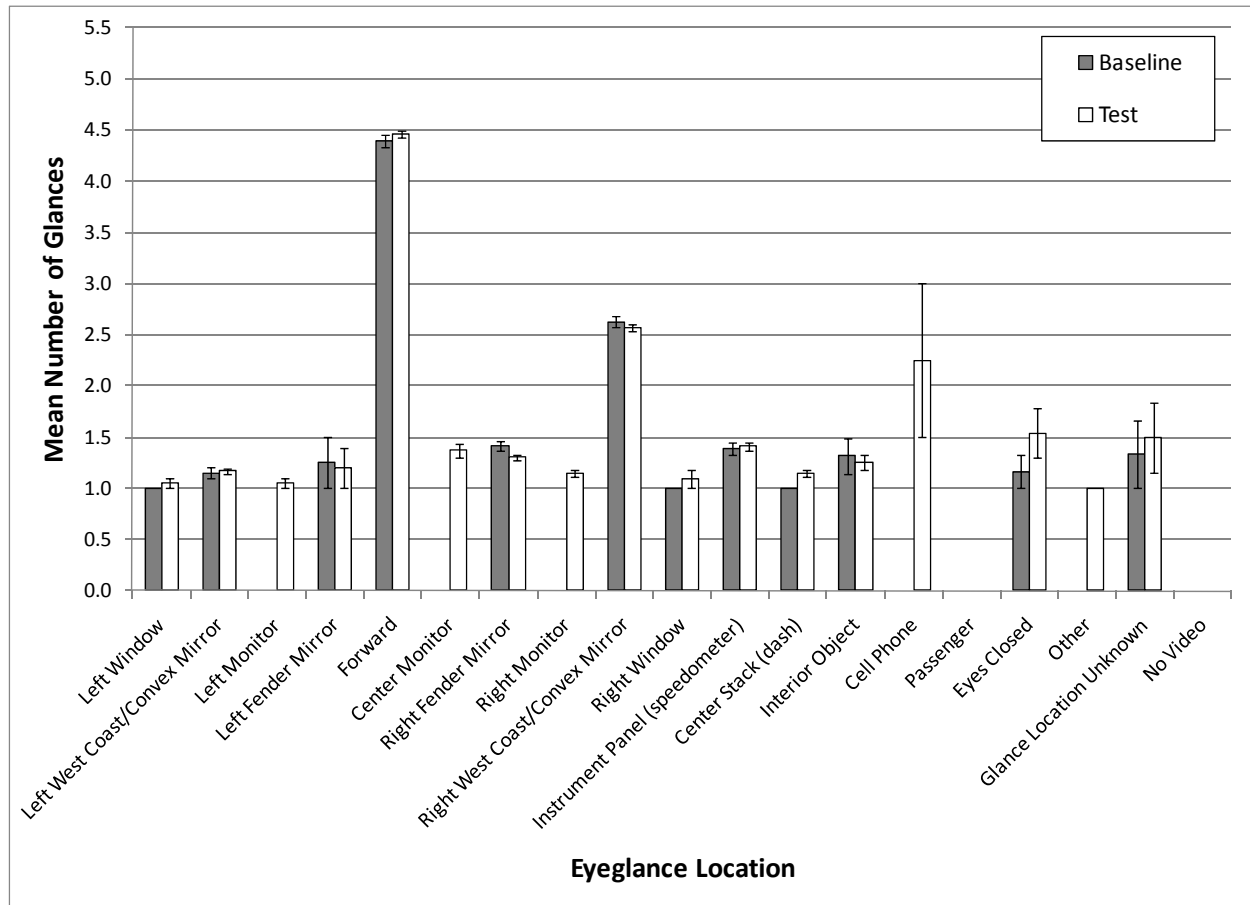


Figure 166. Mean Number of Glances when Making a Right Lane Change by Experimental Condition

The mean number of times drivers looked at a recorded glance location when making a right lane change is shown in Figure 167 by C/VIS and Experimental Condition. Drivers' visual behavior here does not appear to change when driving with a C/VIS.

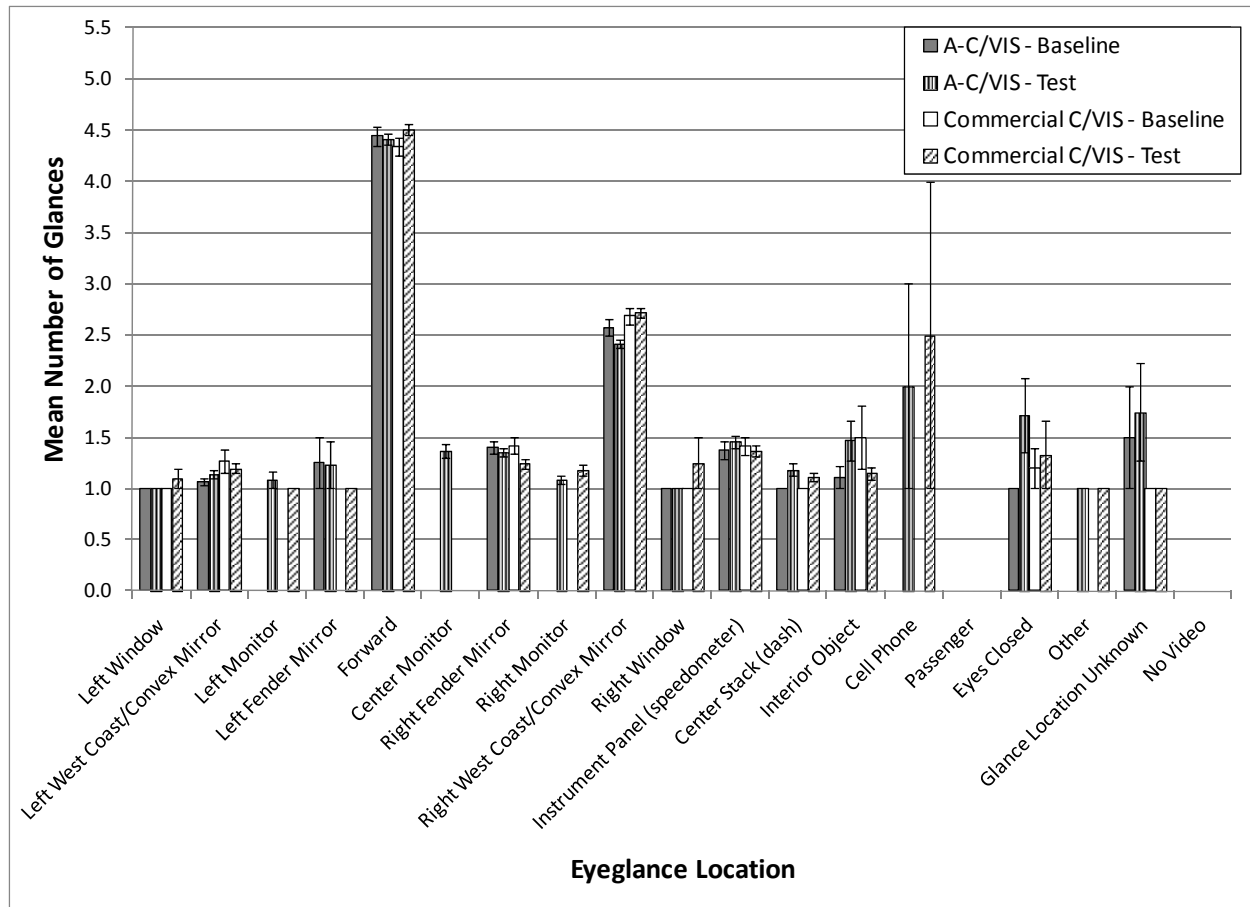


Figure 167. Mean Number of Glances when Making a Right Lane Change by C/VIS and Experimental Condition

Mean Glance Duration when Making Right Lane Changes

The mean amount of time drivers spent looking in the recorded glance locations when making a right lane change is shown in Figure 168 by experimental condition. It can be seen that in the Baseline condition, drivers looked at the forward location, on average, 3.52 s (SE = 0.13 s, n = 389, Min = 0.10 s, Max = 10.80 s) while their mean forward glance duration in the Test condition was 3.49 s (SE = 0.07 s, n = 1086, Min = 0.10 s, Max = 9.80 s). In the Baseline condition, drivers looked at the right west coast/convex mirror, on average, 1.21 s (SE = 0.02 s, n = 389, Min = 0.20 s, Max = 3.70 s) while their mean right west coast/convex mirror glance duration in the Test condition was 1.16 s (SE = 0.01 s, n = 1080, Min = 0.10 s, Max = 3.30 s). Drivers' mean eye glance duration when looking at the right monitor was 0.73 s (SE = 0.02 s, n = 165, Min = 0.20 s, Max = 1.60 s), 0.75 s when looking at the center monitor (SE = 0.04 s, n = 111, Min = 0.20 s, Max = 2.30 s), and 0.63 s when looking at the left monitor (SE = 0.06 s, n = 20, Min = 0.30 s, Max = 1.40 s).

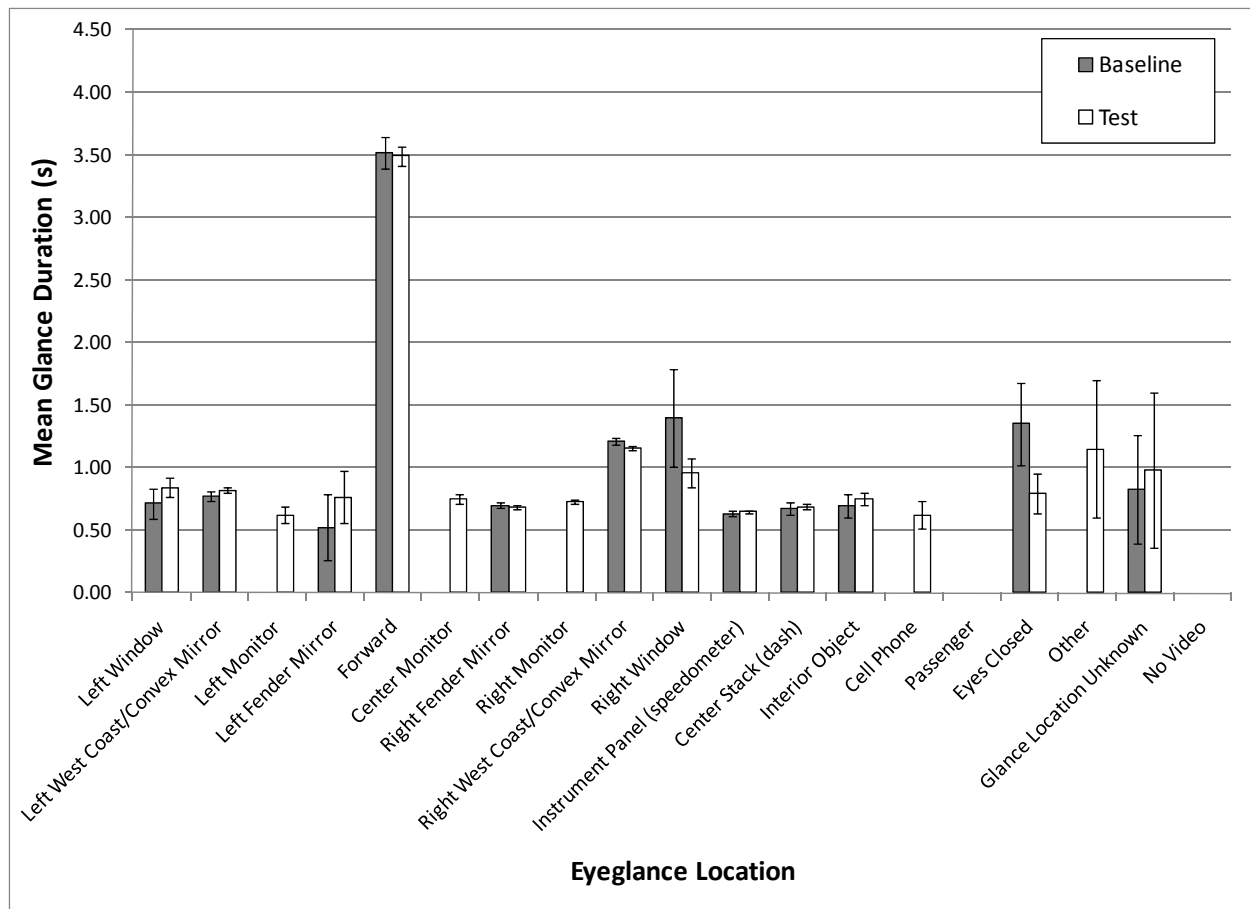


Figure 168. Mean Glance Duration when Making Right Lane Changes by Experimental Condition

The mean amount of time drivers spent looking in the recorded glance locations when making a right lane change is shown in Figure 169. For drivers of A-C/VIS-equipped trucks, the mean eye glance duration was 0.77 s when looking at the right monitor (SE = 0.03 s, n = 57, Min = 0.20 s, Max = 1.30 s), 0.75 s when looking at the center monitor (SE = 0.04 s, n = 111, Min = 0.20 s, Max = 2.30 s), and 0.57 s when looking at the left monitor (SE = 0.07 s, n = 12, Min = 0.30 s, Max = 1.10 s). For drivers of commercial C/VIS-equipped trucks, the mean eye glance duration was 0.71 s when looking at the right monitor (SE = 0.02 s, n = 108, Min = 0.20 s, Max = 1.60 s), and 0.71 s when looking at the left monitor (SE = 0.11 s, n = 8, Min = 0.40 s, Max = 1.40 s). It should be noted that there were only two observations of glances to the left fender mirror, one observation of a glance to the right window, and two observations of glance locations unknown during right lane changes; hence the reason for the large error bars.

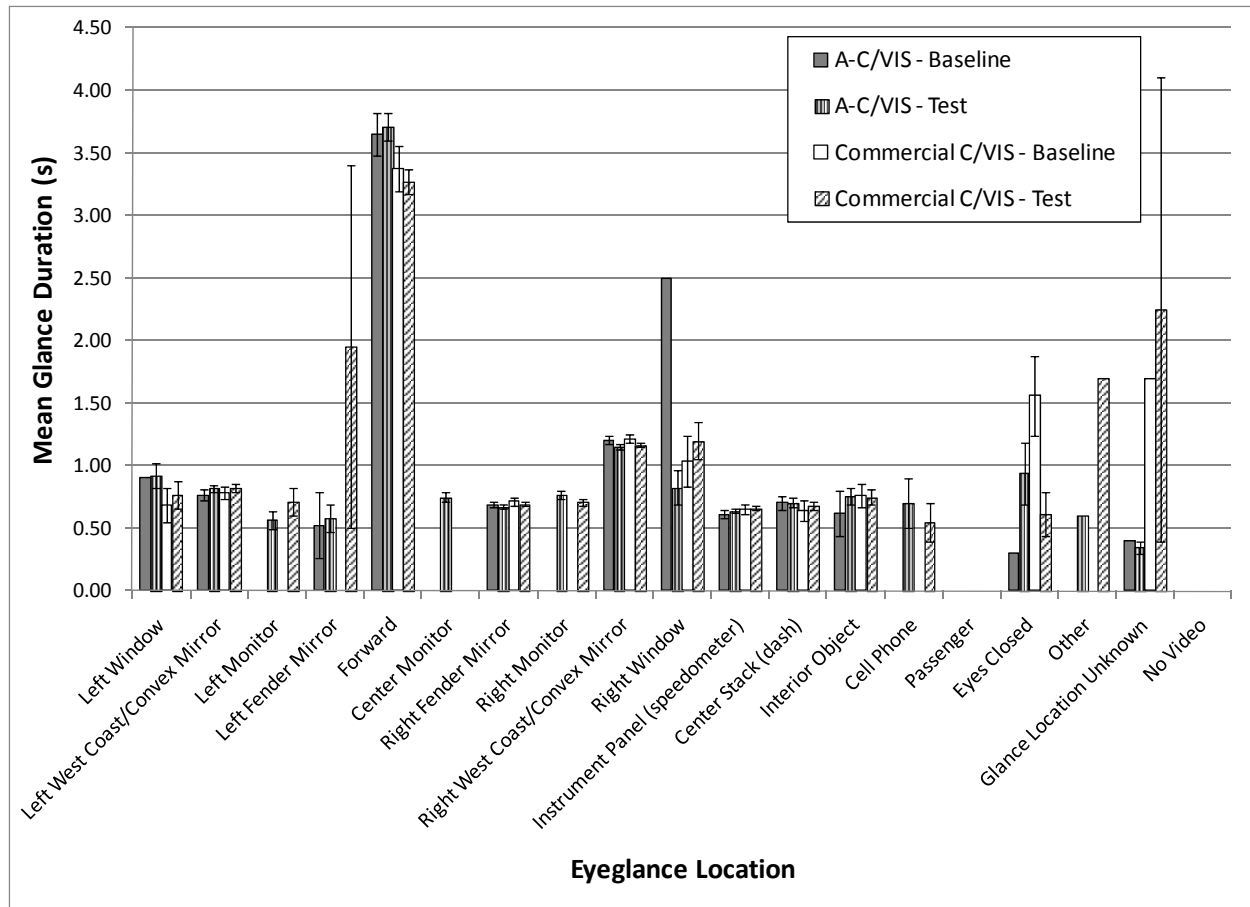


Figure 169. Mean Glance Duration when Making Right Lane Changes by C/VIS and Experimental Condition

Further Exploration of Drivers' Eye Glances Prior to Performing Lane Changes

Eye glance data beyond the 8 s prior to changing lanes were explored. Five lane changes per week for the first six drivers in the study were reviewed. For each, it was determined whether the driver looked at least one time at the monitors over the interval of time spanning 30 s prior to changing lanes to 8 s prior to changing lanes. A total of 200 lane changes were reviewed for this exploratory analysis. It was found that 20 percent of the 200 lane changes were made in which drivers looked at the monitors at least once in the 30 s-to-8 s time period. Drivers may only be using the monitors when they need reassurance that they have clearance to change lanes. Recall that the observed lane changes predominantly occur at night with few cars on the roadway. If the driver believes that he has enough clearance to change lanes, it is possible that he will not use the monitors.

Elapsed Time from Maneuver Initiation to Crossing Lane Markings

A 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA was performed on the time-to-cross-lane-markings dependent variable. A Condition main effect was not found ($F(1, 10) = 2.26, p = 0.164$). Drivers' mean time to cross lane markings in the Baseline condition was 2.22 s (SE = 0.05 s, $n = 528$, Min = 0.10 s, Max = 9.20 s), while their mean time to cross lane markings

in the Test condition was 2.01 s (SE = 0.02 s, n = 1482, Min = 0.10 s, Max = 6.70 s) (Figure 170).

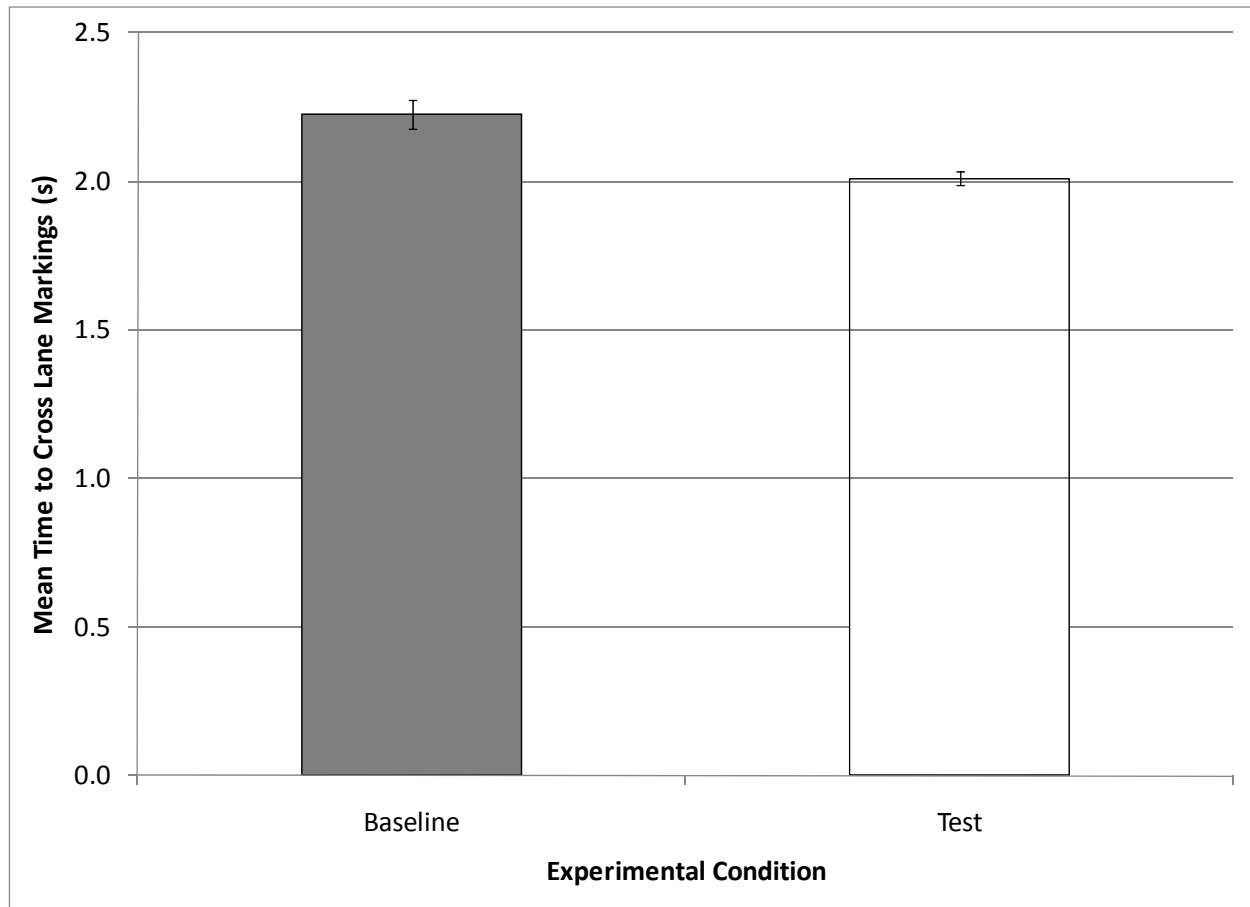


Figure 170. Drivers' Mean Time to Cross Lane Markings by Experimental Condition

Figure 171 shows drivers' mean time to cross lane markings by month in study. A 2 (System) x 4 (Month) Mixed Factors ANOVA was also performed on the time-to-cross-lane-markings dependent variable. A significant Month effect was found ($F(3, 29) = 6.06, p = 0.0025$). A Tukey HSD multiple comparisons test revealed that drivers' mean times to cross the lane markings in Months 3 and 4 were significantly shorter than their time to cross the lane markings in Month 1 ($p = 0.0078$ and $p = 0.0082$, respectively). Their mean time to cross lane markings in Month 1 was 2.22 s (SE = 0.05 s, n = 528, Min = 0.10 s, Max = 9.20 s), 2.14 s in Month 2 (SE = 0.04 s, n = 528, Min = 0.10 s, Max = 6.20 s), 1.96 s in Month 3 (SE = 0.04 s, n = 488, Min = 0.20 s, Max = 6.70 s), and 1.92 s in Month 4 (SE = 0.04 s, n = 466, Min = 0.10 s, Max = 5.50 s). Drivers were found to cross the lane markings sooner when driving with a C/VIS.

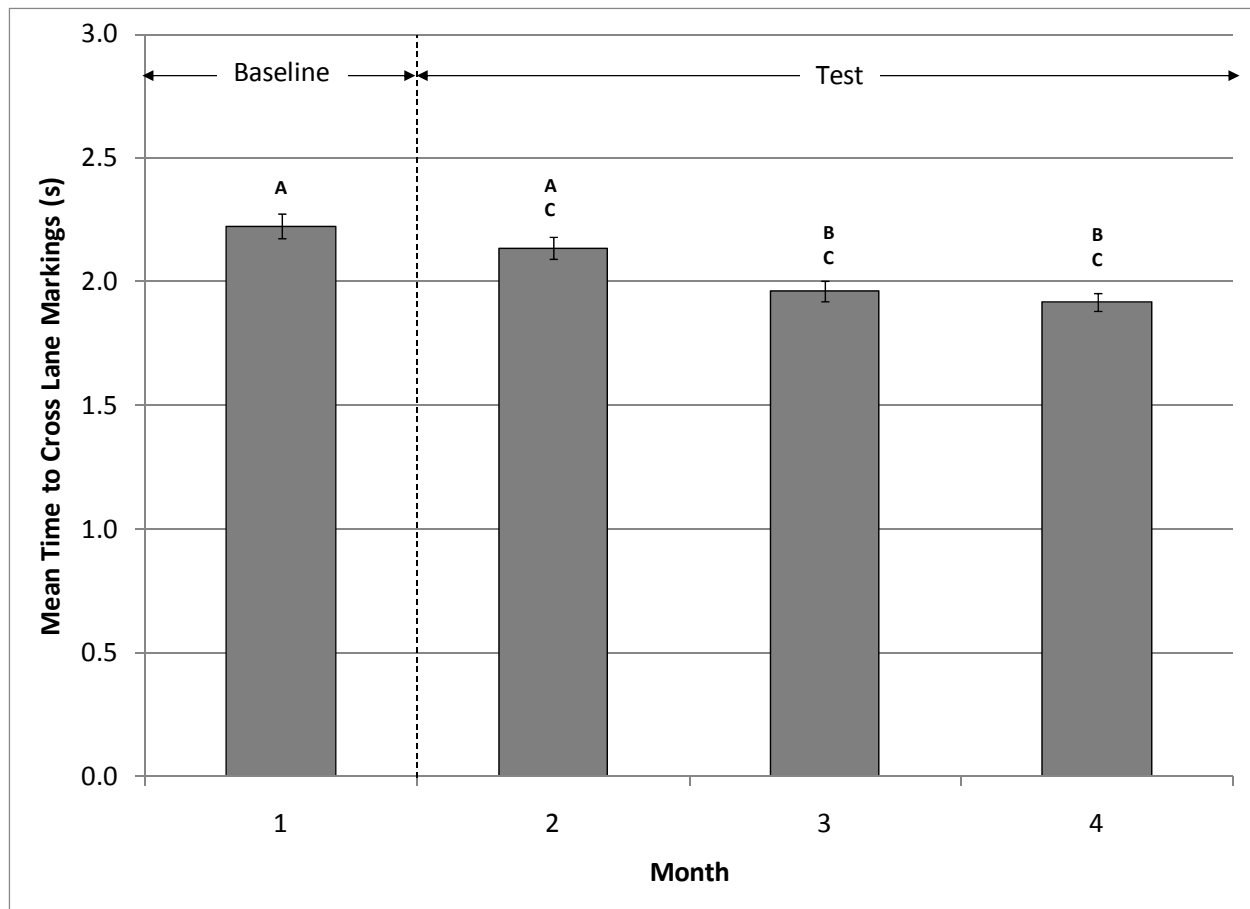


Figure 171. Drivers' Mean Time to Cross Lane Markings by Month in Study

With regard to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA that was performed, a C/VIS x Condition interaction was investigated to determine whether the time to cross lane markings adopted by drivers of A-C/VIS-equipped trucks, or commercial C/VIS-equipped trucks, differed across experimental condition. A C/VIS x Condition interaction was not found ($F(1, 10) = 0.49, p = 0.4987$). The mean time to cross lane markings for drivers of A-C/VIS-equipped trucks was 2.27 s in the Baseline condition (SE = 0.07 s, $n = 264$, Min = 0.10 s, Max = 9.20 s) and 2.07 s in the Test condition (SE = 0.03 s, $n = 691$, Min = 0.10 s, Max = 6.10 s) (Figure 172). The mean time to cross lane markings for drivers of commercial C/VIS-equipped trucks was 2.18 s in the Baseline condition (SE = 0.07 s, $n = 264$, Min = 0.10 s, Max = 7.40 s) and 1.96 s in the Test condition (SE = 0.03 s, $n = 791$, Min = 0.10 s, Max = 6.70 s). The lack of an interaction also means that the mean time to cross lane markings adopted by drivers using the A-C/VIS was not found to be significantly different from the mean time to cross lane markings adopted by drivers using the commercially available C/VIS.

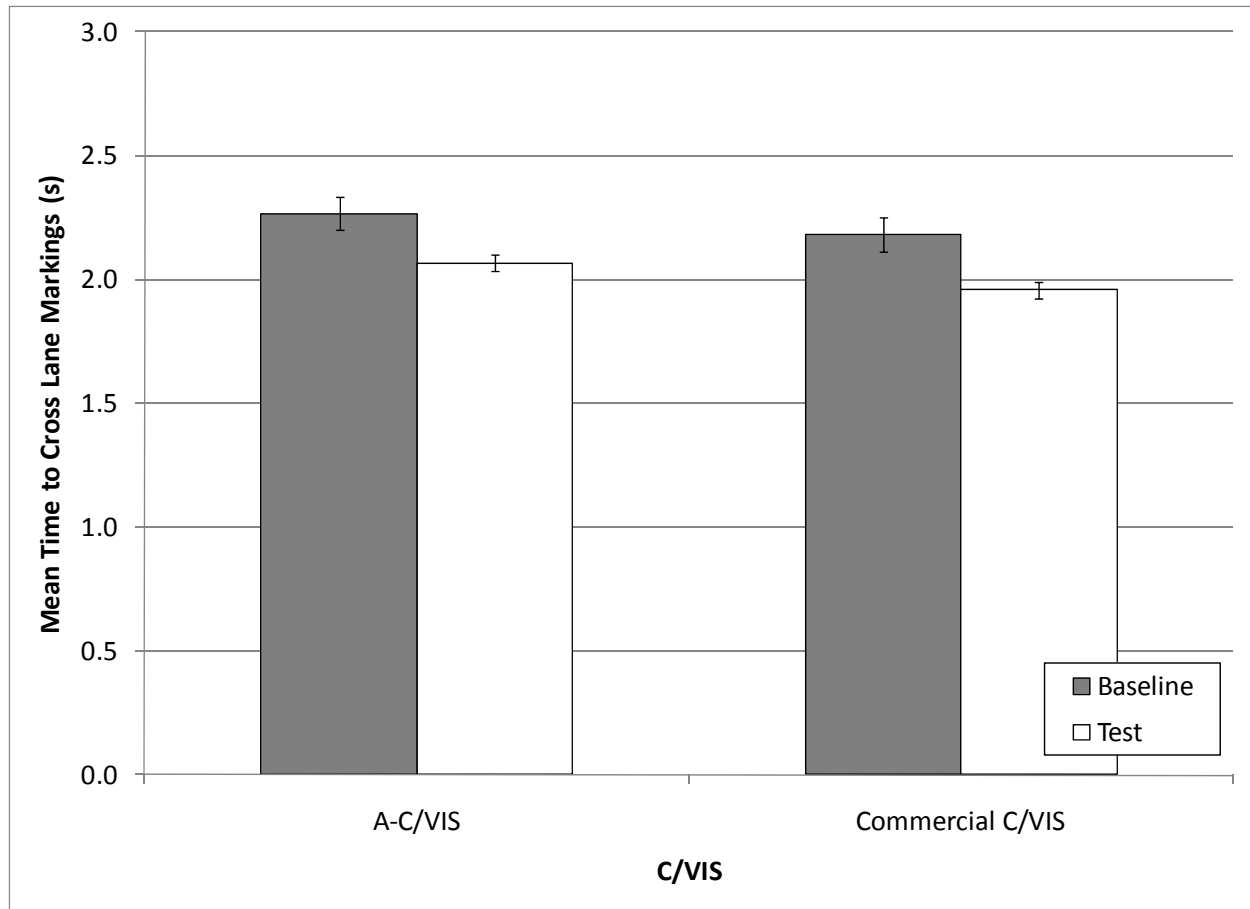


Figure 172. Drivers' Mean Time to Cross Lane Markings by C/VIS and Experimental Condition

With respect to the 2 (System) x 4 (Month) Mixed Factors ANOVA that was performed, a System x Month interaction was not found ($F(3, 29) = 0.65, p = 0.5898$). Figure 173 and Table 37 show the mean times to cross lane markings for drivers of both A-C/VIS-equipped and commercial C/VIS-equipped trucks by month in study. It appears as though drivers of both A-C/VIS-equipped trucks and commercial C/VIS-equipped trucks decreased their time to cross the lane markings when driving with a C/VIS.

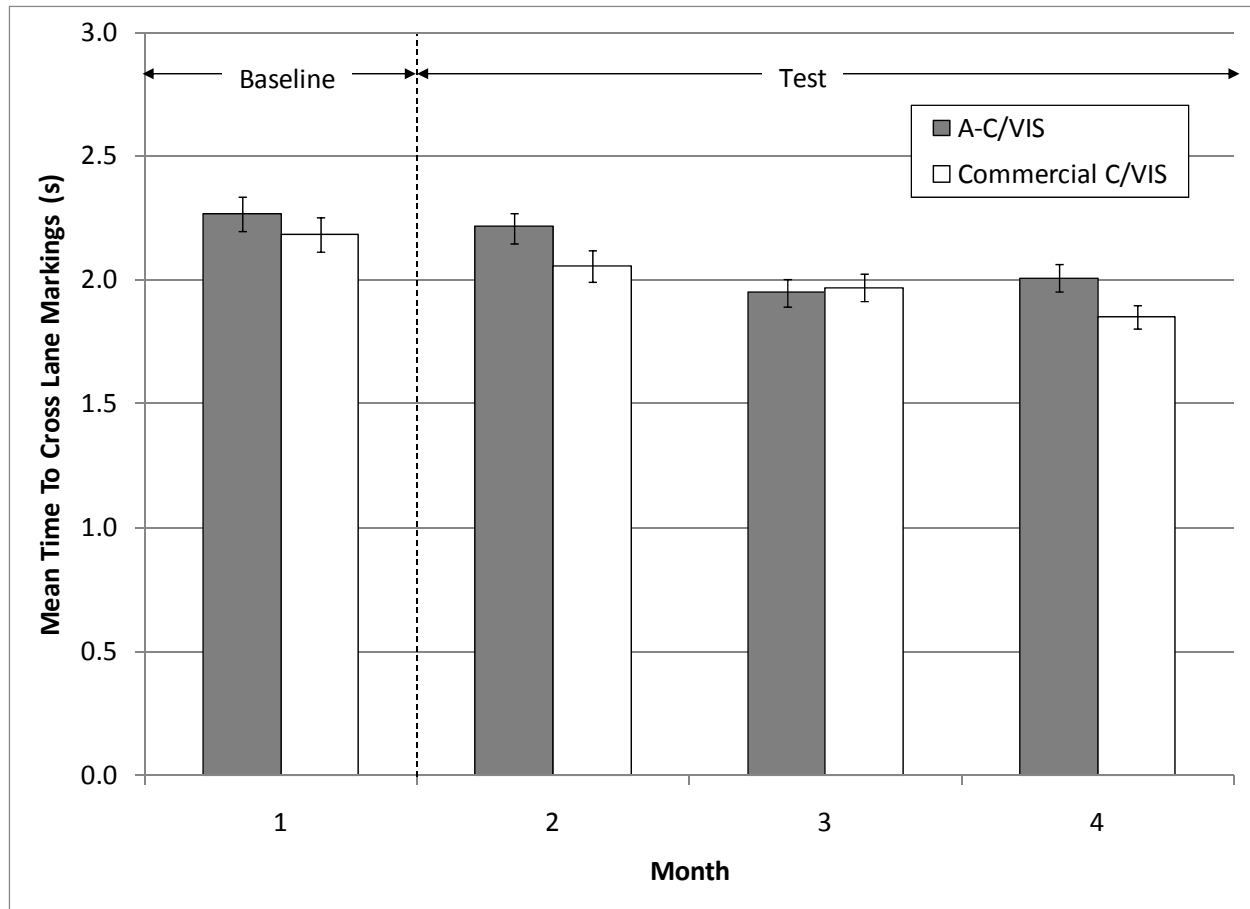


Figure 173. Drivers' Mean Time to Cross Lane Markings by C/VIS and Month in Study

Table 37. Drivers' Mean Time to Cross Lane Markings by C/VIS and Month in Study

C/VIS	Month	M (s)	SE (s)	n	Min (s)	Max (s)
A-C/VIS	1	2.30	0.08	208	0.10	9.20
	2	2.19	0.06	209	0.10	5.30
	3	1.96	0.06	185	0.20	6.10
	4	1.98	0.07	155	0.60	5.50
Commercial C/VIS	1	2.20	0.08	191	0.10	6.80
	2	2.04	0.08	185	0.10	6.20
	3	2.00	0.07	188	0.20	6.70
	4	1.86	0.05	207	0.10	4.40

With respect to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA that was performed, a Direction main effect was not found ($F(1, 10) = 1.95, p = 0.1925$). Drivers' mean time to cross lane markings to an adjacent vehicle when making left lane changes was 2.05 s ($SE = 0.05$ s, $n = 482$, Min = 0.10 s, Max = 7.40 s), while their mean time to cross lane markings when making right lane changes was 2.07 s ($SE = 0.02$ s, $n = 1528$, Min = 0.10 s, Max = 9.20 s) (Figure 174).

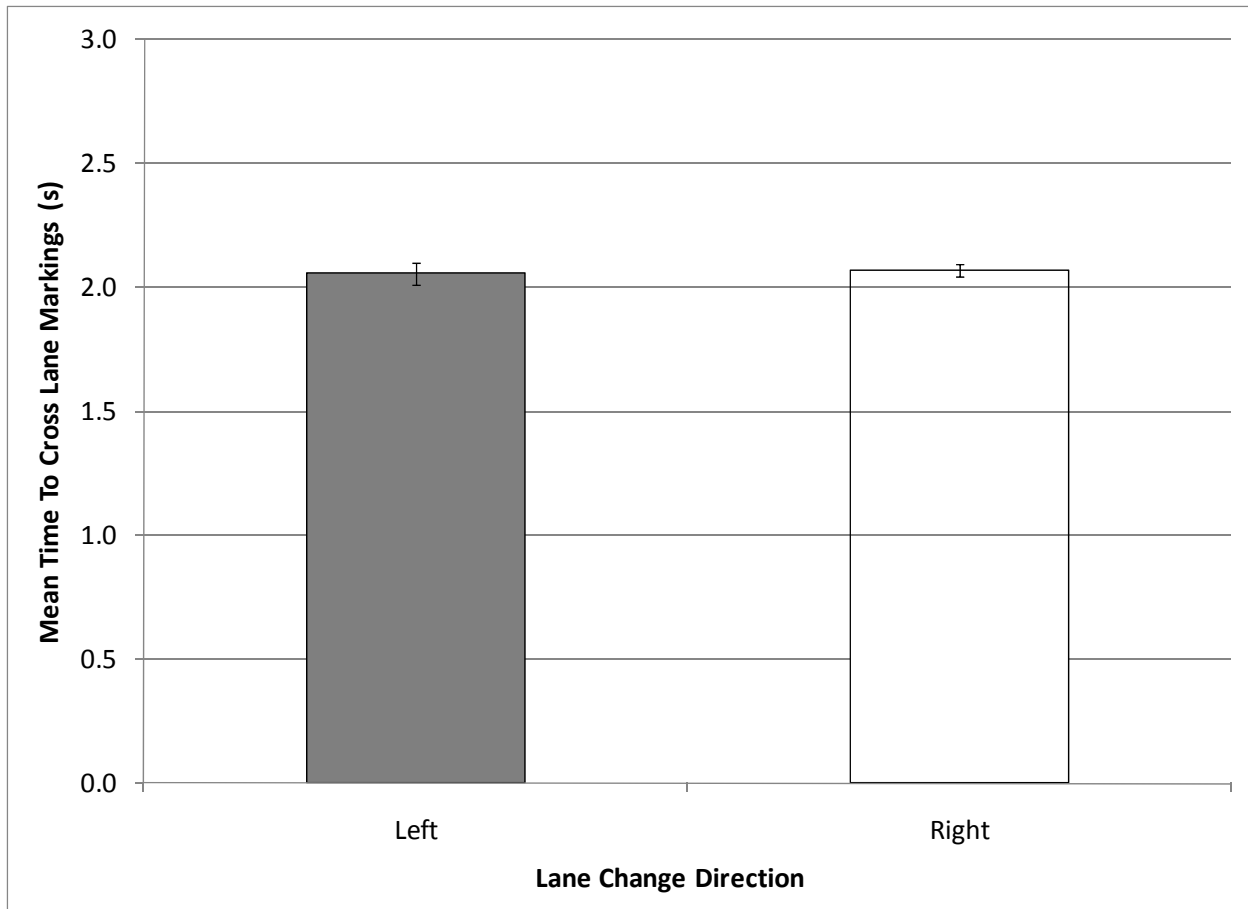


Figure 174. Drivers' Mean Time to Cross Lane Markings by Lane-Change Direction

Using the same ANOVA, a Condition x Direction interaction was tested to investigate whether drivers' mean time to cross lane markings when making left or right lane changes differed between the Baseline and Test conditions. A Condition x Direction interaction was found ($F(1, 10) = 9.3, p = 0.0123$). When making left lane changes, drivers' mean time to cross lane markings in the Baseline condition was 2.14 s (SE = 0.10 s, $n = 129$, Min = 0.10 s, Max = 7.40 s), while their mean time to cross lane markings in the Test condition was 2.02 s (SE = 0.05 s, $n = 353$, Min = 0.10 s, Max = 5.50 s). When making right lane changes, drivers' mean time to cross lane markings in the Baseline condition was 2.25 s (SE = 0.06 s, $n = 399$, Min = 0.10 s, Max = 9.20 s), while their mean time to cross lane markings in the Test condition was 2.01 s (SE = 0.03 s, $n = 1129$, Min = 0.10 s, Max = 6.70 s).

In further pursuing this research question, a C/VIS x Condition x Direction interaction was tested, but was not found to be significant ($F(1, 10) = 3.55, p = 0.089$). Drivers' mean times to cross lane markings by C/VIS, Experimental Condition, and Lane-Change Direction are depicted in Figure 175.

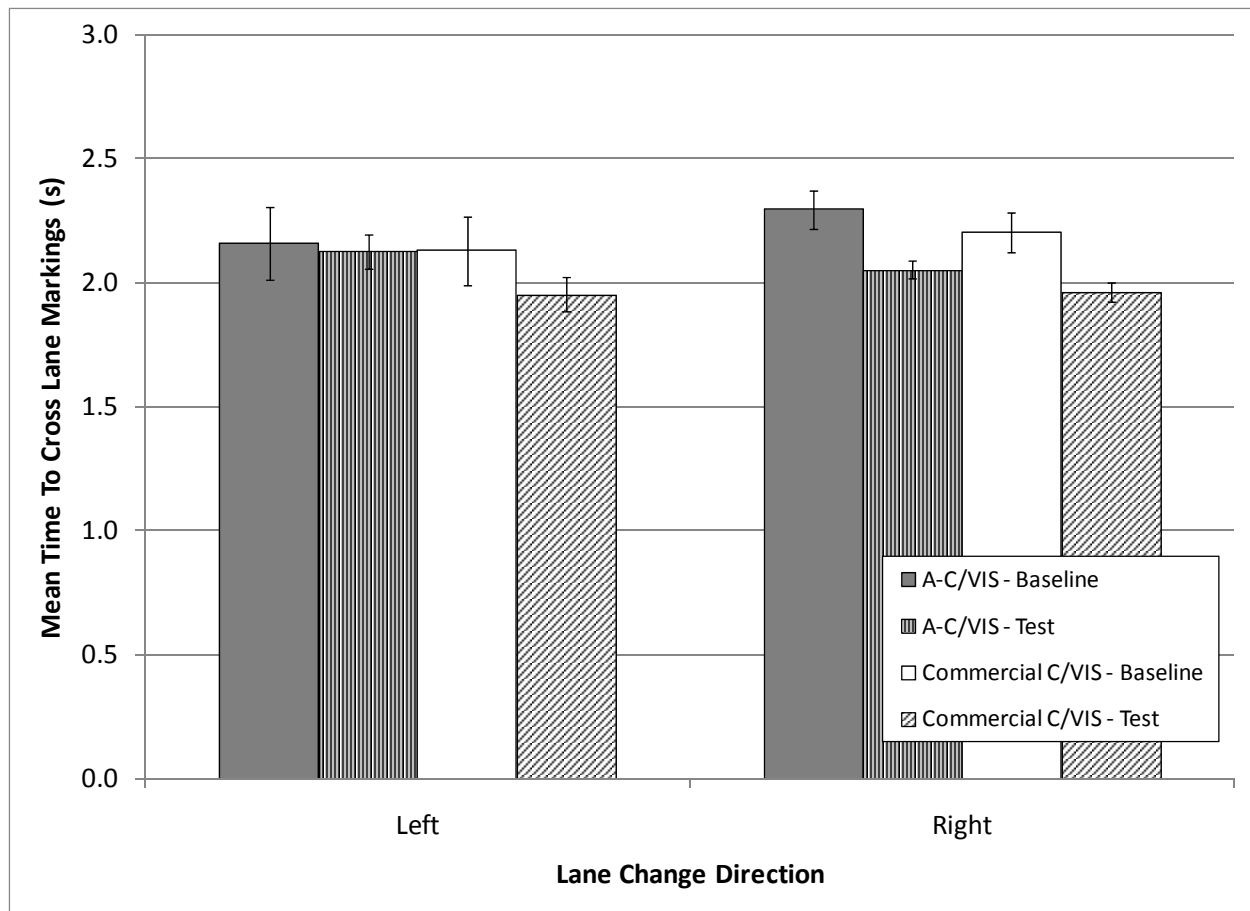


Figure 175. Drivers' Mean Times to Cross Lane Markings by C/VIS, Experimental Condition, and Lane-Change Direction

Since daylight and weather affect driver visibility, drivers' mean time to cross lane markings under various environmental conditions was explored. A 2 (Condition) x 2 (C/VIS) x 4 (Environmental Condition) Mixed Factors ANOVA was performed on the time to cross lane markings dependent variable. An Environment main effect was not found ($F(3, 28) = 2.19, p = 0.1111$). Figure 176 shows drivers' mean time to cross lane markings by Environmental Condition. Drivers' mean time to cross lane markings during clear daytime conditions was 1.94 s (SE = 0.04 s, n = 673, Min = 0.10 s, Max = 7.40 s), 2.14 s during clear nighttime conditions (SE = 0.03 s, n = 1108, Min = 0.10 s, Max = 9.20 s), 2.01 s during inclement daytime conditions (SE = 0.10 s, n = 90, Min = 0.30 s, Max = 5.90 s), and 2.15 s in inclement nighttime conditions (SE = 0.08 s, n = 139, Min = 0.50 s, Max = 4.70 s).

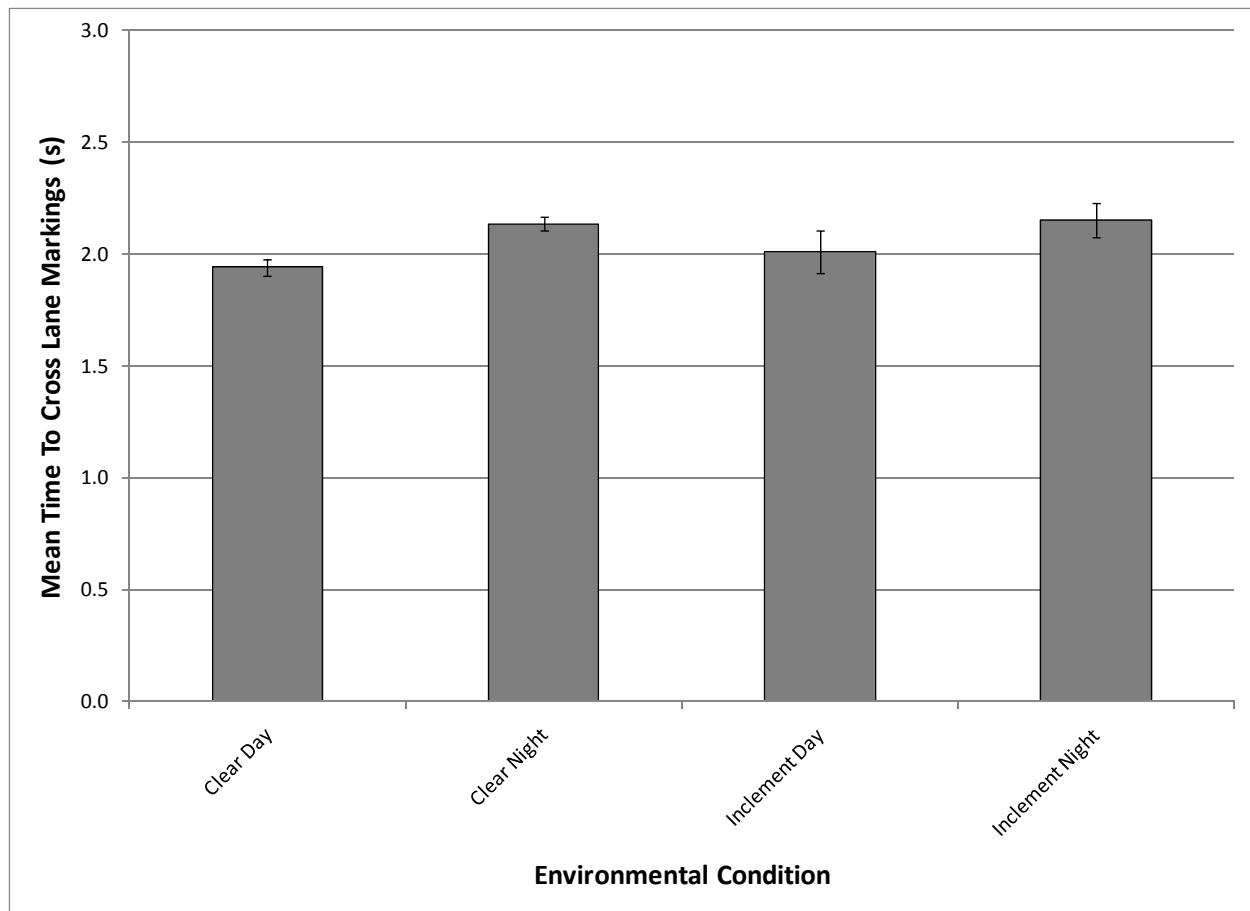


Figure 176. Drivers' Mean Time to Cross Lane Markings by Environmental Condition

Using the same ANOVA, an Experimental Condition x Environmental Condition interaction was not found ($F(3, 22) = 0.48$, $p = 0.7014$). Figure 177 and Table 38 show drivers' mean times to cross lane markings by Experimental Condition and Environmental Condition. Drivers did not significantly reduce the time to cross the lane markings when driving with a C/VIS.

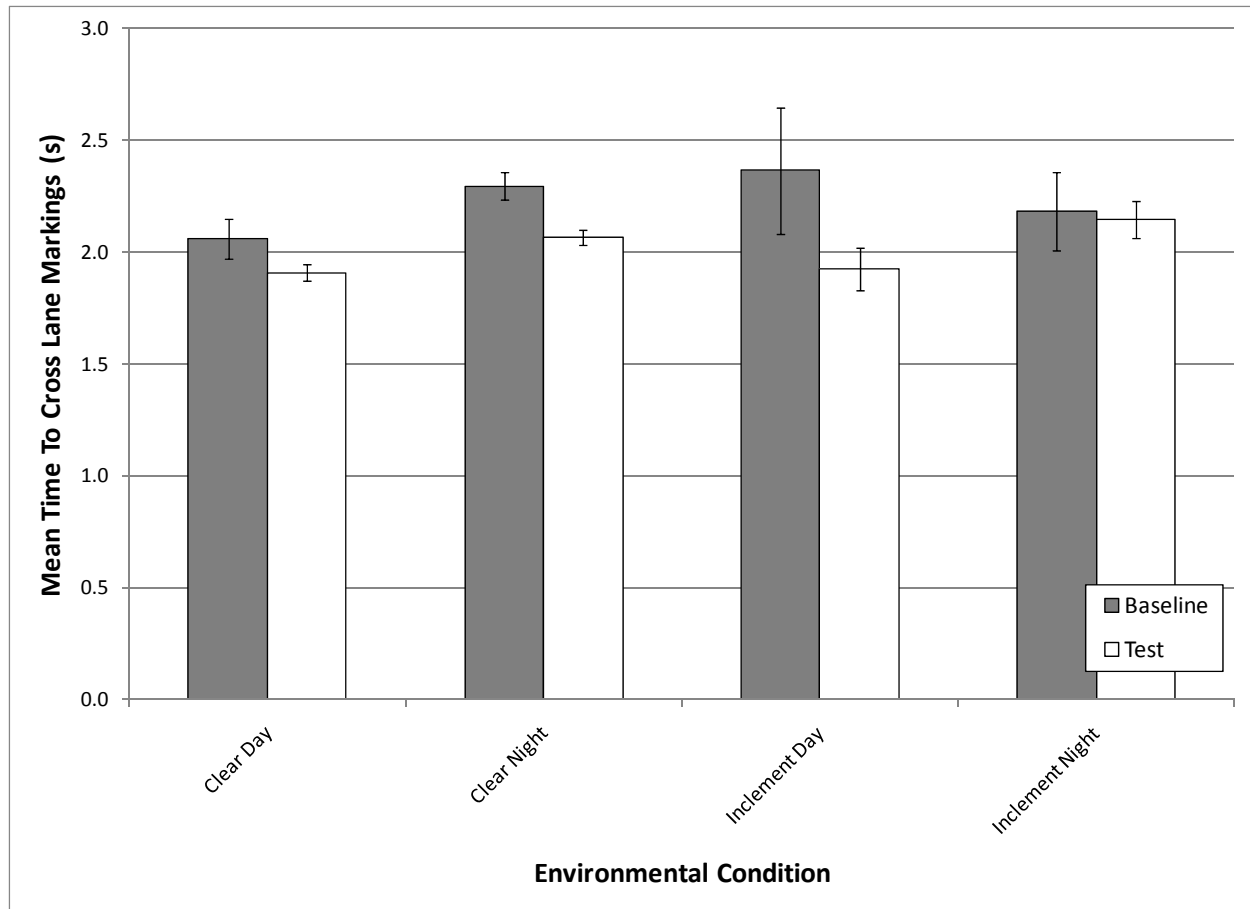


Figure 177. Drivers' Mean Times to Cross Lane Markings by Experimental Condition and Environmental Condition

Table 38. Drivers' Mean Times to Cross Lane Markings by Environmental and Experimental Conditions

Environmental Condition	Experimental Condition	Mean (s)	SE (s)	n	Min (s)	Max (s)
Clear Day	Baseline	2.06	0.09	147	0.00	7.40
	Test	1.91	0.04	526	0.00	6.70
Clear Night	Baseline	2.30	0.06	330	0.00	9.20
	Test	2.07	0.03	778	0.10	6.20
Inclement Day	Baseline	2.36	0.28	17	0.30	5.90
	Test	1.93	0.10	73	0.30	4.30
Inclement Night	Baseline	2.18	0.17	34	0.50	4.70
	Test	2.15	0.09	105	0.50	4.30

An Experimental Condition x Environmental Condition x C/VIS interaction was not found ($F(3, 22) = 0.36, p = 0.7791$). Figure 178 and Table 39 show drivers' mean times to cross the lane markings by Environmental Condition, C/VIS, and Experimental Condition.

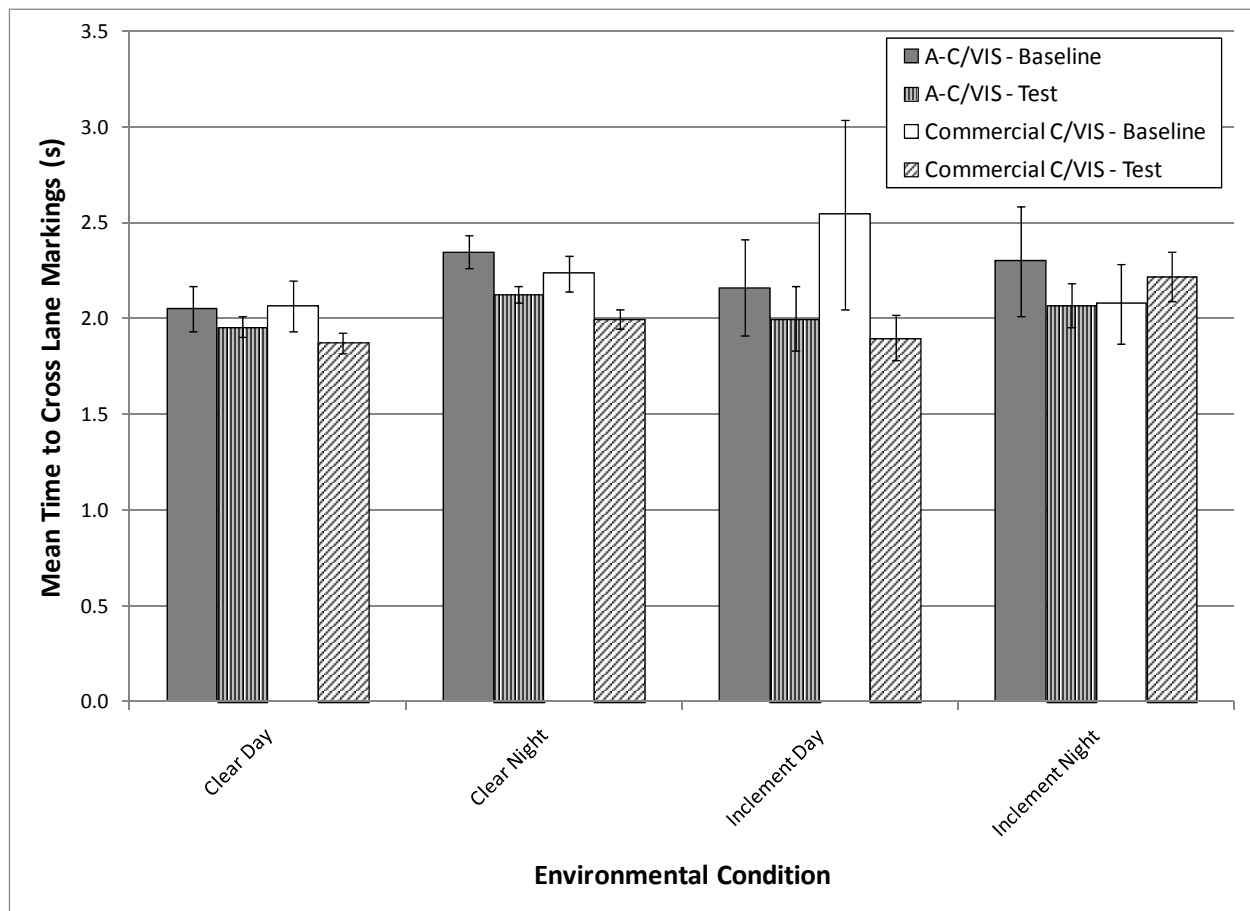


Figure 178. Drivers' Mean Time to Cross Lane Markings by C/VIS, Experimental Condition, and Environmental Condition

Table 39. Drivers' Mean Times to Cross Lane Markings by C/VIS, Experimental Condition, and Environmental Condition

Environmental Condition	C/VIS	Experimental Condition	Mean (s)	SE (s)	n	Min (s)	Max (s)
Clear Day	A-C/VIS	Baseline	2.05	0.12	66	0.60	6.60
		Test	1.96	0.05	214	0.30	4.60
	Commercial C/VIS	Baseline	2.07	0.13	81	0.00	7.40
		Test	1.88	0.05	312	0.00	6.70
Clear Night	A-C/VIS	Baseline	2.35	0.09	174	0.10	9.20
		Test	2.13	0.04	406	0.10	6.10
	Commercial C/VIS	Baseline	2.24	0.09	156	0.00	6.80
		Test	2.00	0.05	372	0.10	6.20
Inclement Day	A-C/VIS	Baseline	2.16	0.25	8	0.80	2.70
		Test	2.00	0.17	19	1.00	4.30
	Commercial C/VIS	Baseline	2.54	0.49	9	0.30	5.90
		Test	1.90	0.12	54	0.30	4.10
Inclement Night	A-C/VIS	Baseline	2.30	0.29	16	0.80	4.70
		Test	2.07	0.11	52	0.50	4.30
	Commercial C/VIS	Baseline	2.08	0.21	18	0.50	3.60
		Test	2.22	0.13	53	0.60	4.20

Lane-Change Maneuver Duration

A 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA was performed on the time-to-complete-lane-change dependent variable. A Condition main effect was not found ($F(1, 10) = 1.69, p = 0.2234$). Drivers' mean time to complete a lane change was 8.81 s in the Baseline condition ($SE = 0.13$ s, $n = 528$, $Min = 3.90$ s, $Max = 20.80$ s) and 8.32 s in the Test condition ($SE = 0.07$ s, $n = 1484$, $Min = 3.60$ s, $Max = 22.80$ s) (Figure 179).

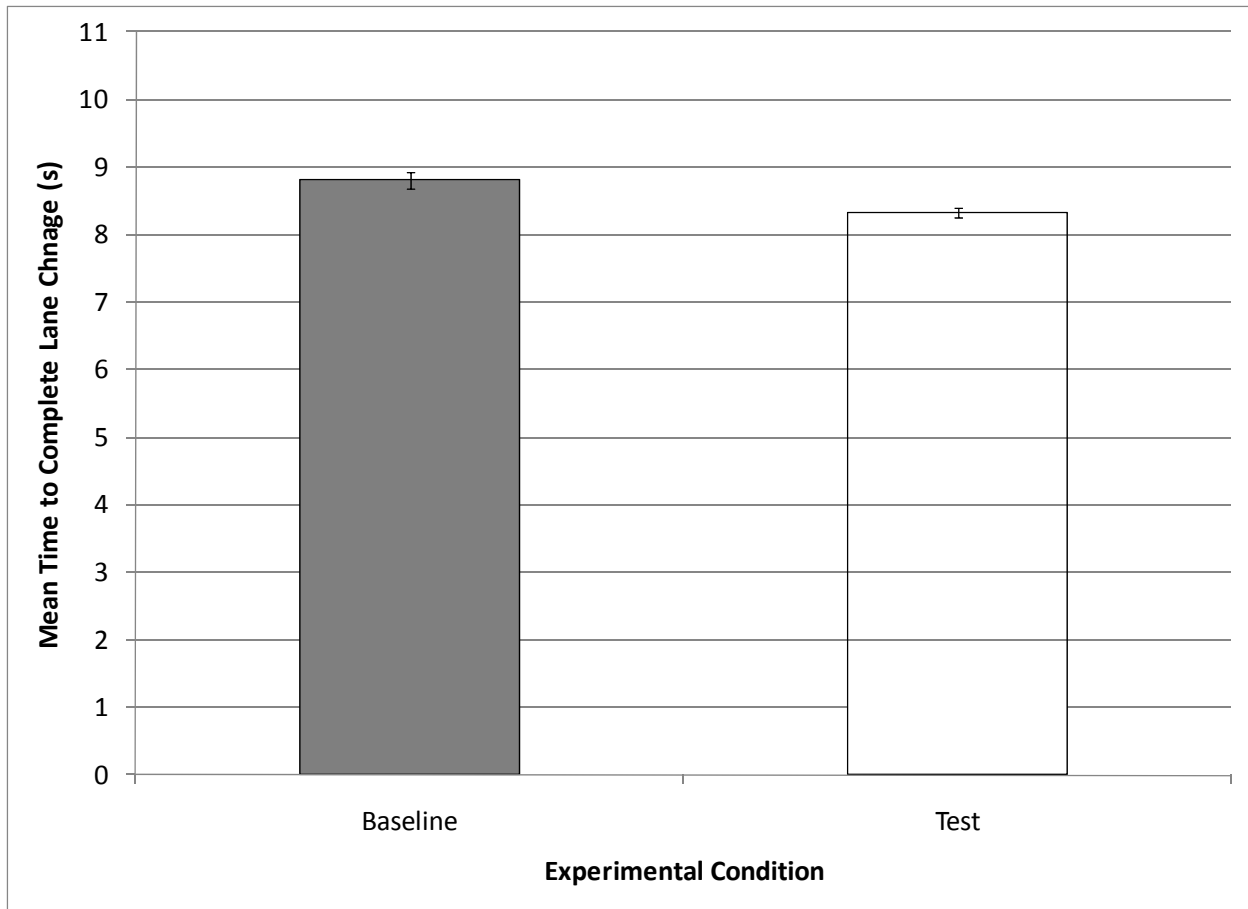


Figure 179. Drivers' Mean Time to Complete a Lane Change by Experimental Condition

Figure 180 shows drivers' mean time to complete a lane change by month in study. A 2 (System) x 4 (Month) Mixed Factors ANOVA was also performed on the time to complete a lane-change dependent variable. A Month main effect was found ($F(3, 29) = 5.28, p = 0.005$). Drivers' mean time to complete a lane change in Month 1 was 8.81 s (SE = 0.13 s, $n = 528$, Min = 3.90 s, Max = 20.80 s), 8.92 s in Month 2 (SE = 0.12 s, $n = 528$, Min = 3.90 s, Max = 19.60 s), 8.06 s in Month 3 (SE = 0.11 s, $n = 490$, Min = 3.60 s, Max = 22.80 s), and 7.91 s in Month 4 (SE = 0.12 s, $n = 466$, Min = 3.70 s, Max = 22.70 s). A Tukey HSD multiple comparisons test found that drivers' mean times to complete a lane change in Month 1 and Month 2 were significantly longer than in Month 4 ($p = 0.0426$ and $p = 0.0229$, respectively).

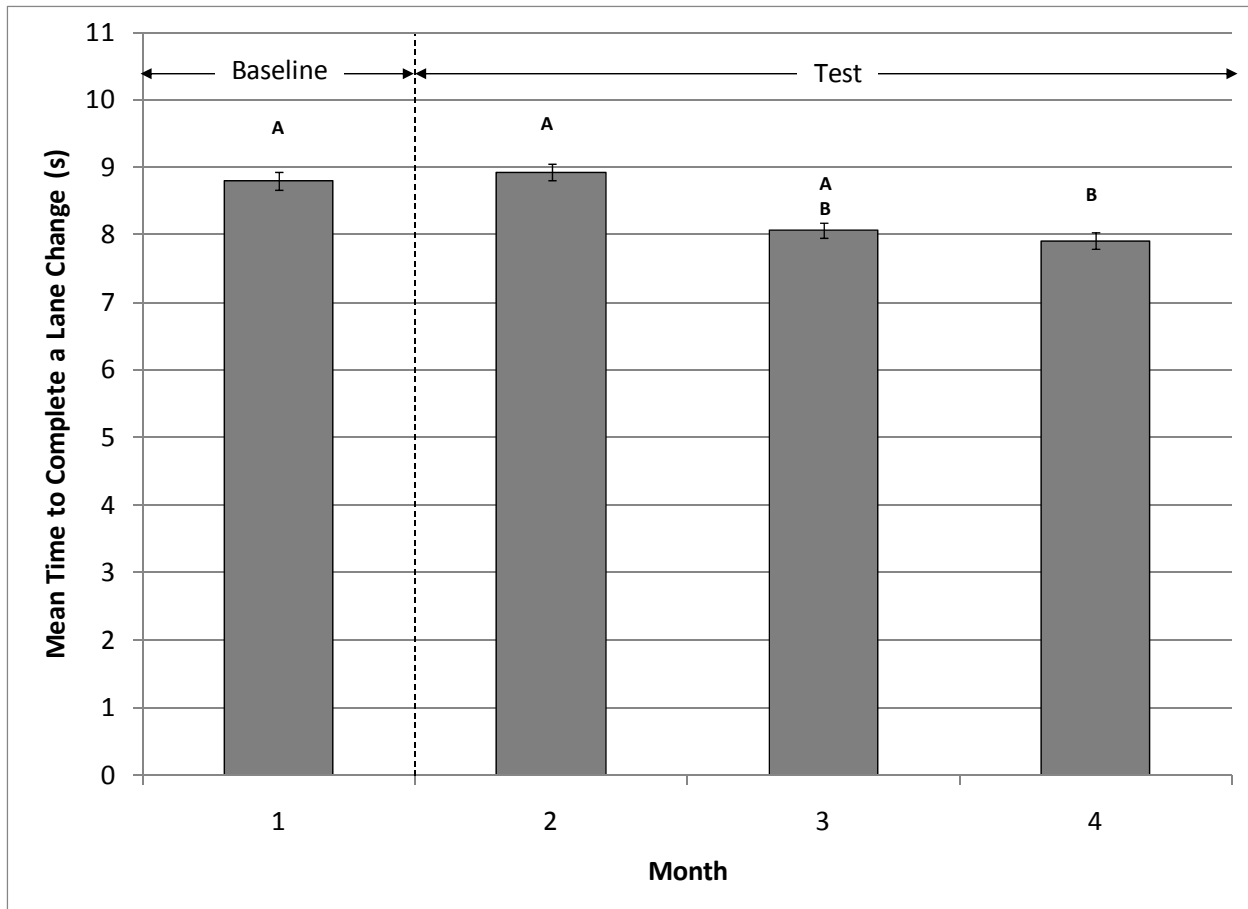


Figure 180. Drivers' Mean Time to Complete a Lane Change by Month in Study

With respect to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA that was performed, a C/VIS x Condition interaction was investigated to determine whether the time to complete a lane change adopted by drivers of A-C/VIS-equipped trucks, or commercial C/VIS-equipped trucks, differed across experimental condition. A C/VIS x Condition interaction was not found ($F(1, 10) = 0.57, p = 0.4667$). The mean time to complete a lane change for drivers of A-C/VIS-equipped trucks was 8.40 s in the Baseline condition (SE = 0.17 s, $n = 264$, Min = 4.00 s, Max = 18.60 s) and 8.13 s in the Test condition (SE = 0.09 s, $n = 692$, Min = 3.60 s, Max = 18.30 s) (Figure 181). The mean time to complete a lane change for drivers of commercial C/VIS-equipped trucks was 9.21 s in the Baseline condition (SE = 0.20 s, $n = 264$, Min = 3.90 s, Max = 20.80 s), and 8.49 s in the Test condition (SE = 0.10 s, $n = 792$, Min = 3.90 s, Max = 22.80 s). The lack of an interaction also means that the mean time to complete a lane change adopted by drivers using the A-C/VIS was not found to be significantly different from the mean time to complete a lane change adopted by drivers using the commercially available C/VIS.

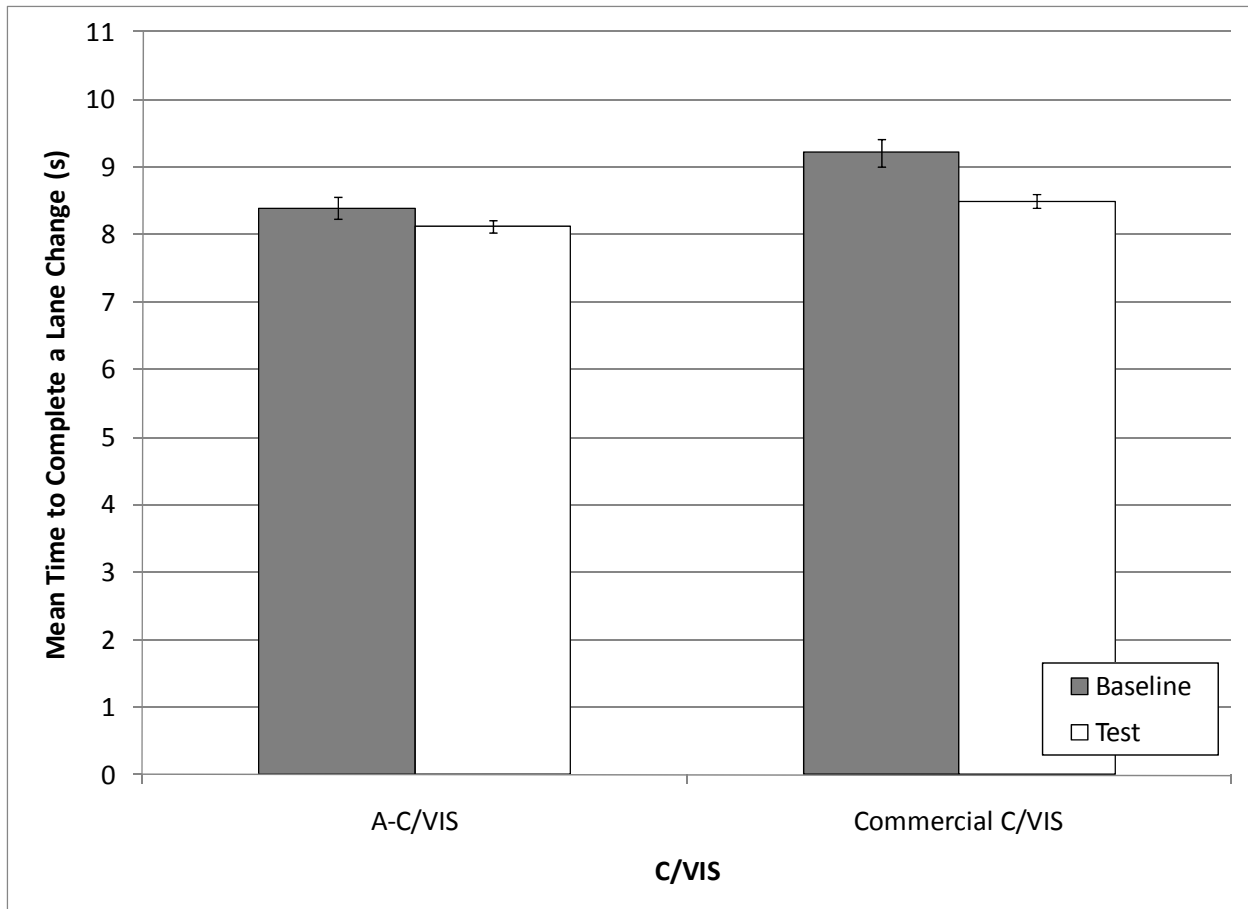


Figure 181. Drivers' Mean Time to Complete a Lane Change by C/VIS and Experimental Condition

Figure 182 shows the mean times to complete a lane change for drivers of both A-C/VIS-equipped and commercial C/VIS-equipped trucks by month in study. With respect to the 2 (System) x 4 (Month) Mixed Factors ANOVA that was performed, a System x Month interaction was not found ($F(3, 29) = 0.26$, $p = 0.8514$).

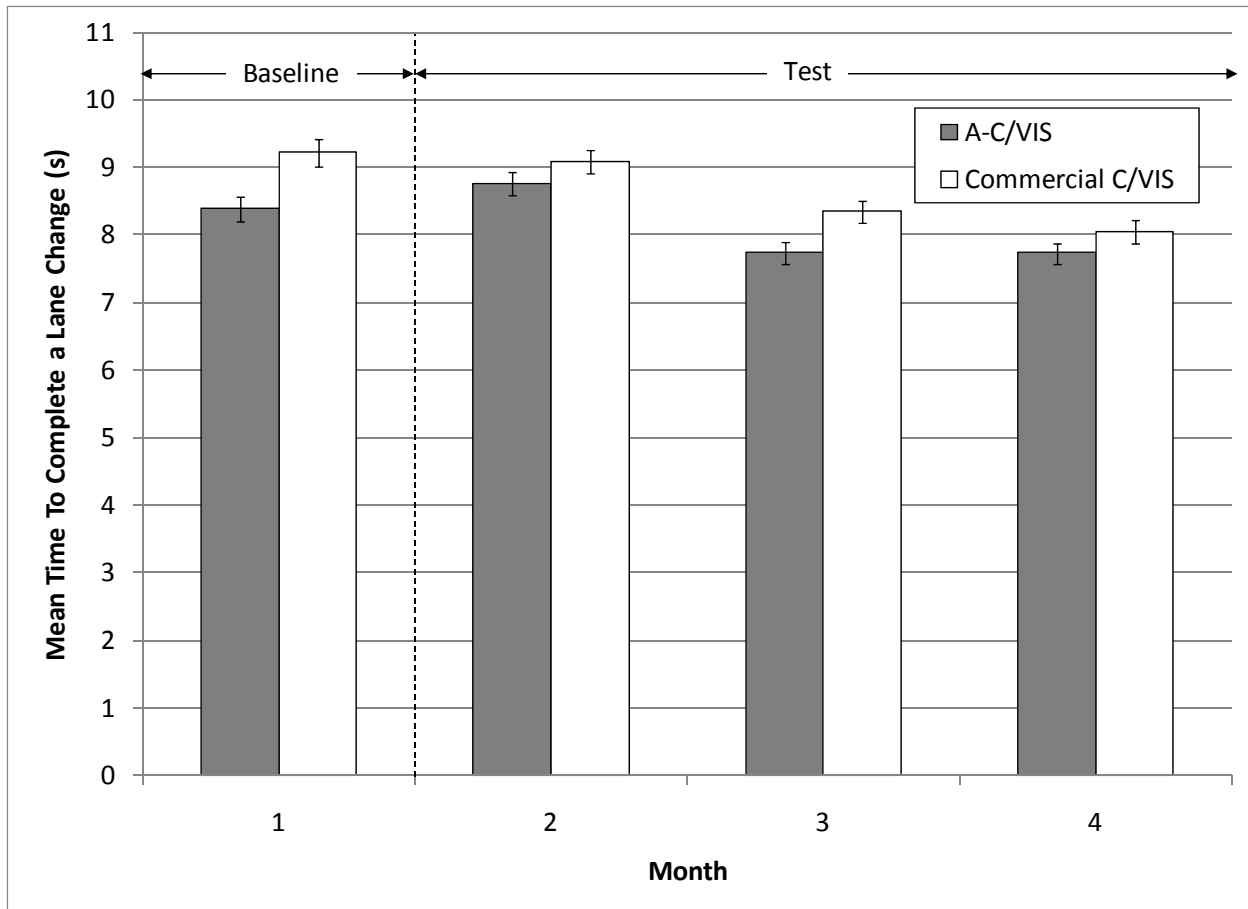


Figure 182. Mean Time to Complete a Lane Change by C/VIS and Month in Study

With respect to the 2 (C/VIS) x 2 (Condition) x 2 (Direction) Mixed Factors ANOVA that was performed, a Direction main effect was investigated to determine whether drivers' mean time to complete a lane change differed between left and right lane changes. A Direction main effect was not found ($F(1, 10) = 0.27, p = 0.6134$). Drivers' mean time to complete a lane change when making left lane changes was 8.63 s (SE = 0.12 s, $n = 483$, Min = 3.90 s, Max = 20.80 s), and 8.39 s when making right lane changes (SE = 0.07 s, $n = 1529$, Min = 3.60 s, Max = 22.80 s) (Figure 183).

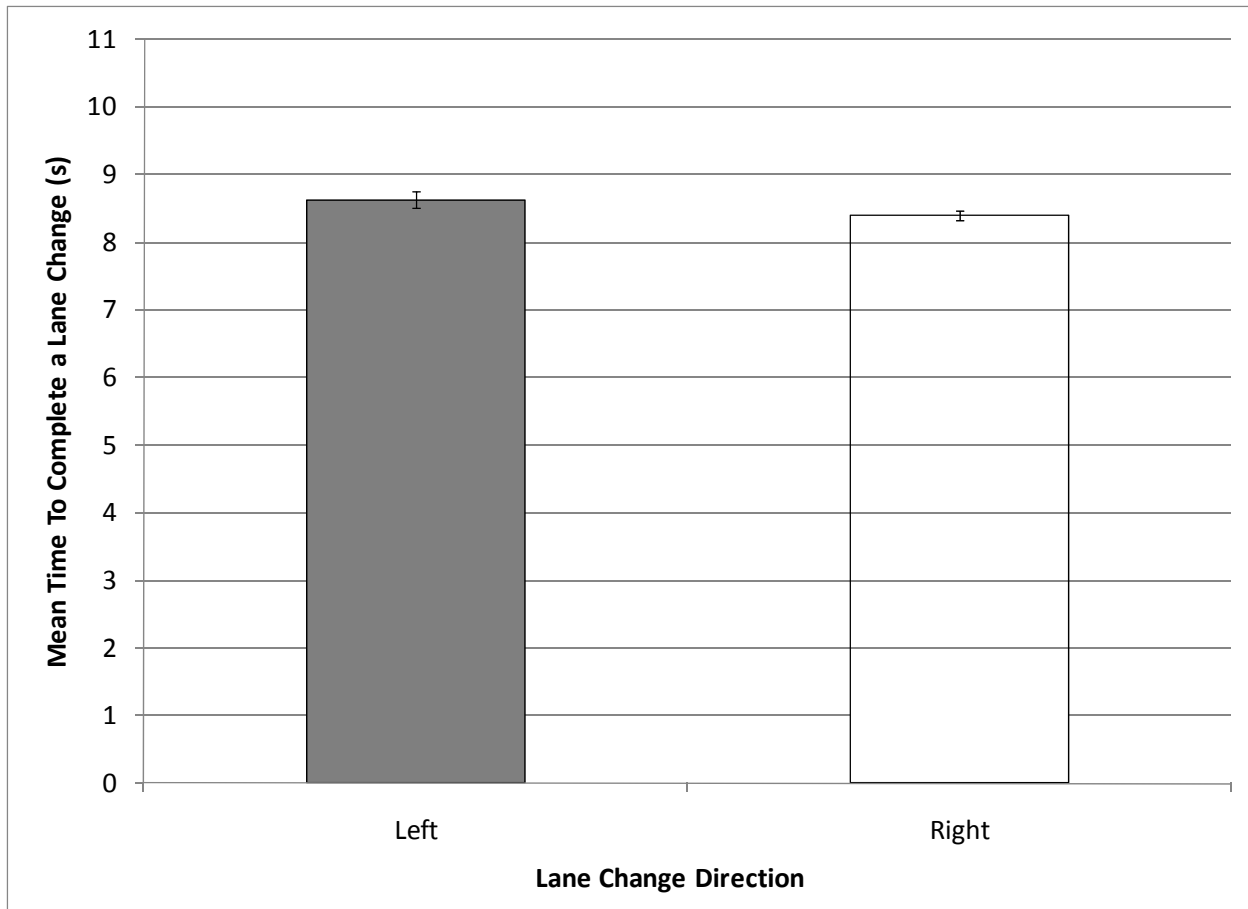


Figure 183. Drivers' Mean Time to Complete a Lane Change by Lane-Change Direction

Using the same ANOVA, a Condition x Direction interaction was tested to explore whether drivers' mean time to complete a lane change when making left or right lane changes differed between the Baseline and Test conditions. A Condition x Direction interaction was not found ($F(1, 10) = 0.16, p = 0.6936$).

In further pursuing this research question, a C/VIS x Condition x Direction interaction was tested, but was also not found to be significant ($F(1, 10) = 0.03, p = 0.8576$). Drivers' mean times to complete a lane change by C/VIS, Experimental Condition, and Lane-Change Direction are depicted in Figure 184 and listed in Table 40.

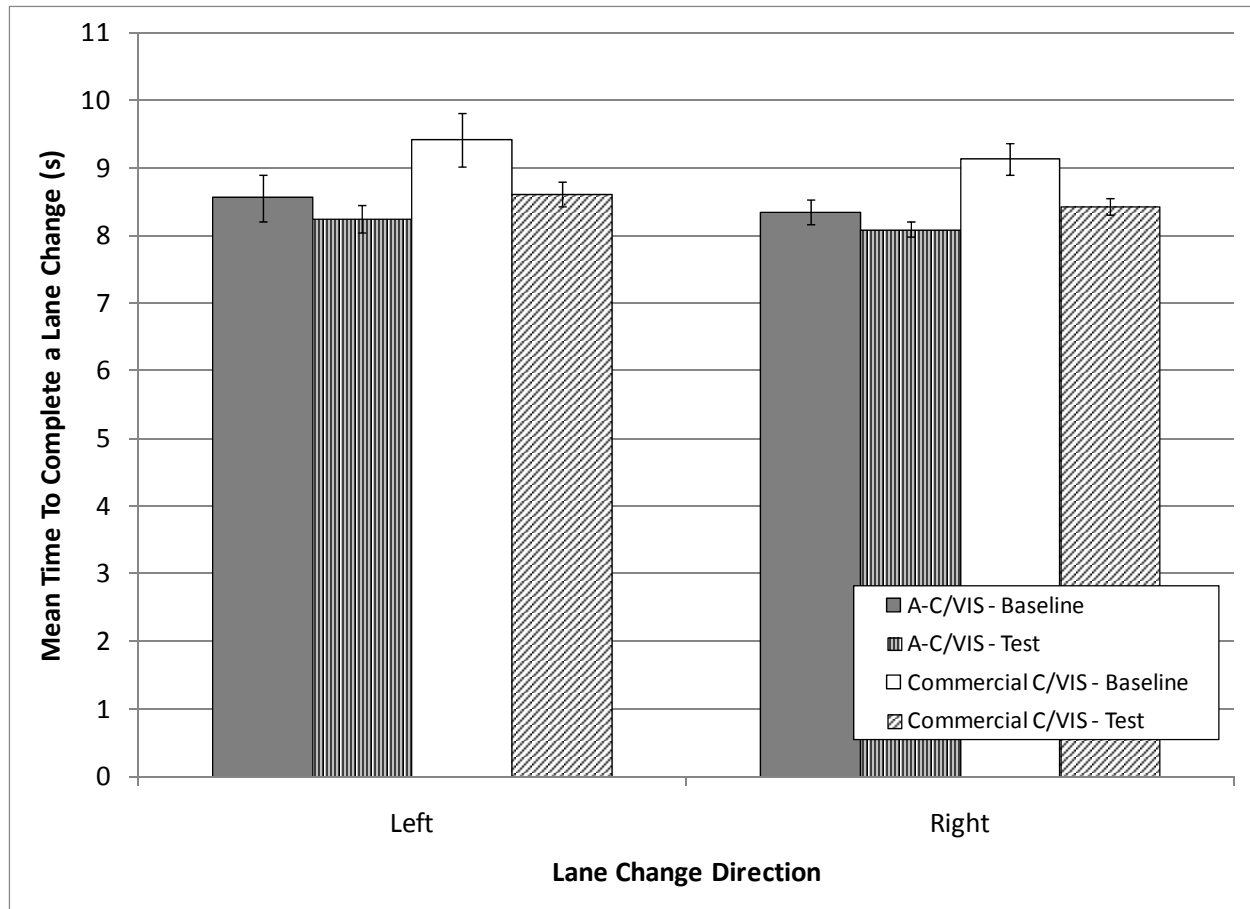


Figure 184. Drivers' Mean Times to Complete a Lane Change by C/VIS, Experimental Condition, and Lane-Change Direction

Table 40. Drivers' Mean Time to Complete a Lane Change by Direction, C/VIS and Experimental Condition

Direction	C/VIS	Condition	Mean (s)	SE (s)	n	Min (s)	Max (s)
Left	A-C/VIS	Baseline	8.56	0.34	56	5.00	16.00
		Test	8.25	0.20	142	4.10	16.50
	Commercial C/VIS	Baseline	9.43	0.40	73	4.10	20.80
		Test	8.62	0.18	212	3.90	20.00
Right	A-C/VIS	Baseline	8.35	0.19	208	4.00	18.60
		Test	8.10	0.11	550	3.60	18.30
	Commercial C/VIS	Baseline	9.13	0.23	191	3.90	19.40
		Test	8.44	0.12	580	3.90	22.80

Drivers' mean time to complete a lane change under various environmental conditions was explored. A 2 (Condition) x 2 (C/VIS) x 4 (Environmental Condition) Mixed Factors ANOVA was performed on the time to complete lane-change dependent variable. An Environment main effect was not found ($F(3, 28) = 0.19, p = 0.8995$). Figure 185 shows drivers' mean time to complete a lane change by Environmental Condition. Drivers' mean time to complete a lane

change during clear daytime conditions was 7.72 s (SE = 0.09 s, n = 673, Min = 3.60 s, Max = 18.00 s), 8.74 s during clear nighttime conditions (SE = 0.09 s, n = 1108, Min = 3.90 s, Max = 22.70 s), 9.25 s during inclement daytime conditions (SE = 0.33 s, n = 91, Min = 3.90 s, Max = 17.70 s), and 9.12 s during inclement nighttime conditions (SE = 0.26 s, n = 140, Min = 3.90 s, Max = 22.80 s).

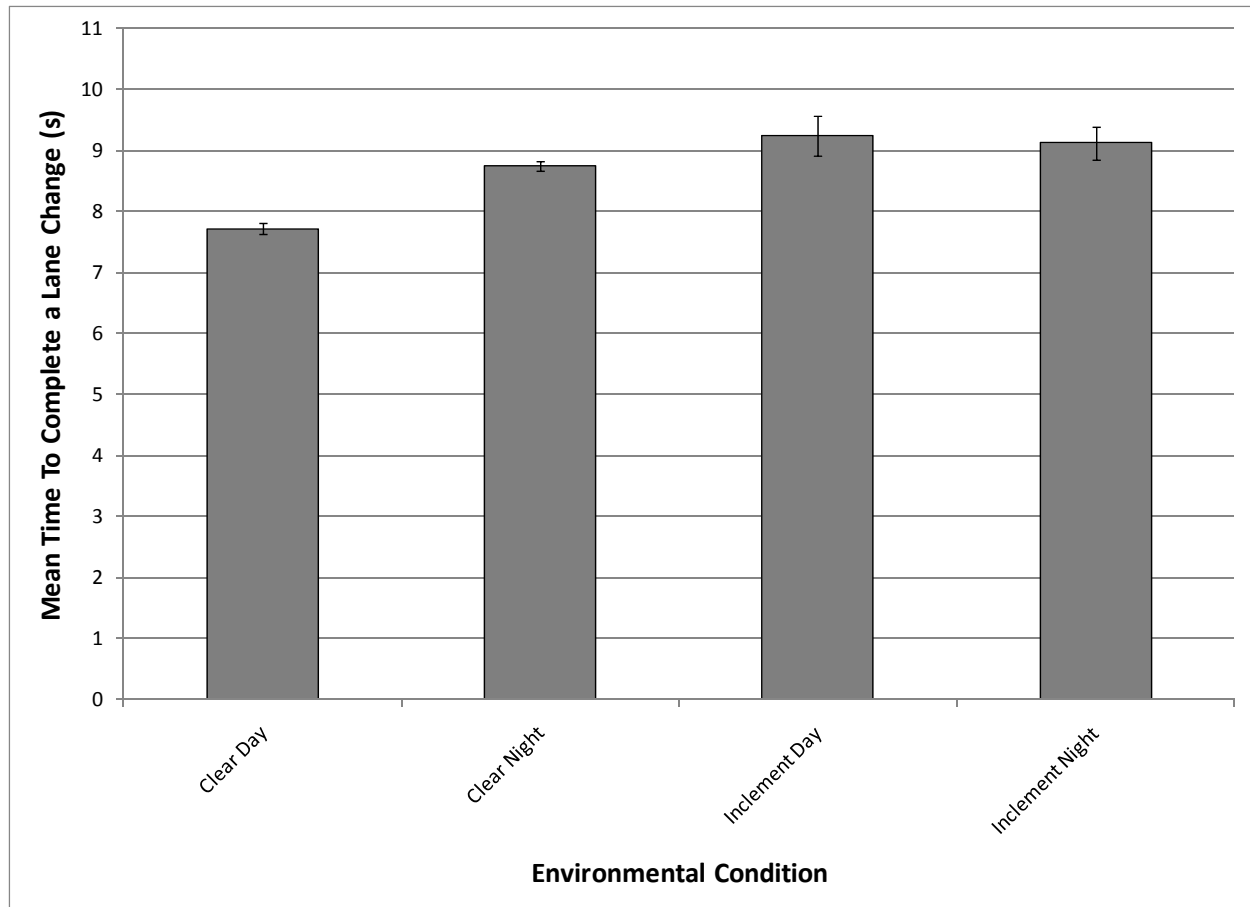


Figure 185. Drivers' Mean Time to Complete a Lane Change by Environmental Condition

Using the same ANOVA, an Experimental Condition x Environmental Condition interaction was not found ($F(3, 22) = 0.19$, $p = 0.8995$). Figure 186 and Table 41 show drivers' mean time to complete a lane change by Experimental Condition and Environmental Condition. Although it appears as though drivers took longer to complete lane changes in inclement daytime conditions, the reader is reminded that few lane changes were observed in this environmental condition.

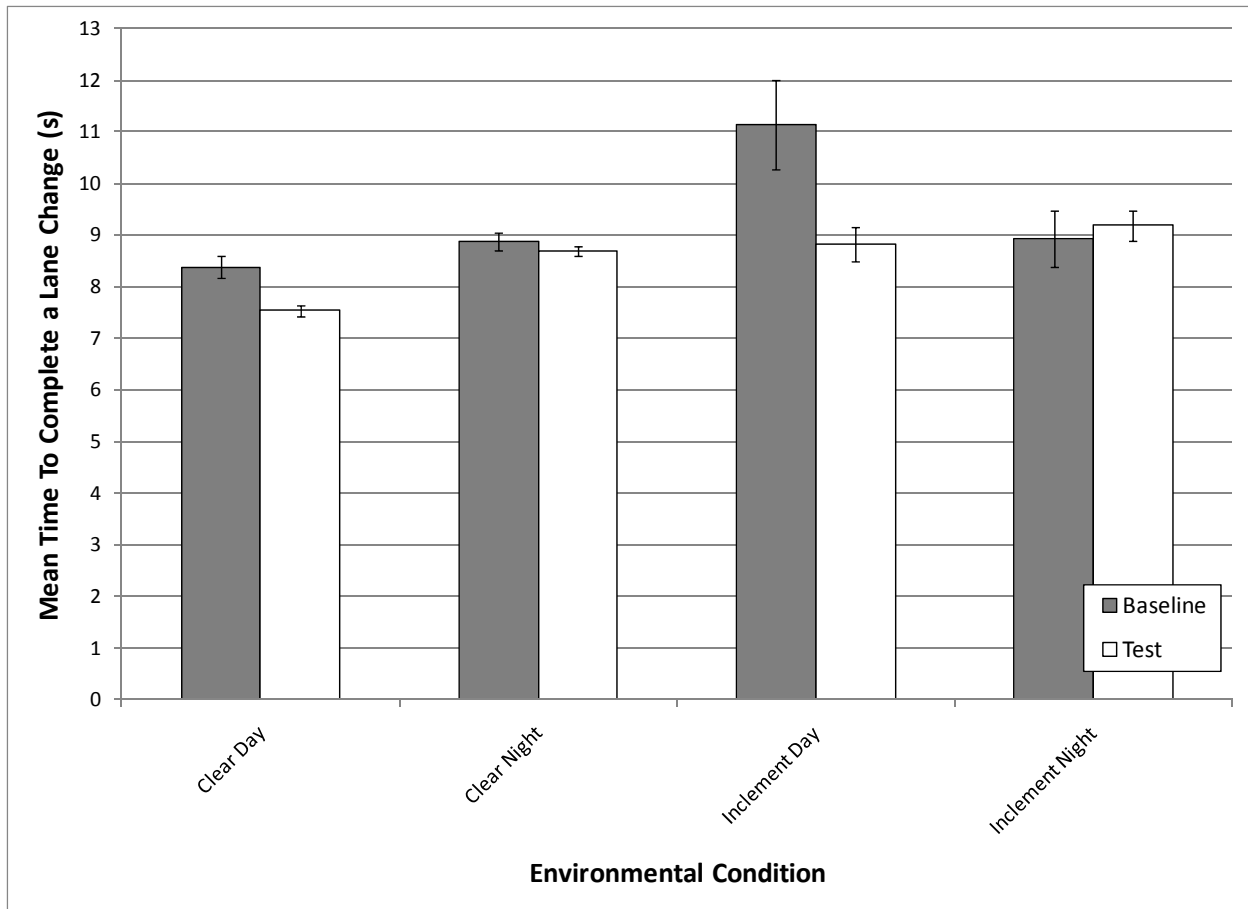


Figure 186. Drivers' Mean Time to Complete a Lane Change by Experimental Condition and Environmental Condition

Table 41. Drivers' Time to Complete a Lane Change by Experimental Condition and Environmental Condition

Environmental Condition	Experimental Condition	Mean (s)	SE (s)	n	Min (s)	Max (s)
Clear Day	Baseline	8.37	0.21	147	4.00	18.00
	Test	7.53	0.10	526	3.60	15.80
Clear Night	Baseline	8.87	0.17	330	3.90	20.80
	Test	8.69	0.10	778	4.20	22.70
Inclement Day	Baseline	11.14	0.87	17	6.50	16.60
	Test	8.81	0.33	74	3.90	17.70
Inclement Night	Baseline	8.92	0.55	34	5.00	18.60
	Test	9.18	0.30	106	3.90	22.80

An Experimental Condition x Environmental Condition x C/VIS interaction was not found ($F(3, 22) = 1.38, p = 0.2755$). Figure 187 and Table 42 show drivers' mean time to cross the lane markings by Environmental Condition, C/VIS, and Experimental Condition.

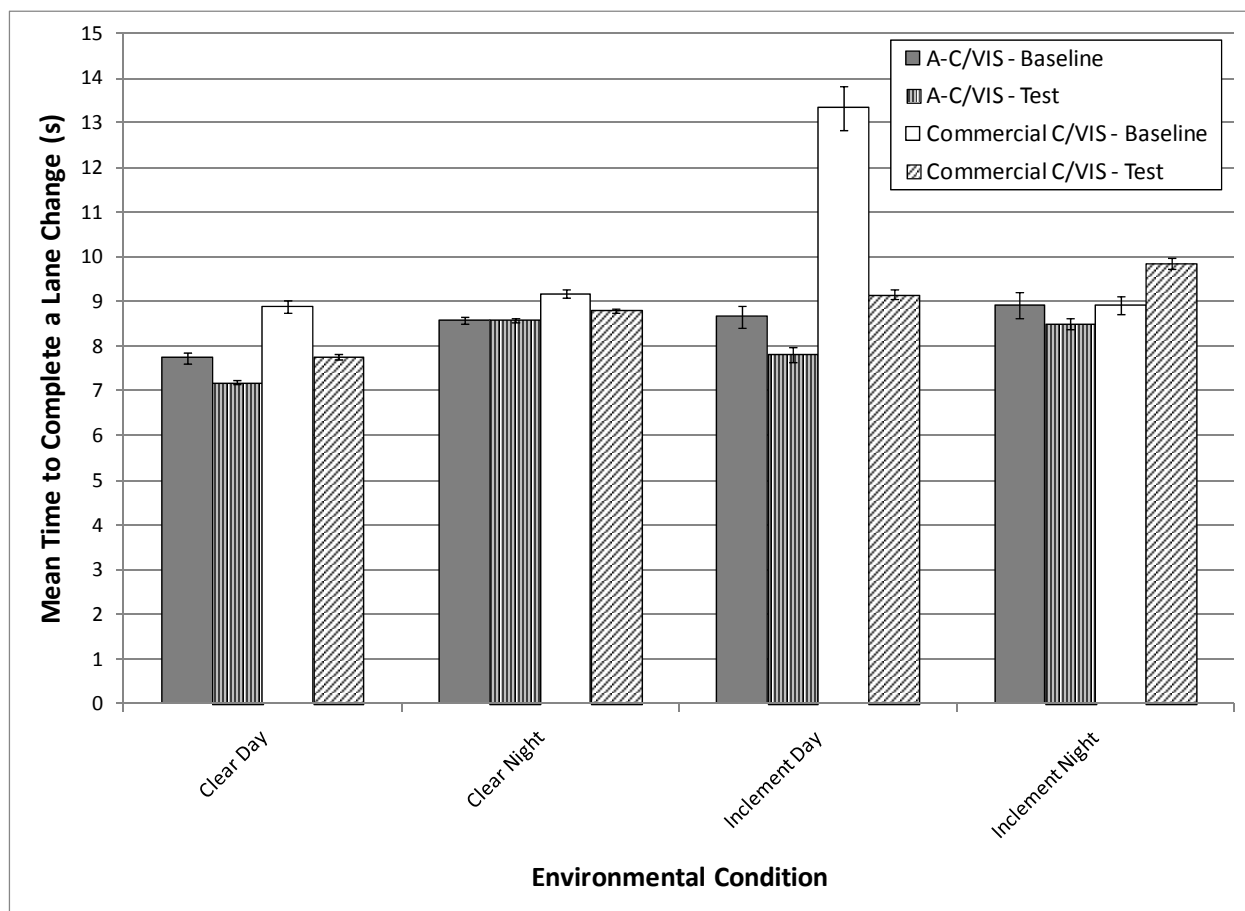


Figure 187. Drivers' Mean Time to Complete a Lane Change by C/VIS, Experimental Condition, and Environmental Condition

Table 42. Drivers' Time to Complete a Lane Change by C/VIS, Experimental Condition, and Environmental Condition

Environmental Condition	C/VIS	Experimental Condition	Mean (s)	SE (s)	n	Min (s)	Max (s)
Clear Day	A-C/VIS	Baseline	7.74	0.29	66	4.00	13.90
		Test	7.19	0.14	214	3.60	15.60
	Commercial C/VIS	Baseline	8.90	0.29	81	4.80	18.00
		Test	7.77	0.13	312	3.90	15.80
Clear Night	A-C/VIS	Baseline	8.59	0.21	174	4.00	16.00
		Test	8.59	0.12	406	4.20	18.30
	Commercial C/VIS	Baseline	9.18	0.27	156	3.90	20.80
		Test	8.81	0.16	372	4.40	22.70
Inclement Day	A-C/VIS	Baseline	8.66	0.77	8	6.50	12.70
		Test	7.82	0.51	19	4.70	12.60
	Commercial C/VIS	Baseline	13.33	1.05	9	7.90	16.60
		Test	9.16	0.40	55	3.90	17.70
Inclement Night	A-C/VIS	Baseline	8.93	0.94	16	5.00	18.60
		Test	8.51	0.34	53	3.90	15.30
	Commercial C/VIS	Baseline	8.92	0.64	18	5.20	13.80
		Test	9.85	0.48	53	5.20	22.80

Drivers' Lane Change Performance by C/VIS Use

Although not pertaining to the original research questions, an explorative analysis was performed to investigate whether drivers' lane change performance when they looked at the monitors differed from their lane change performance when they did not look at the monitors. The data below are provided to offer additional insight on placing C/VISs in commercial trucks.

C/VIS Use by Environmental Condition

Table 43 shows the percentage of the 2012 lane changes in which drivers looked at least once at the C/VIS monitors by the recorded environmental condition. A relationship between the environmental condition and whether drivers look at the C/VIS when making a lane change was found ($\chi^2 = 12.3125$, $p = 0.0065$). Odds ratios were computed for each of the environmental conditions. Performing lane changes during clear daytime conditions was found to significantly decrease the likelihood that drivers would look at the monitors (Odds Ratio = 0.6847). Performing lane changes during clear nighttime conditions was found to significantly increase the likelihood that drivers would look at the monitors (Odds Ratio = 1.4119). These data suggest that drivers were more inclined to use a C/VIS during clear nighttime conditions.

Table 43. Percentage of Lane Changes Drivers Looked at Monitors by Environmental Condition

Environmental Conditions	Looked At Least Once at Monitors	Did not Look at Monitors	Number of Lane Changes	Odds Ratio	LCL	UCL
Clear Day	13%	87%	673	0.6847*	0.5246	0.8938
Clear Night	18%	82%	1108	1.4119*	1.1055	1.8031
Inclement Day	10%	90%	91	0.5639	0.2803	1.1341
Inclement Night	19%	81%	140	1.2773	0.8244	1.9791
Number of Lane Changes	322	1690	2012			

* Indicates $p < 0.05$

C/VIS Use by Lane Change Direction

Table 44 shows the percentage of left and right lane changes made when drivers looked, and did not look, at the C/VIS monitors. A relationship between the lane change direction and whether drivers look at the C/VIS when making a lane change was found ($\chi^2 = 11.9666$, $p = 0.0005$). The execution of right lane changes increased the likelihood that drivers would look at the monitors (Odds Ratio = 1.7322).

Table 44. Percentage of Lane Changes Drivers Looked at Monitors by Lane Change Direction

Environmental Conditions	Looked At Least Once at Monitors	Did not Look at Monitors	Number of Lane Changes	Odds Ratio	LCL	UCL
Right	18%	82%	483	1.7322*	1.26502	2.37135
Left	11%	89%	1529			
Number of Lane Changes	322	1690	2012			

* Indicates $p < 0.05$

C/VIS Use by Clearance Grouping

Table 45 shows the percentage of lane changes made with various clearances when drivers looked, and did not look, at the C/VIS monitors. A relationship between the clearance grouping and whether drivers look at the C/VIS when making a lane change was not found ($\chi^2 = 7.2326$, $p = 0.1241$). The data suggest that drivers that looked at the C/VIS did not exhibit different clearances from drivers that did not look at the C/VIS.

Table 45. Percentage of Lane Changes Drivers Looked at Monitors by Clearance Grouping

Clearance	Looked At Least Once at Monitors	Did not Look at Monitors	Number of Lane Changes
1 - Overlapping	0%	100%	7
2 - Less than 6 m	7%	93%	29
3 - Less than 12 m	12%	88%	147
4 - Less than 18 m	18%	82%	802
5 - Greater than 18 m	15%	85%	1027
Number of Lane Changes	322	1690	2012

A-C/VIS Drivers' Use of the Object Detection Feature

Drivers' use of the A-C/VIS's object detection feature was investigated. Figure 188 shows the percentage of time that the feature was turned on during the lane changes sampled from the drivers of A-C/VIS-equipped trucks in the Test condition. The time interval considered began 8 s before changing lanes and ended 5 s after initiating the lane change. The following was observed:

- Driver 1 used the object detection feature throughout his first month in Test mode, but stopped using it shortly into the second month of the Test mode.
- Driver 3 appears to have experimented with the feature in the first month of Test mode, and then used the feature at points during Months 2 and 3 of Test mode.
- Driver 4 used the object detection feature throughout the three months of Test mode. However, it appears as though his use may have tapered off in Month 4.
- Driver 5 appears to have tried the feature out during the first week of Test mode, after which it was never used again.
- Driver 13 never used the feature.
- Driver 15 heavily used the object detection feature throughout the first month of Test mode. His use of the feature tapered off halfway through the second month of Test mode. It should be noted that this driver quit Schneider at the end of his second month of Test mode.

Overall, the object detection feature was turned on for 37 percent of the time from the sampled lane changes. The feature was turned on during 43 percent of the lane changes made in the first month of Test mode, 46 percent of the lane changes made in the second month of Test mode, and 19 percent of the lane changes made in the final month of Test mode.

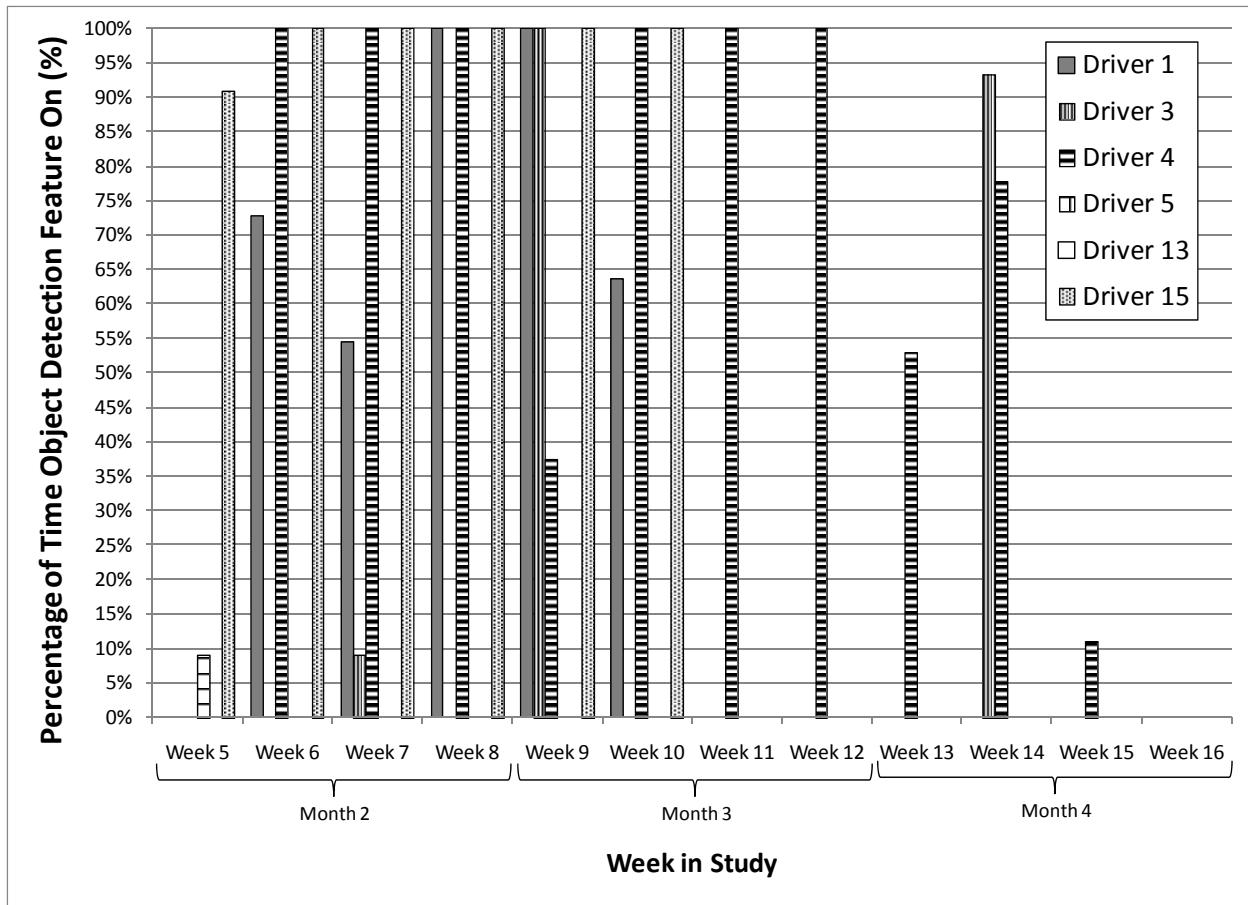


Figure 188. Percentage of Time from Sampled Lane Changes that the Object Detection Feature was Turned On

Because the amount of object detection could be controlled by drivers (levels ranged from 0 to 32), the average object detection level when the feature was turned on was computed for each week in the study (Figure 189). The following was observed:

- Driver 1 used the feature with a mean level of 20.
- Driver 3 used the feature with a mean level of 17.
- Driver 4 used the feature with a mean level of 4.
- Driver 5 used the feature with a mean level of 31.
- Driver 15 used the feature with a mean level of 19.

The data indicate that drivers did not employ the maximum amount of image processing when using the object detection feature. This was likely because, at its maximum level, the object detection feature would produce a multitude of white dots on the displays, which would cover the video image. It should also be noted that the feature was practically non-existent at lower levels. Therefore, Driver 4 may not have been aware that the feature was turned on. This should be considered when using his results.

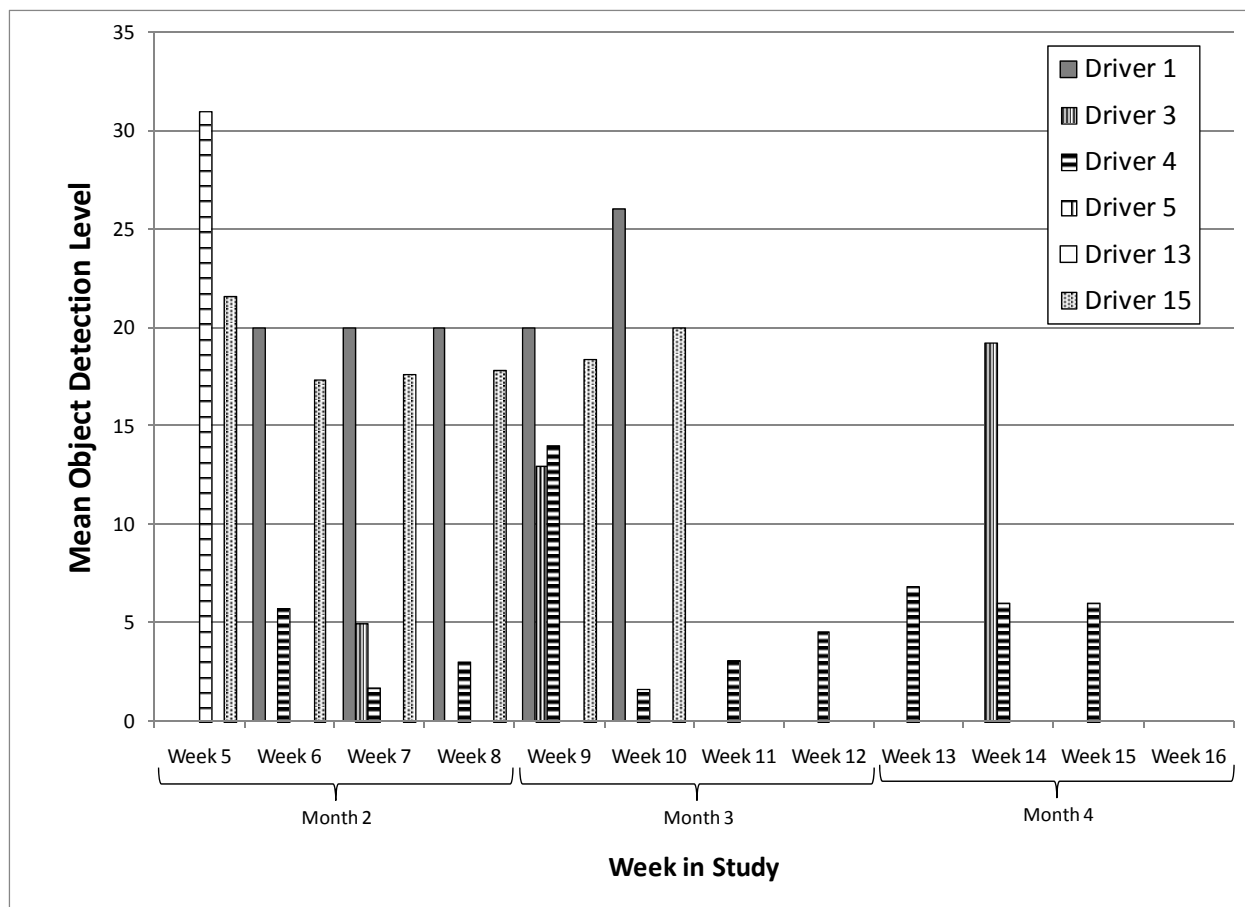


Figure 189. Mean Object Detection Level when the Object Detection Feature was Turned On

These data were further investigated to see if the weather and ambient lighting conditions played a role in each driver's decision to activate the object detection feature. Figure 190 shows the percentage of the lane changes in which the object detection feature was used for the different environmental and lighting conditions. Drivers of A-C/VIS-equipped trucks used the object detection feature more readily during clear daytime conditions than they did during clear nighttime conditions. If Driver 4 is removed from the analysis (because his mean object detection level was low), drivers used the feature in 32 percent of the lane changes made in clear daytime conditions ($n = 110$), 25 percent of the lane changes made during clear nighttime conditions ($n = 385$), 38 percent of the lane changes made during inclement daytime conditions ($n = 13$), and 27 percent of the lane changes made during inclement nighttime conditions ($n = 52$). The data still indicate that drivers used the feature more when making lane changes during clear daytime conditions compared to lane changes made during clear nighttime conditions.

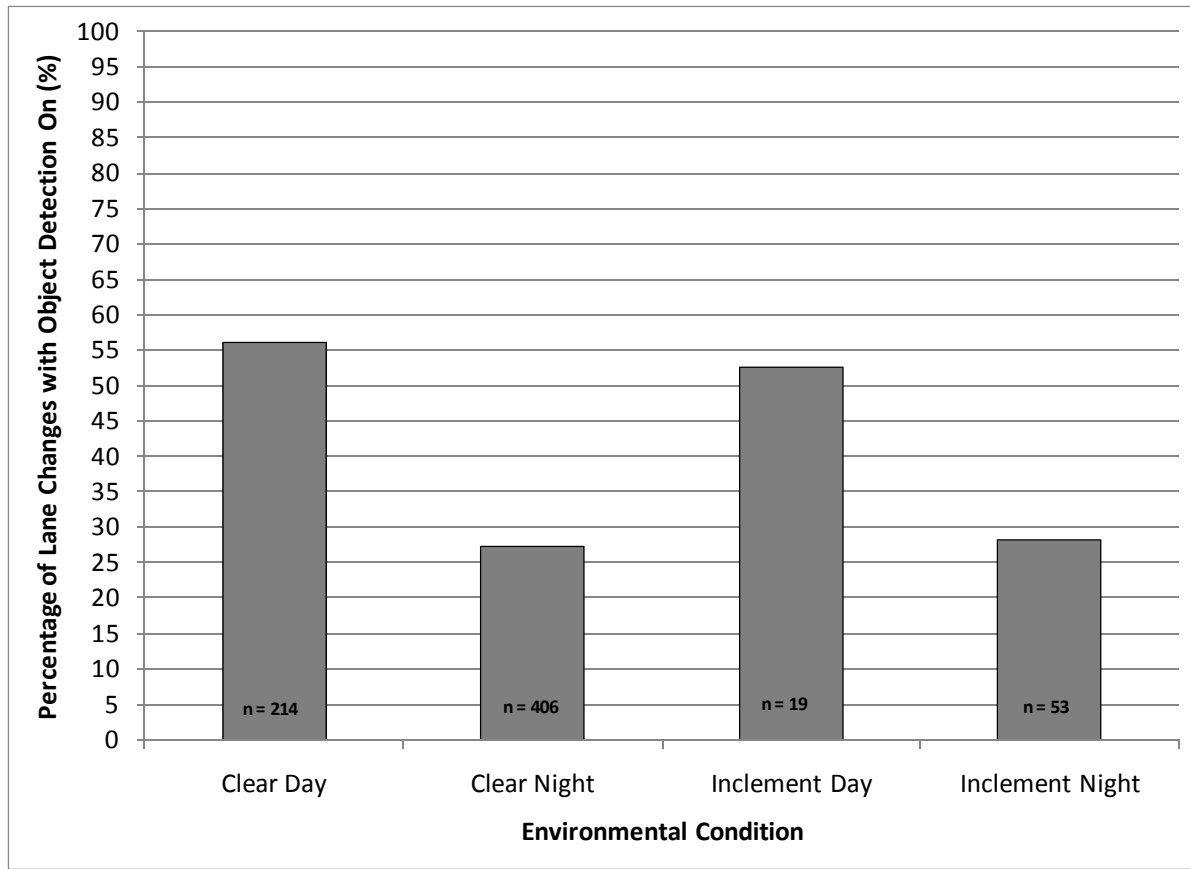


Figure 190. Percentage of Lane Changes with Object Detection Feature Turned On

Summary

This section investigated whether CMV drivers changed their lane-change performance when driving with a C/VIS. The lane-change performance measures investigated were: 1) the clearance to an adjacent vehicle at the initiation of the lane change, 2) their eye glance behavior during the 8 s prior to changing lanes, 3) the time taken to cross the lane markings, and 4) the time taken to complete a lane-change maneuver. The following main results were found:

- Drivers' mean clearance to an adjacent vehicle was not found to change when driving with a C/VIS.
 - Furthermore, drivers that looked at the C/VIS did not exhibit different clearances from drivers that did not look at the C/VIS.
- Drivers mean probability of looking forward did not change when driving with a C/VIS, suggesting that a C/VIS does not take drivers' visual attention away from the forward roadway.
- When driving with a C/VIS, drivers looked at the fender mirrors less frequently.
 - Drivers of commercial C/VIS-equipped trucks looked at the left fender mirror less frequently when making left lane changes with a C/VIS ($p = 0.0099$).
 - Drivers of A-C/VIS-equipped trucks looked at the right fender mirror less frequently when making right lane changes with a C/VIS ($p < 0.0001$).

- Drivers' eye glances to the monitors were all under 1.0 s and predominantly consisted of one glance to the monitor during a lane change.
 - Perhaps professional drivers who participated in the study were reluctant to change their visual behavior, but consulted the C/VIS monitors from time-to-time to validate their assumptions regarding the position of adjacent vehicles.
- Drivers' mean times to cross the lane markings significantly decreased as their time in the study progressed ($p = 0.0025$).
 - Drivers' mean time to complete a lane change significantly decreased as their time in the study progressed ($p = 0.005$).
 - It is possible that drivers changed lanes faster because they could better determine whether they have sufficient clearance when using a C/VIS.
- Drivers' mean clearance during right lane changes was shorter than their clearance during left lane changes ($p < 0.0001$).
 - The majority of the sampled right lane changes consisted of the SV returning to the right lane after completing a passing maneuver, while the majority of the left lane changes consisted of the SV passing a slow lead vehicle.
- Drivers' mean clearance when making right lane changes in clear nighttime conditions was significantly longer than their mean clearance in clear daytime conditions ($p = 0.0117$).
 - Drivers were more likely to look at the C/VIS during clear nighttime conditions relative to the other environmental conditions examined.
 - Drivers may have used the C/VIS more often in clear nighttime conditions because their visibility of the roadway is reduced.
- Drivers were more likely to look at the C/VIS when making right lane changes compared to when making left lane changes.
 - This may be because there is a larger No-Zone on the right side of the truck compared to the left side.
- Drivers used object detection feature in 37 percent of the sampled lane changes.
 - Drivers used the object detection feature more readily during clear daytime conditions compared to clear nighttime conditions.
 - Drivers used the object detection feature in over a third of inclement weather conditions, although few lane changes were observed in these conditions.

DRIVER RATINGS OF DRIVING PERFORMANCE AND C/VISS

Drivers completed questionnaires regarding their driving performance throughout the Baseline and Test conditions. Drivers also completed questionnaires on their opinions of the C/VISs throughout the Test condition. Additional analyses of drivers' opinions of the C/VISs are presented in Appendix AA. The noteworthy findings are presented in this section.

Drivers' Opinions of C/VISs

At the onset of the study, an experimenter explained the concept of a C/VIS to the drivers. Drivers were then given a questionnaire that asked them to rate various dimensions of a hypothetical C/VIS. The ratings gathered in this Baseline condition established drivers' attitudes towards the concept of having a C/VIS in their truck. Throughout the Test condition, drivers

rated the same C/VIS dimensions as they did in the Baseline condition, but this time their ratings pertained to the actual C/VIS that was installed in their truck. Drivers rated the C/VIS dimensions every two weeks in the Test condition. These data allow drivers' initial attitudes towards C/VISs to be compared with their ratings after having actual experience with a C/VIS.

Likeability of the C/VIS

Figure 191 presents month-by-month mean ratings of drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks in response to the question, "How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?" Drivers' mean ratings in Months 1, 2, 3, and 4 were analyzed using a Friedman Two-Way ANOVA. Statistically significant differences between drivers' mean ratings in Month 1, Month 2, Month 3, and Month 4 were not found for drivers of either A-C/VIS-equipped trucks ($p = 0.0605$) or commercial C/VIS-equipped trucks ($p = 0.5888$). Nevertheless, it appears as though drivers' ratings of the A-C/VIS increased as their time in the study progressed, while the drivers' ratings of the commercially available C/VIS remained neutral (four of the six drivers' median ratings in the Test condition were neutral, one driver's median rating was higher (a value of 5.25), and one driver's median rating was lower (a value of 1).

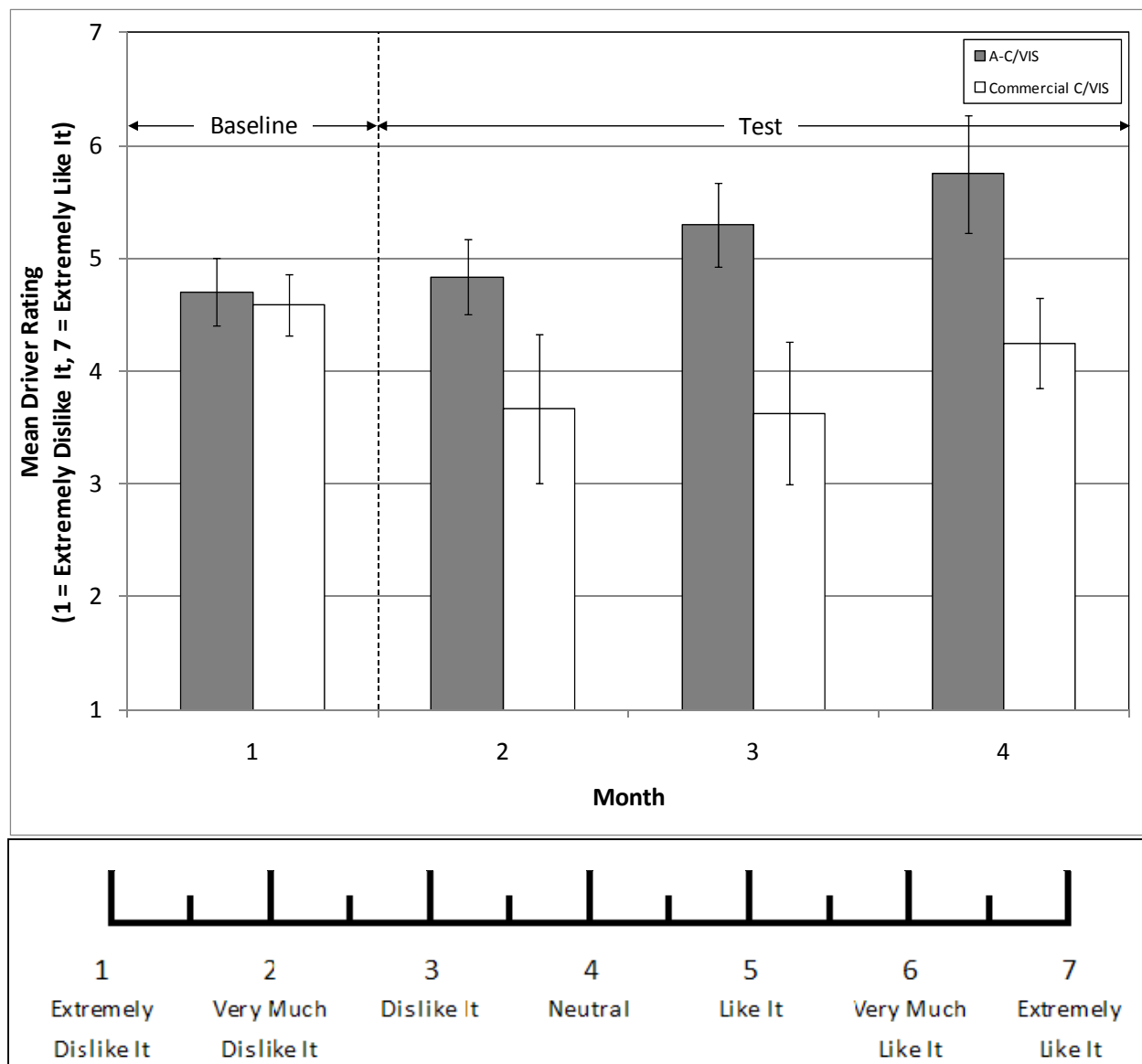


Figure 191. Comparison of Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Question, “How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?”

How Useful is the C/VIS

Drivers’ mean ratings in regard to the statement, “I think the C/VIS is useful,” are presented in Figure 192. Neither the mean ratings of drivers of A-C/VIS-equipped trucks ($p = 0.2942$), or the commercial C/VIS-equipped trucks ($p = 0.1301$) were found to significantly differ by month in the study. Despite the lack of statistical significance, it appears as though drivers’ ratings of the A-C/VIS increased as their time in the study progressed, while the drivers’ ratings of the commercially available C/VIS remained neutral (three of the six drivers’ median ratings in the Test condition were neutral, one driver’s median rating was higher (a value of 5), while two drivers’ median ratings were lower (values of 1 and 3)).

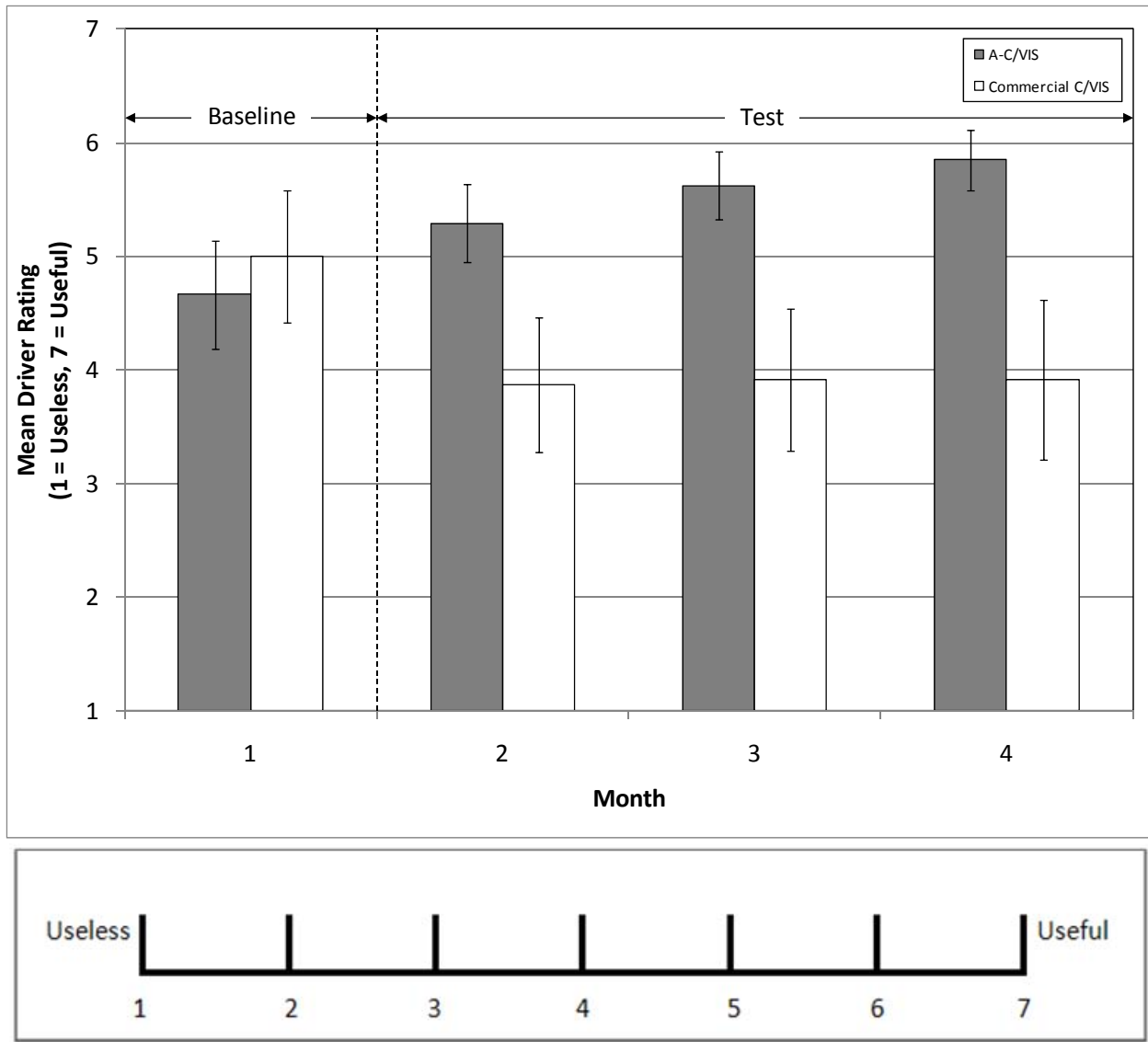


Figure 192. Comparison of Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is useful.”

As data began to be collected and analyzed, it was determined that additional information regarding drivers’ opinions on the usefulness of specific monitors would be desirable. Several modifications to the experimental protocol were made and were approved by the IRB. Since these modifications were made after four drivers had completed the study, the additional questions were posed to only eight drivers.

The eight drivers were asked to rate the usefulness of each monitor.

- Drivers of A-C/VIS-equipped trucks rated the left monitor to be “Useful” ($M = 5.1$, $SE = 0.18$, $Min = 4$, $Max = 7$), while drivers of commercial C/VIS-equipped trucks rated the left monitor to be “Useless” ($M = 3.18$, $SE = 0.42$, $Min = 1$, $Max = 5.5$). However, the ratings of the commercial C/VIS’s left monitor ranged from “Extremely Useless” to “Very Useful.”

- Drivers of A-C/VIS-equipped trucks rated the right monitor to be “Very Useful” ($M = 6.0$, $SE = 0.12$, $Min = 5$, $Max = 7$), while drivers of commercial C/VIS-equipped trucks were neutral when rating the right monitor ($M = 4.19$, $SE = 0.34$, $N = 17$, $Min = 1$, $Max = 6$). Again, the ratings of the commercial C/VIS’s right monitor ranged from “Extremely Useless” to “Very Useful.”
- Drivers of A-C/VIS-equipped trucks rated the center monitor as “Very Useful” ($M = 5.78$, $SE = 0.14$, $Min = 4$, $Max = 7$).

The eight drivers were then asked to rank-order the C/VIS cameras according to their usefulness.

- For drivers of A-C/VIS-equipped trucks, the center monitor was ranked highest by three of the five drivers, the right monitor was ranked highest by one of the five drivers, and the left monitor was ranked highest by one of the five drivers. The left monitor was ranked lowest by the other four drivers.
- The three drivers of commercial C/VIS-equipped trucks ranked the right monitor as more useful than the left monitor.

The eight drivers were asked: “Do you ever look at a monitor from the corner of your eye while looking in another direction? For example, do you ever look at the left monitor while looking at the forward roadway? If so, please explain.”

- Five of the eight drivers (two of which drove A-C/VIS-equipped trucks and three of which drove commercial C/VIS-equipped trucks) indicated that they did look at a monitor using their peripheral vision, one A-C/VIS driver said that he did not, one A-C/VIS driver was unsure, and one A-C/VIS driver did not respond to this question.

These eight drivers were then asked when they used the C/VIS. Drivers indicated that they looked at the monitors before changing lanes (to make sure a vehicle was not passing them in the destination lane), when turning into parking lots, and when making right turns since the trailer can be out of view in the mirrors but remains visible in the monitor.

Drivers’ Opinions of C/VIS Camera FOV

The following question was also posed to the last eight drivers: “The camera’s Field-of-View determines how much area around the truck can be seen in the monitor at once. However, as the Field-of-View increases, the size and clarity of objects in the monitor decrease. Given this trade-off, how would you rate the Field-of-View of the side cameras and resulting size of objects in the monitors?” Drivers of A-C/VIS-equipped trucks rated the A-C/VIS’s FOV as “Very Good” ($M = 5.7$, $SE = 0.12$, $Min = 5$, $Max = 7$), and drivers of commercial C/VIS-equipped trucks were neutral when rating the commercial C/VIS’s FOV ($M = 4.29$, $SE = 0.11$, $Min = 4$, $Max = 5$).

The driver opinion analyses presented in the remainder of this section are based on responses obtained from all 12 drivers.

How Irritating is the C/VIS

The drivers’ mean ratings concerning the statement, “I think the C/VIS is irritating,” are presented in Figure 193. Drivers of A-C/VIS-equipped trucks rated the A-C/VIS as more likeable as their time in the study progressed ($\chi^2 = 12.87$, $p = 0.0049$). Post hoc multiple comparison tests

found drivers' mean ratings in Month 1 to differ from their mean ratings in Month 4 at the 0.05 level of significance.³

Drivers of commercial C/VIS-equipped trucks indicated that the C/VIS became less likable as their time in the study progressed ($\chi^2 = 8.09, p = 0.0441$). However, the multiple comparison tests performed across the month in study did not show where this difference existed.

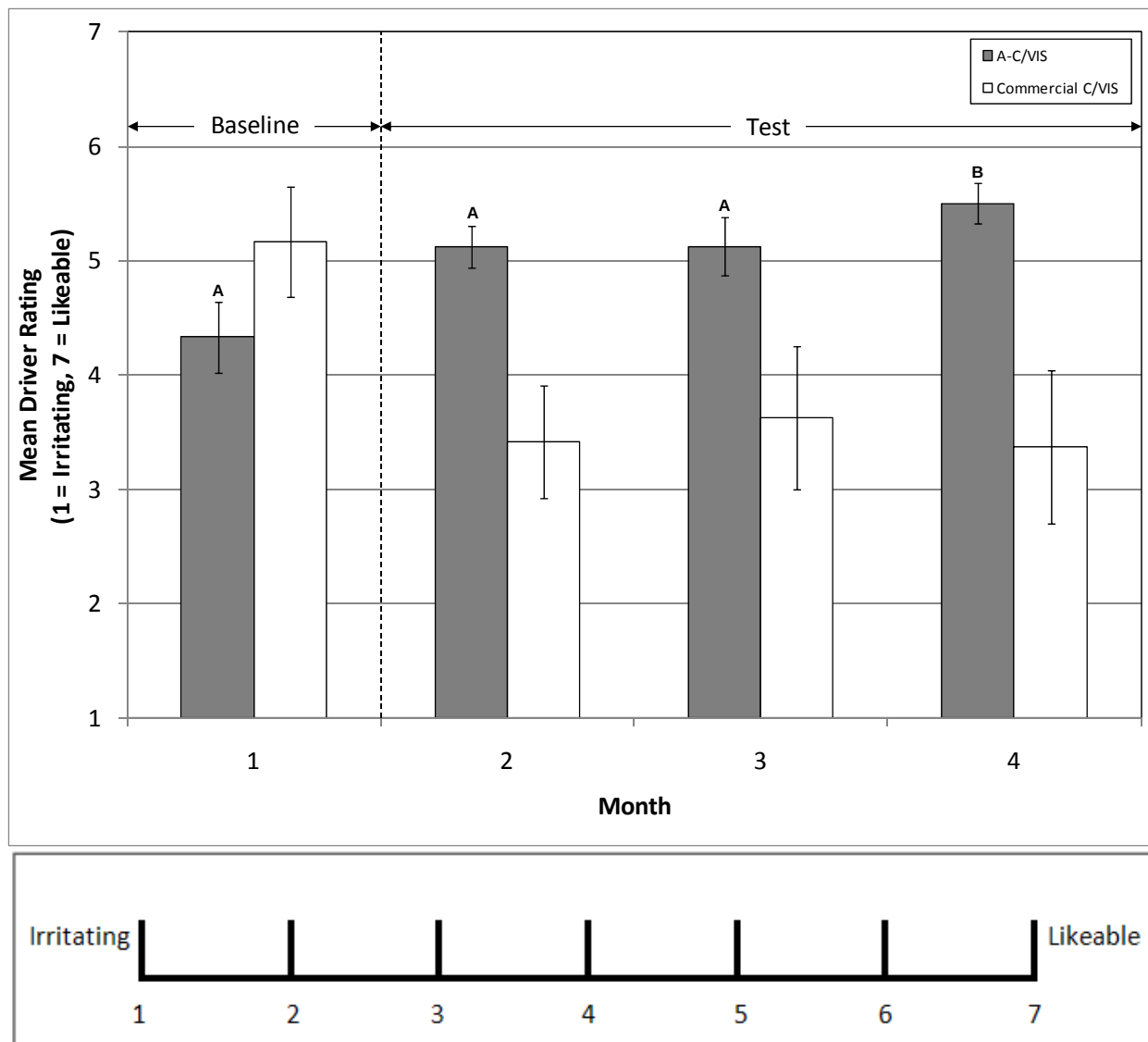


Figure 193. Comparison of Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Irritating.”

³ The multiple comparison tests that were performed pertain to the Friedman Two-Way ANOVA and are specified in Siegel & Castellan (1988).

How Desirable is the C/VIS

Figure 194 presents drivers' mean ratings per month in response to the statement, "I think the C/VIS is desirable." Drivers of A-C/VIS-equipped trucks indicated that the A-C/VIS was more desirable as their time in the study progressed ($\chi^2 = 12.17$, $p = 0.0068$). A statistically significant difference between drivers' mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$).

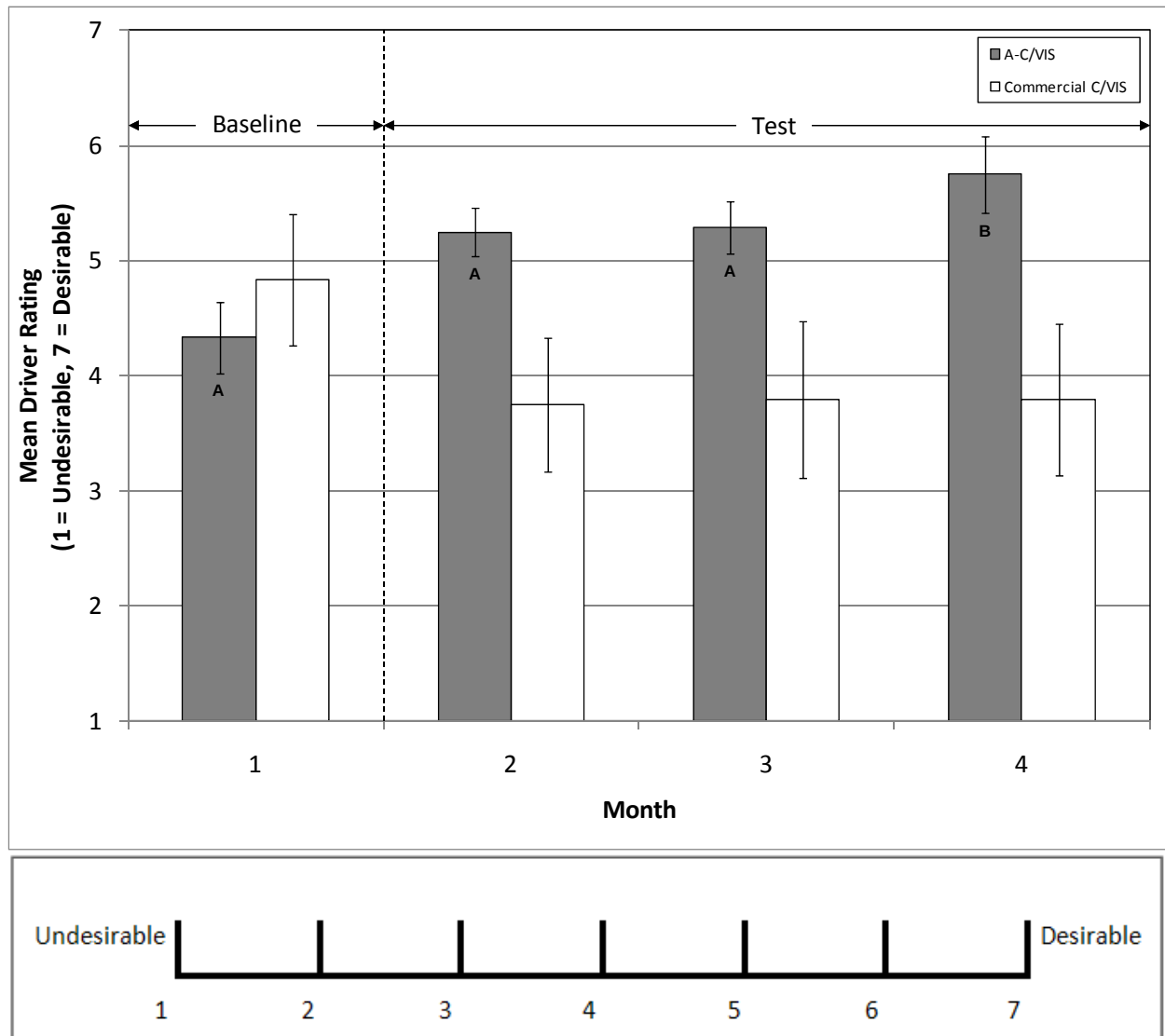


Figure 194. Comparison of Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, "I think the C/VIS is Desirable."

C/VIS's Ability to Eliminate Blind Spots around the Truck

Drivers' mean ratings in regard to the question, "How much do you agree with the statement, 'This C/VIS eliminates the blind spots around my truck?'" are presented in Figure 195. A Mann-Whitney U test using each driver's median rating was performed to analyze between-subjects differences between the ratings of A-C/VIS-equipped and commercial C/VIS-equipped trucks. A

C/VIS main effect was found ($U = 56.00, p = 0.0065$). Drivers of A-C/VIS-equipped trucks indicated that the A-C/VIS helped eliminate blind spots around their truck ($M = 6.19, SE = 0.12, Min = 5, Max = 7$), while drivers of commercial C/VIS-equipped trucks opinions varied ($M = 3.72, SE = 0.24, Min = 1, Max = 7$). Some drivers of commercial C/VIS-equipped trucks indicated that the commercially available C/VIS eliminated blind spots, while others disagreed that it eliminated blind spots.

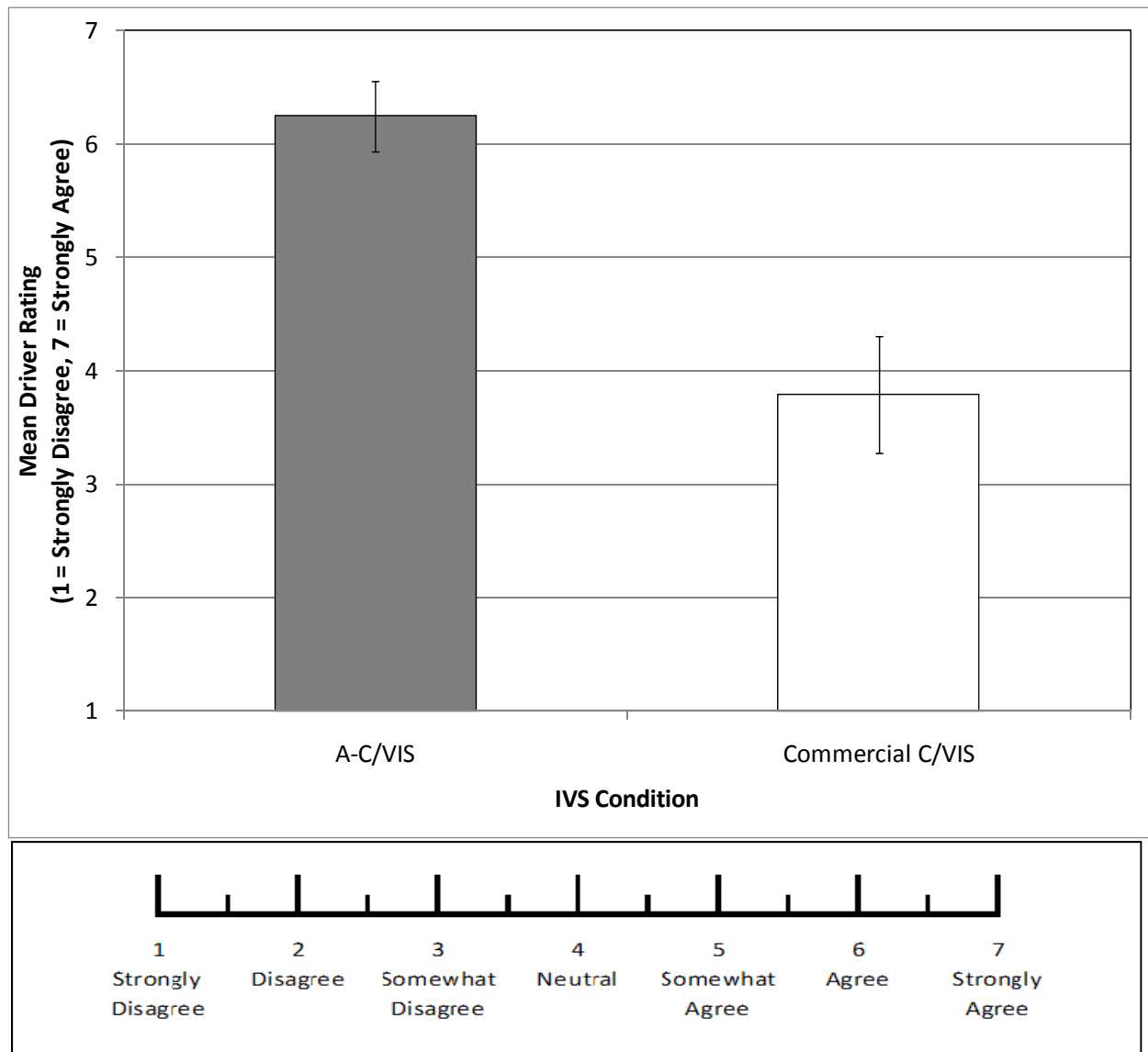


Figure 195. Comparison of Mean Driver Ratings in Response to the Question, “How Much do you Agree with the Statement, ‘This C/VIS Eliminates the Blind Spots Around My Truck?’”

Ease of Use of the C/VIS

Figure 196 presents the mean ratings of drivers of both A-C/VIS-equipped trucks and commercial C/VIS-equipped trucks in regard to the question, “How much do you agree with the

statement, ‘This C/VIS is easy to use?’” Drivers of both trucks found the system easy to use. Their mean ratings did not significantly differ ($p = 0.4589$).

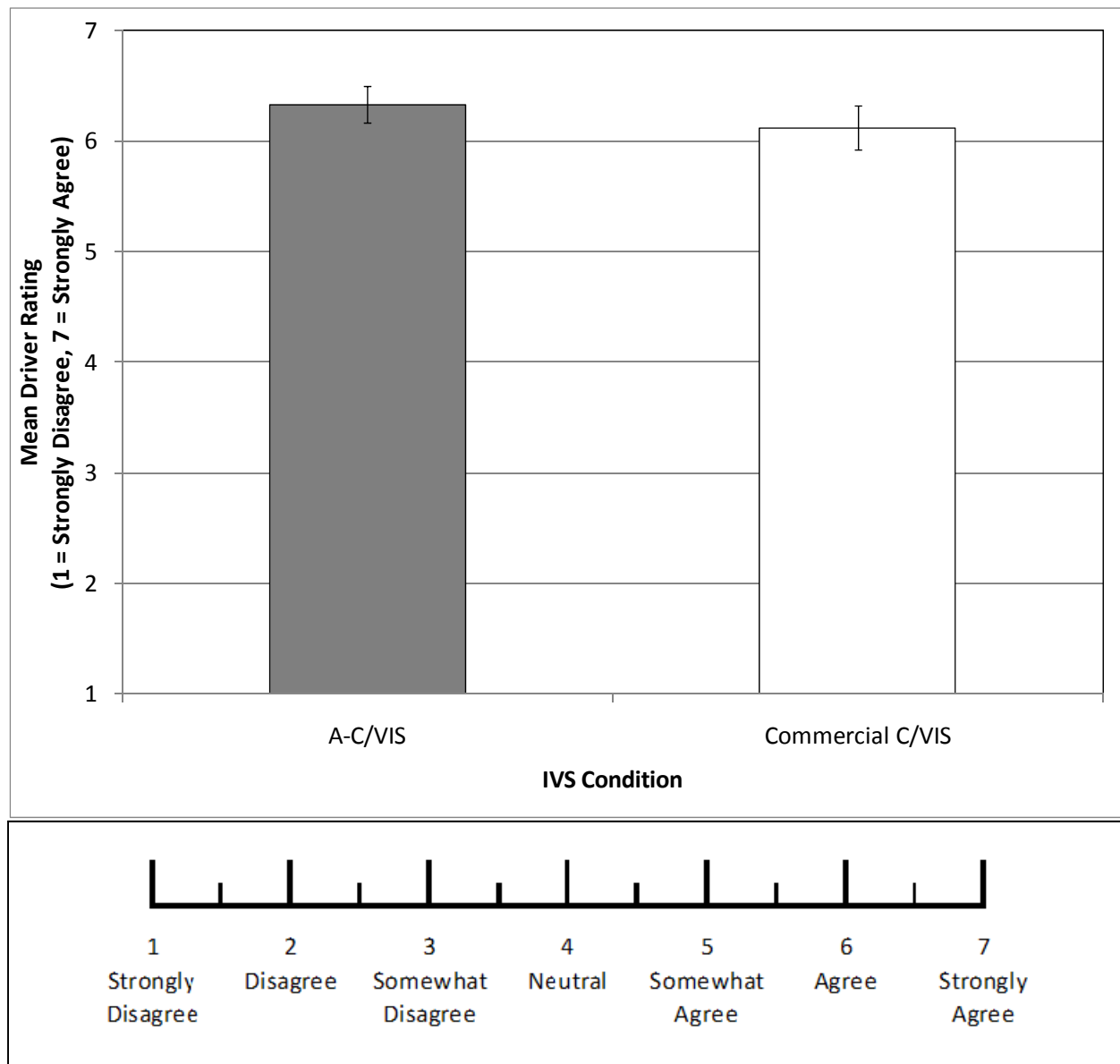


Figure 196. Comparison of Mean Driver Ratings in Response to the Question, “How Much do you Agree with the Statement, ‘This C/VIS is Easy to Use?’”

Usefulness of the Object Detection Feature

Drivers of A-C/VIS-equipped trucks’ mean ratings in response to the question, “How much do you agree with the statement, ‘The object detection feature is useful?’” are presented in Figure 197. Drivers of A-C/VIS-equipped trucks indicated the object detection feature was useful. Drivers’ mean ratings did not significantly differ by month in study ($p = 0.9410$).

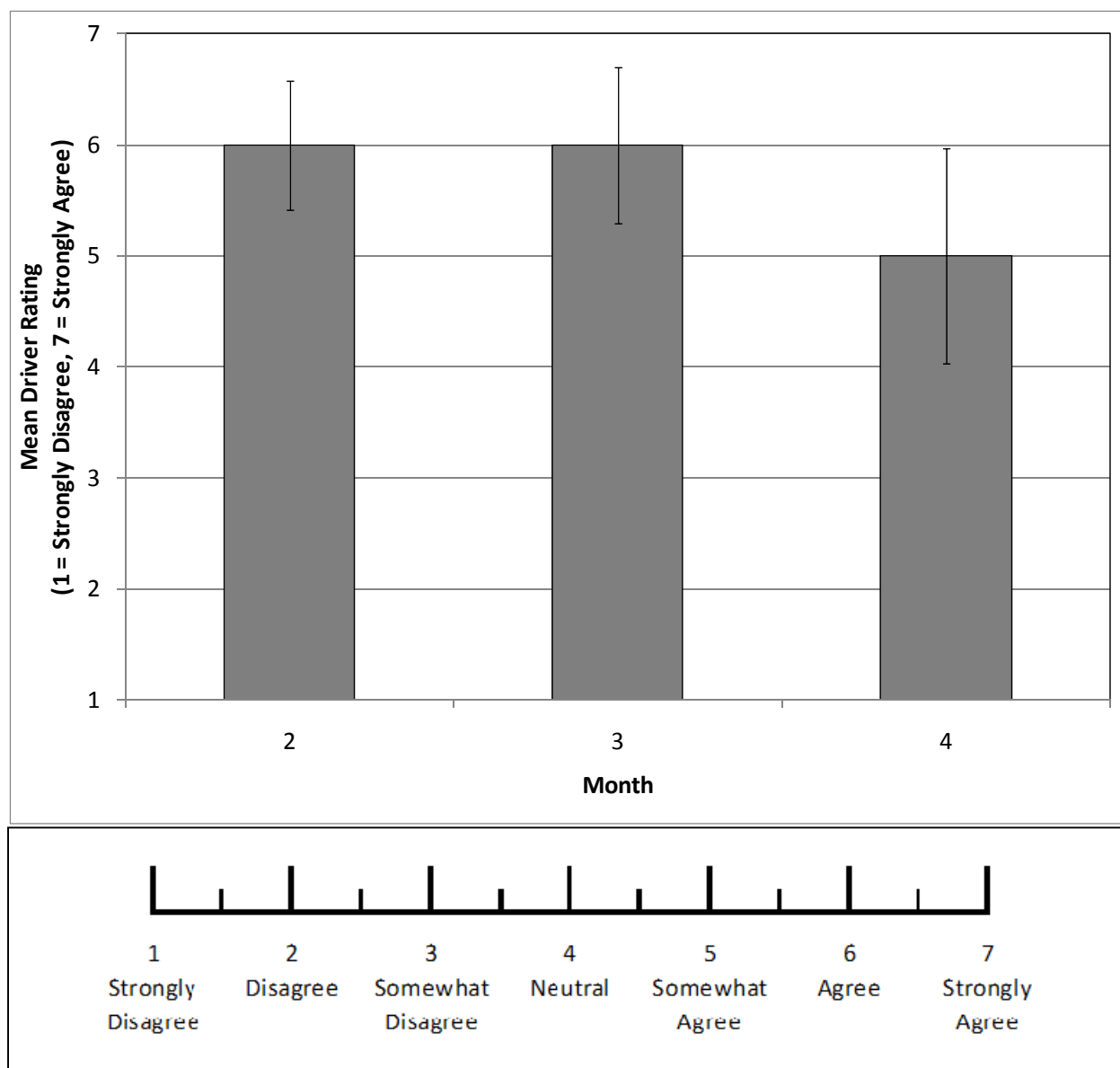


Figure 197. Comparison of Mean Driver Rating in Month 2, Month 3, and Month 4 in Response to the Question, “How Much do you Agree with the Statement, ‘The Object Detection Feature is Useful’?”

Glare from Monitors at Night

Drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks’ mean ratings in regard to the question, “How uncomfortable is the glare from the monitors when you are driving at night looking forward down the road?” are presented in Figure 198. A significant difference between the ratings of drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks was found ($p = 0.0152$). Drivers indicated that the glare from the A-C/VIS monitors was significantly more comfortable ($Min = 3$, $Max = 6$) than the glare produced by the commercial C/VIS’s monitors ($Min = 1$, $Max = 4.75$).

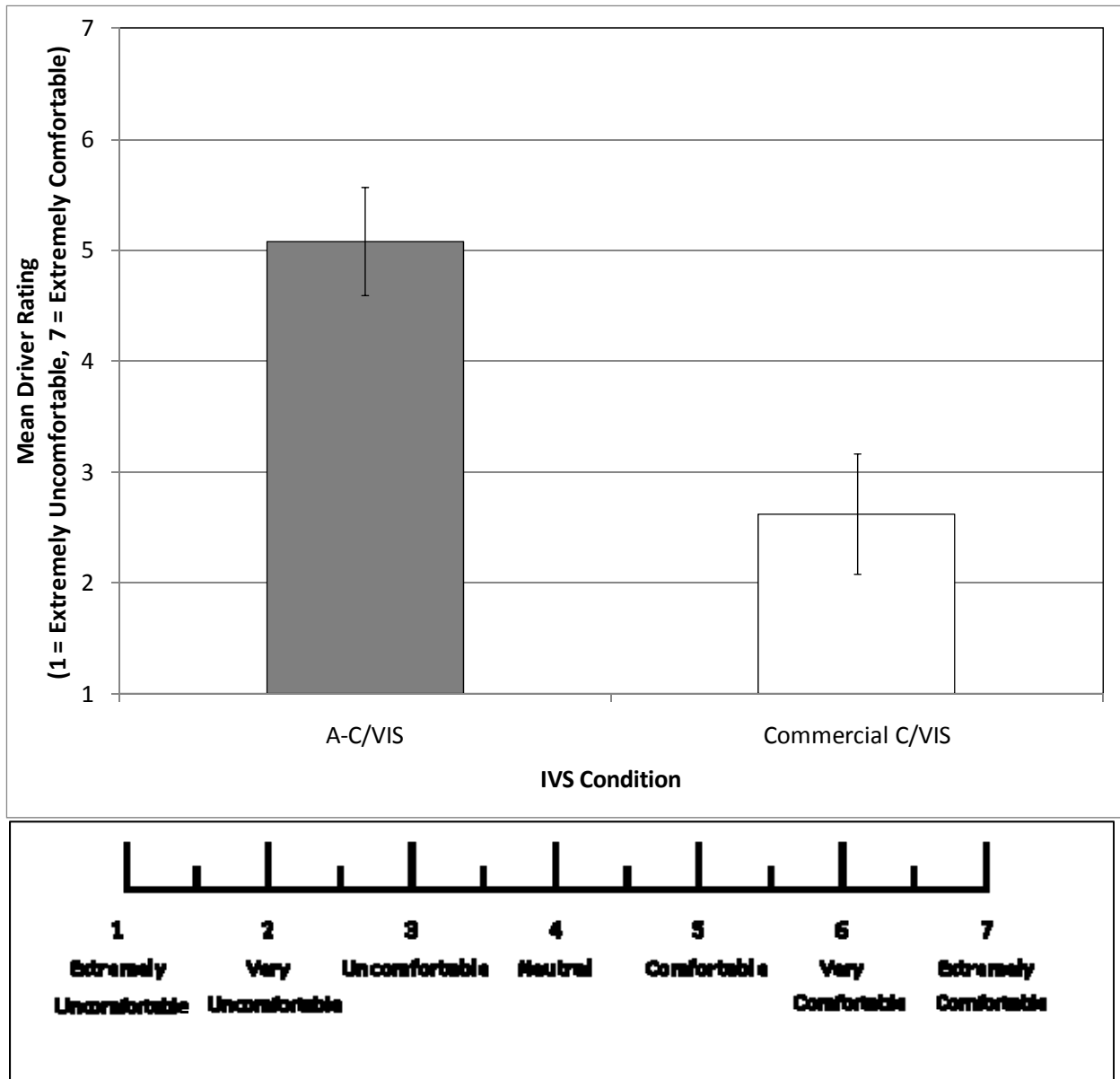


Figure 198. Comparison of Mean Driver Ratings in Response to the Question, “How Uncomfortable is the Glare from the Monitors when you are Driving at Night Looking Forward Down the Road?”

Degree to which Monitor Glare Reduces Ability to See the Road

In regard to the question, “By how much does the lighting from the monitors reduce your ability to see details in the road ahead of you (for example, ability to read the license plate characters)?” drivers’ mean ratings are presented in Figure 199. A significant difference in drivers’ mean ratings was found ($p = 0.0238$). The drivers indicated that the lighting from the A-C/VIS monitors slightly reduced their ability to see details in the road ($Min = 4$, $Max = 6.25$), while drivers indicated the lighting from the commercial C/VIS’s monitors reduced their ability to see details in the road by a moderate amount ($Min = 1$, $Max = 5.5$).

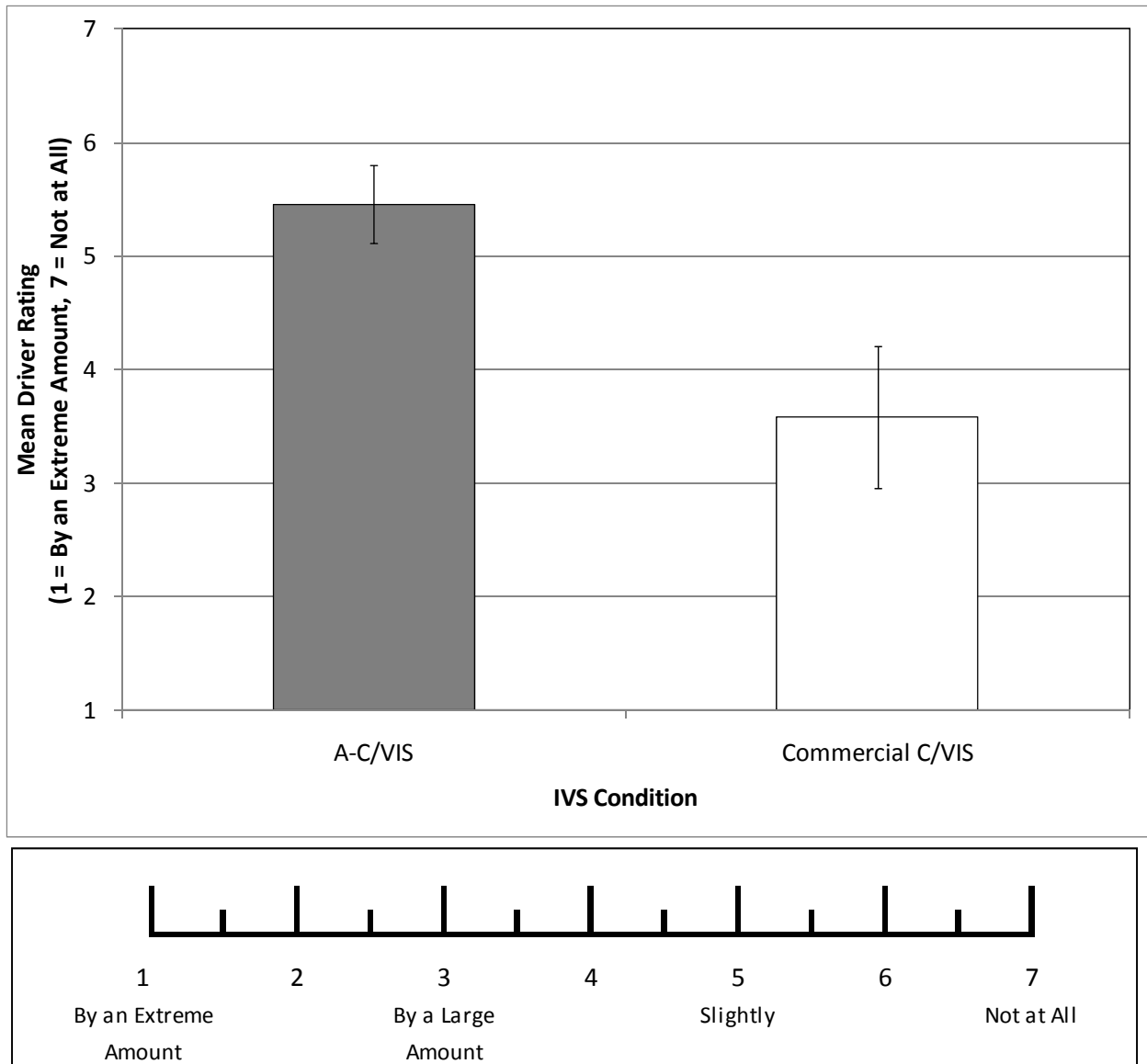


Figure 199. Comparison of Mean Driver Ratings in Response to the Question, “By How Much Does the Lighting From the Monitors Reduce your Ability to See Details in the Road Ahead of You (for example, ability to read the license plate characters)?”

It is foreseeable that drivers’ height may contribute to their visual impairment ratings. Shorter drivers may be affected to a greater degree by the display glare because their eyes are closer to the display. Drivers’ mean ratings are plotted against their height in Figure 200. However, a relationship was not found ($R^2 = 0.2837$).

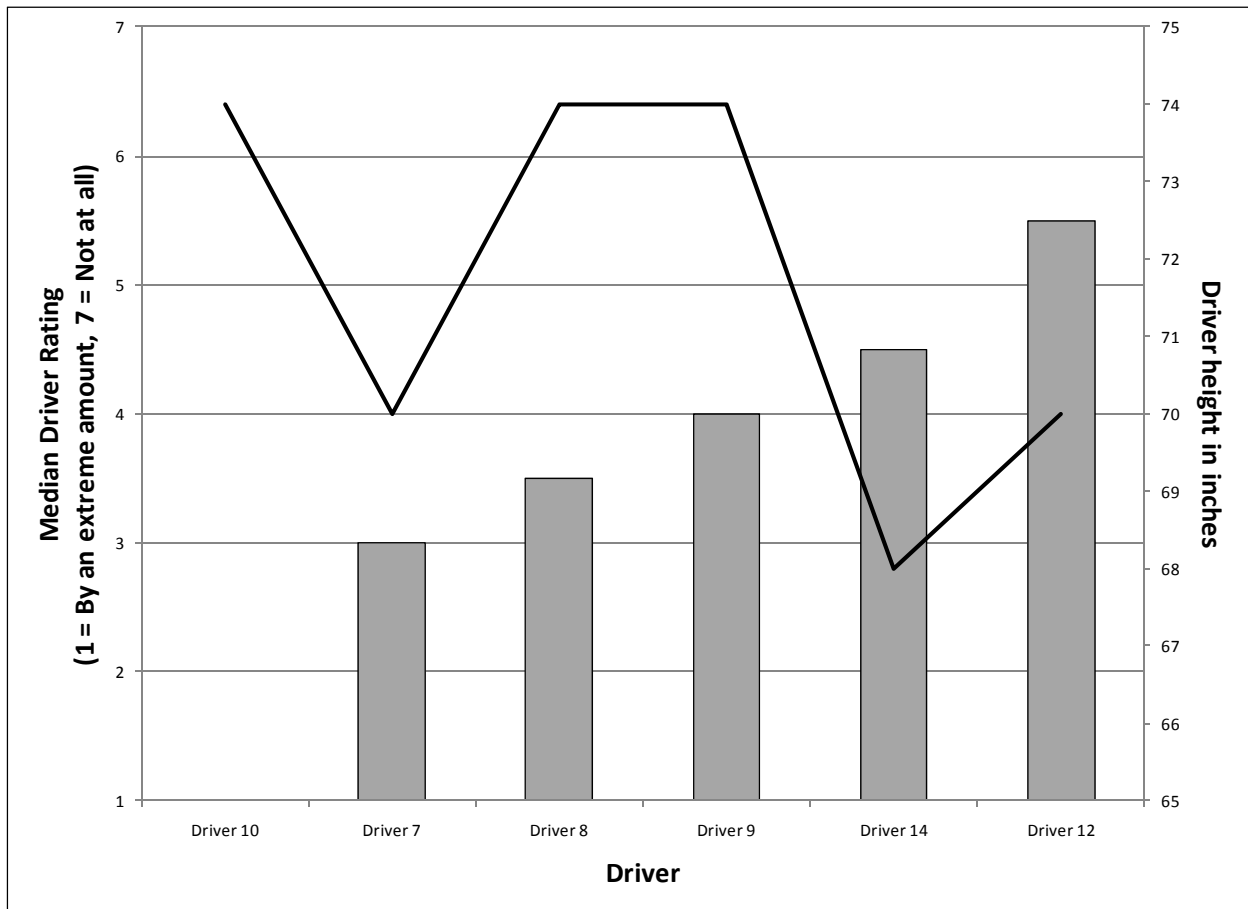


Figure 200. Comparison of the Commercially Available C/VIS Drivers' Heights and Their Median Ratings in Response to the Question, "By How Much Does the Lighting From the Monitors Reduce your Ability to See Details in the Road Ahead of you (for example, ability to read the license plate characters)?"

Degree to which Monitor Blocks View of Roadway

Drivers' mean ratings in response to the question, "How much does the monitor block your view of the road?" are presented in Figure 201. Drivers' mean ratings were found to significantly differ ($p = 0.0238$). The A-C/VIS monitors blocked the drivers' view of the road by a very small amount ($Min = 5$, $Max = 7$), while the commercial C/VIS's monitors blocked the drivers' view of the road by a moderate amount ($Min = 1$, $Max = 6$). Possible ties between a driver's height and the degree to which the monitors block the view of the road were examined, and no association was found ($R^2 = 0.2565$) (Figure 202).

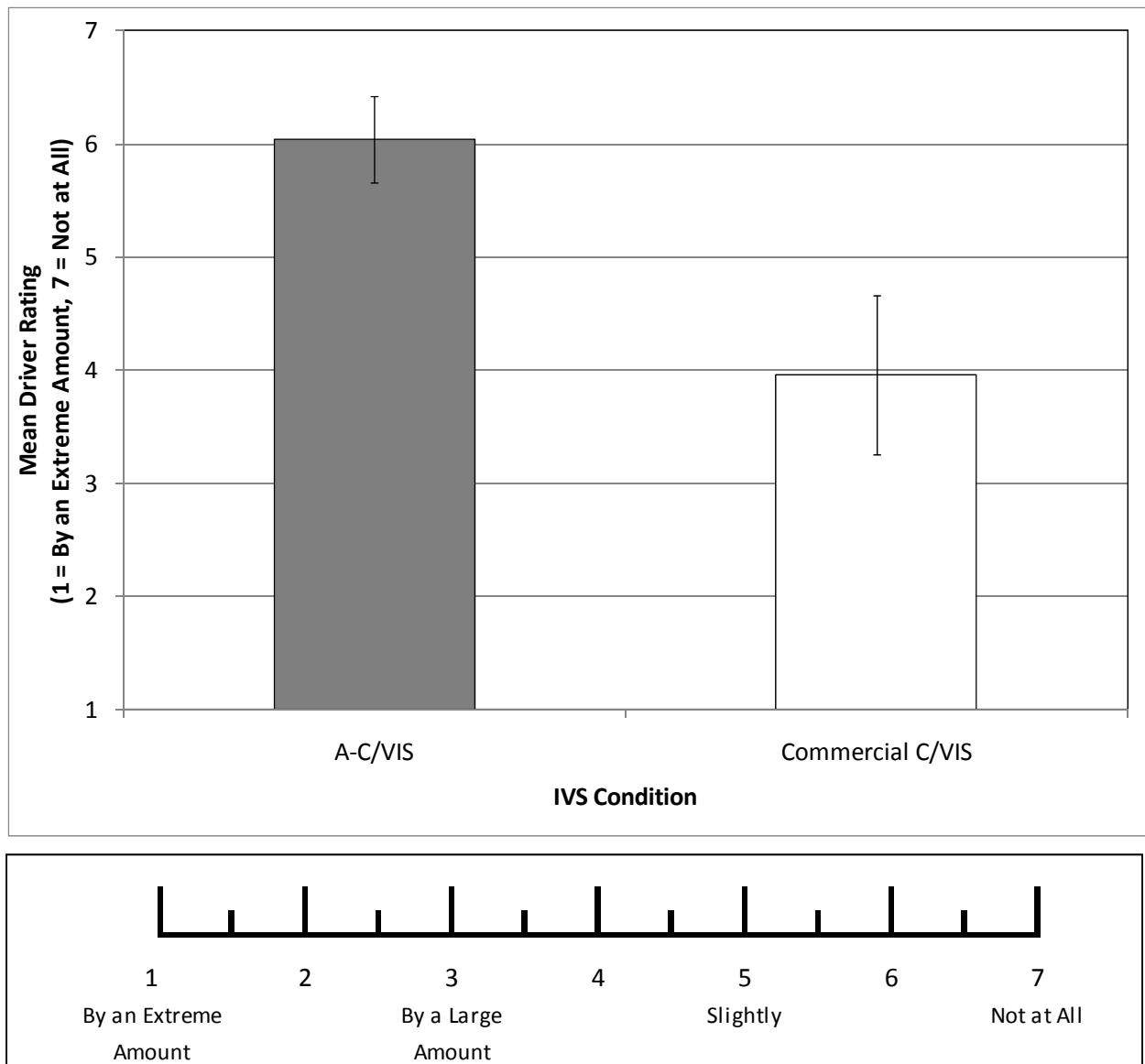


Figure 201. Comparison of Mean Driver Ratings in Response to the Question, “How Much Does the Monitor Block your View of the Road?”

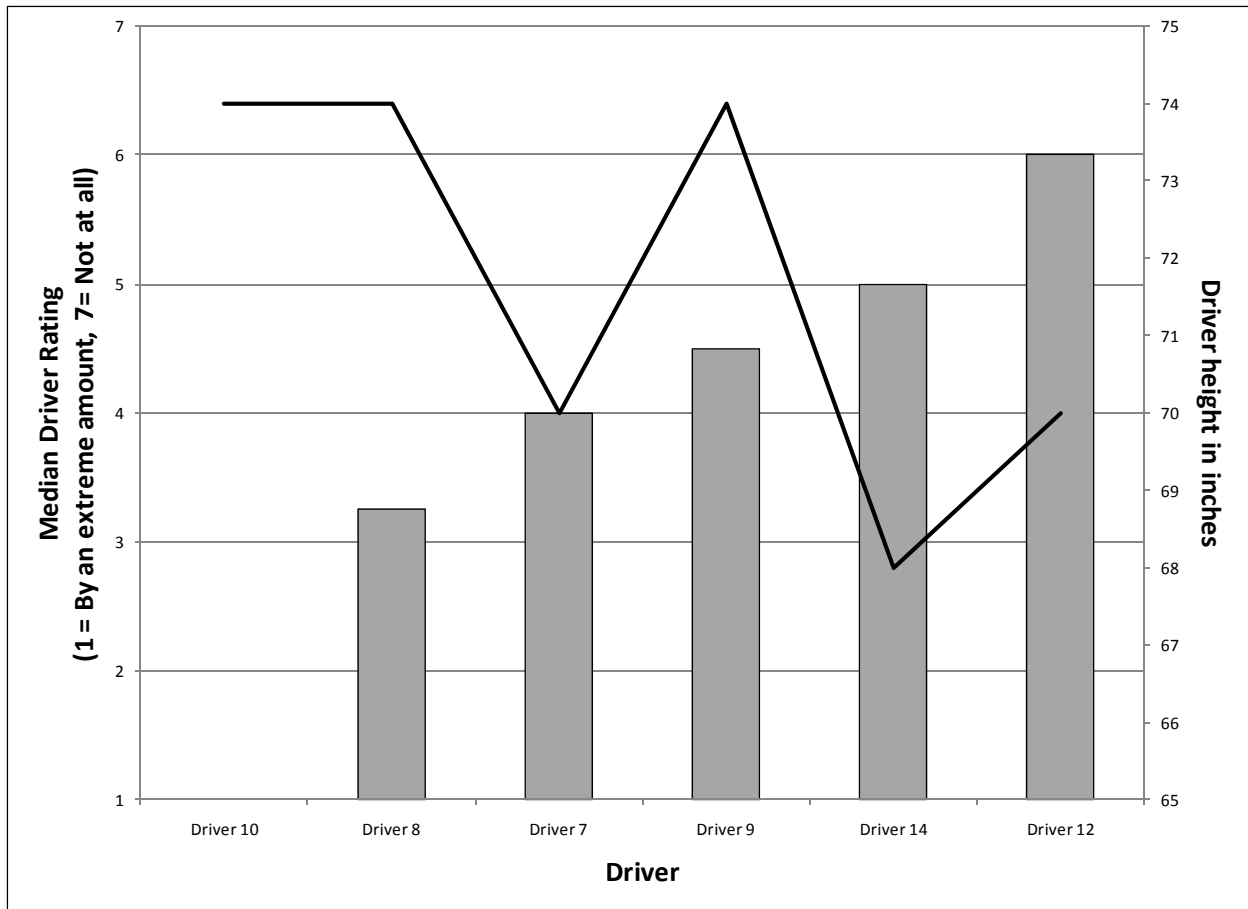


Figure 202. Comparison of the Commercially Available C/VIS Drivers' Heights and Their Median Ratings in Response to the Question, "How Much Does the Monitor Block your View of the Road?"

Effort to Clean Camera Lens

Figure 203 illustrates drivers' mean ratings in relation to the question, "How easy is it to clean the camera lens?" As illustrated in the figure, drivers of both the A-C/VIS-equipped and the commercial C/VIS-equipped trucks indicated it was very easy to clean the camera lenses. Drivers' mean ratings were not found to significantly differ ($p = 0.4048$).

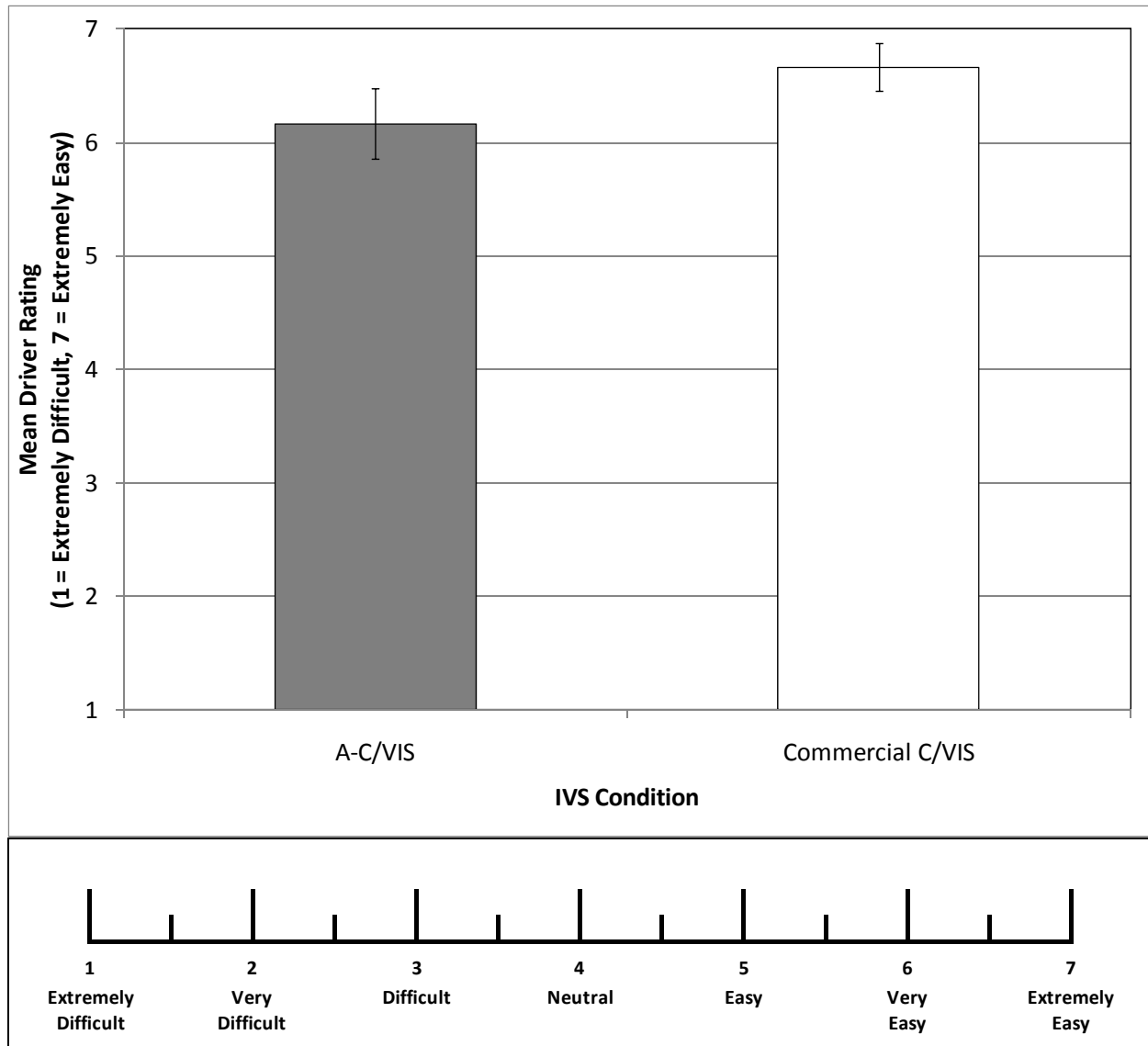


Figure 203. Comparison of Mean Driver Ratings in Response to the Question, “How Easy is It to Clean the Camera Lens?”

Drivers’ Ratings of the Driving Task

The driving performance questionnaire was administered to drivers every two weeks throughout the study. Multiple questions regarding various aspects of the driving task were posed. The questionnaire repeated each question four times, once for each of the following four environmental conditions: 1) clear daytime driving, 2) daytime driving with inclement weather, 3) clear nighttime driving, and 4) nighttime driving with inclement weather. Drivers’ ratings were analyzed using inferential statistical tests across experimental condition, type of C/VIS, and by month in study.

Awareness of Objects Located Around the Truck and Trailer

Figure 204 presents drivers' mean ratings across the four environmental conditions to the question "How difficult is it to be aware of the objects located in the area around your truck and trailer while driving? This includes the blind spots (no-zone) area." For each environmental condition, Wilcoxon Signed Ranks Tests were performed to determine if there was a difference between drivers' mean ratings in the Baseline and Test conditions. These tests were performed separately using the rating data collected from drivers of A-C/VIS-equipped trucks and drivers of commercial C/VIS-equipped trucks. Drivers' mean ratings in the Baseline and Test conditions were not found to significantly differ in any of the environmental conditions examined ($p > 0.05$).

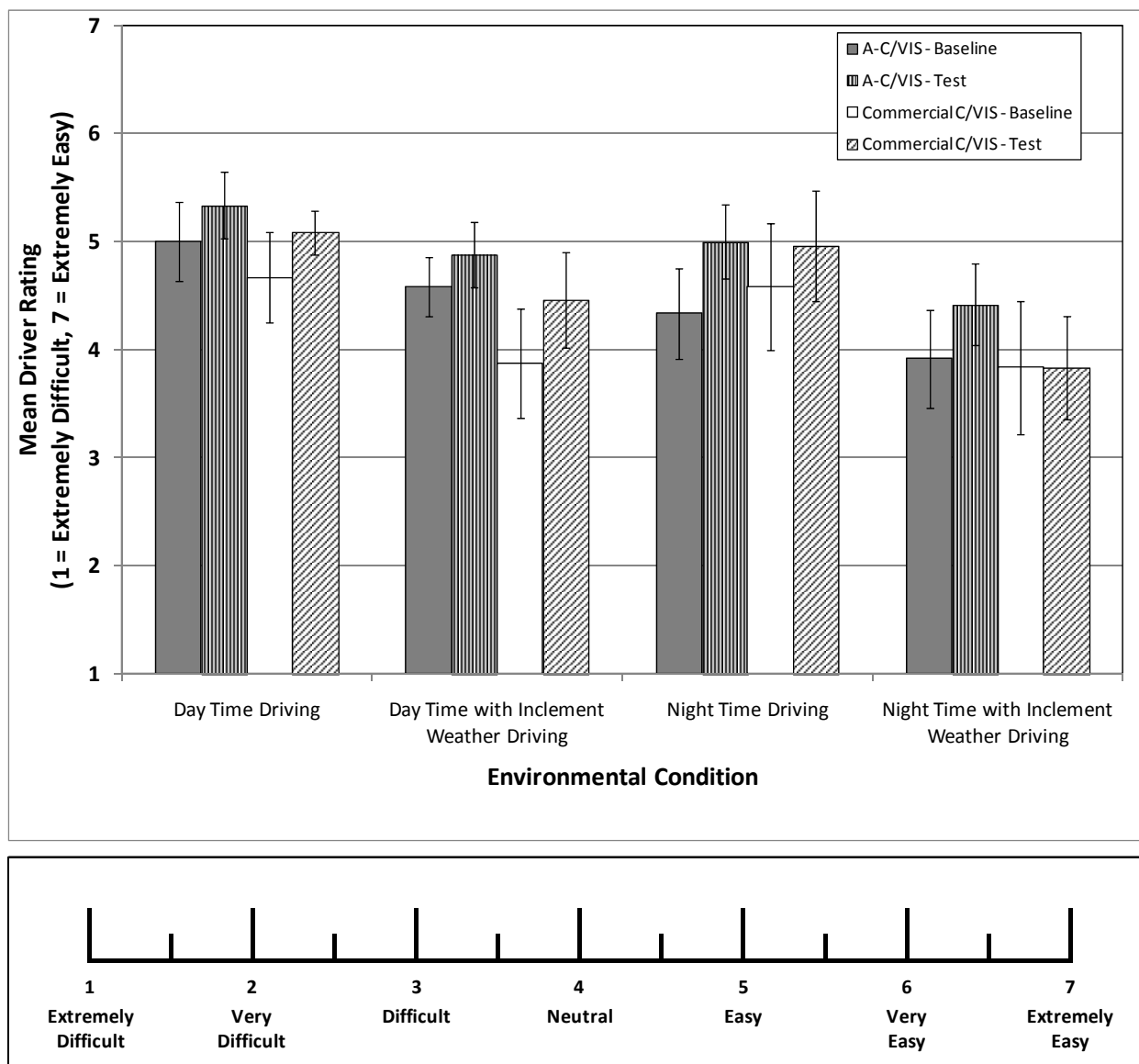


Figure 204. Comparison of Driver Responses to the Question, "How Difficult is it to be Aware of Objects Located in the Area Around your Truck and Trailer while Driving?"

Drivers' mean ratings in the Baseline and Test conditions were further investigated to see if drivers' mean ratings significantly changed as their time in the study progressed. Drivers' mean ratings in months 1, 2, 3, and 4 were analyzed using a Friedman Two-Way ANOVA. For drivers of A-C/VIS-equipped trucks, a significant Month in Study effect was found when using the rating data that pertained to inclement nighttime driving ($\chi^2 = 8.02$, $p = 0.0455$). These drivers indicated that it became easier to be aware of surrounding objects when the A-C/VIS was available (Figure 205). Statistically significant pairwise comparisons between drivers' mean ratings in Month 1, Month 2, Month 3, and Month 4 were not found ($p > 0.05$).

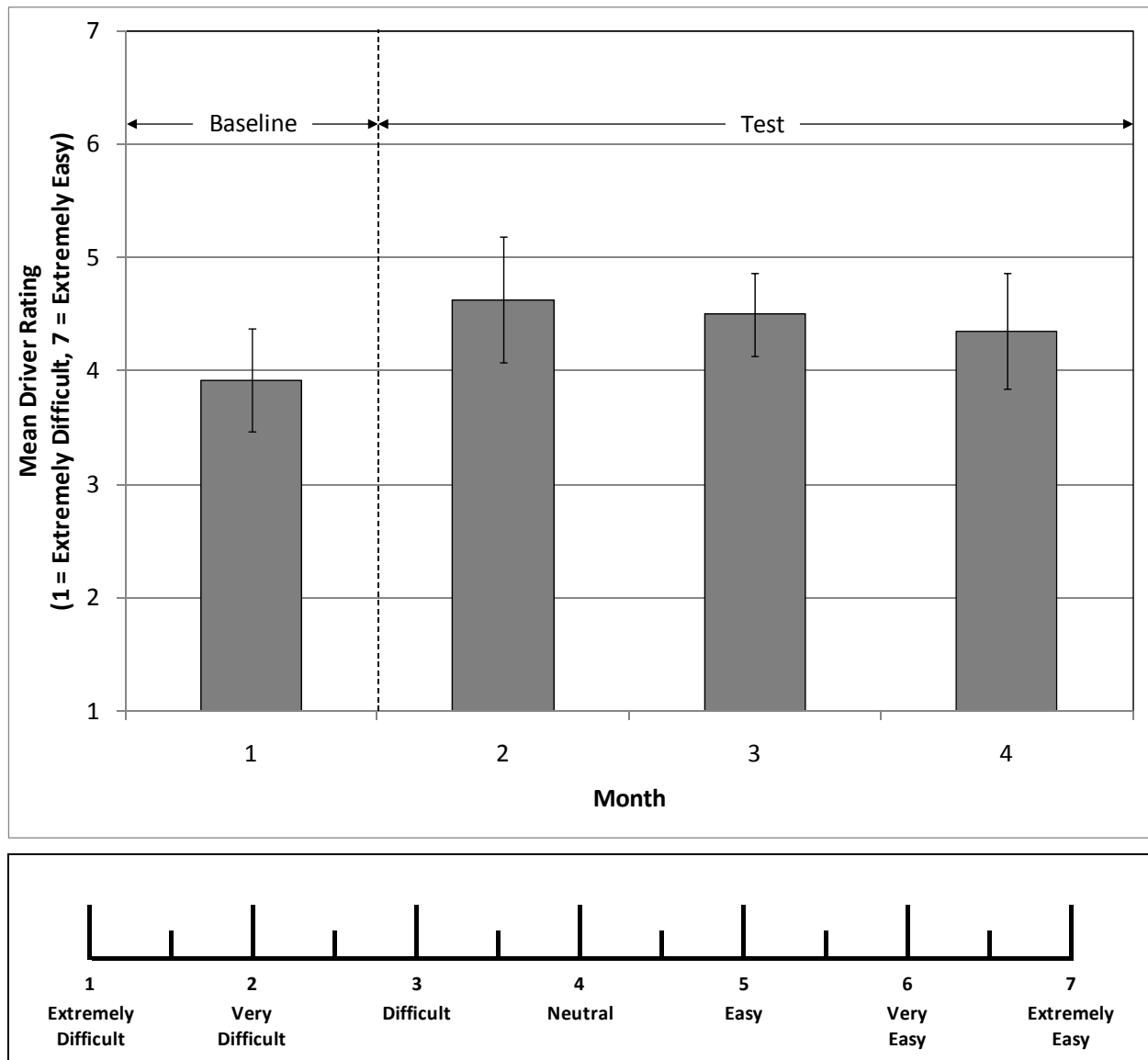


Figure 205. Comparison of A-C/VIS Drivers' Mean Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Question, "During the Night and When There is Inclement Weather, how Difficult is it to be Aware of Objects Located in the Area Around your Truck while Driving?" (D = number of drivers; R = number of responses)

Assessment of Clearance to Adjacent Vehicles

Figure 206 presents drivers' mean ratings to the question, "How difficult is it to determine whether there is clearance between the back edge of the trailer and the front of a vehicle traveling beside the truck?" Wilcoxon Signed Rank Tests were performed as described above for each environmental condition. Statistically significant differences between drivers' mean ratings in the Baseline and Test conditions were not found ($p > 0.05$). Furthermore, significant differences in drivers' mean Month in Study ratings did not exist in any environmental condition ($p > 0.05$).

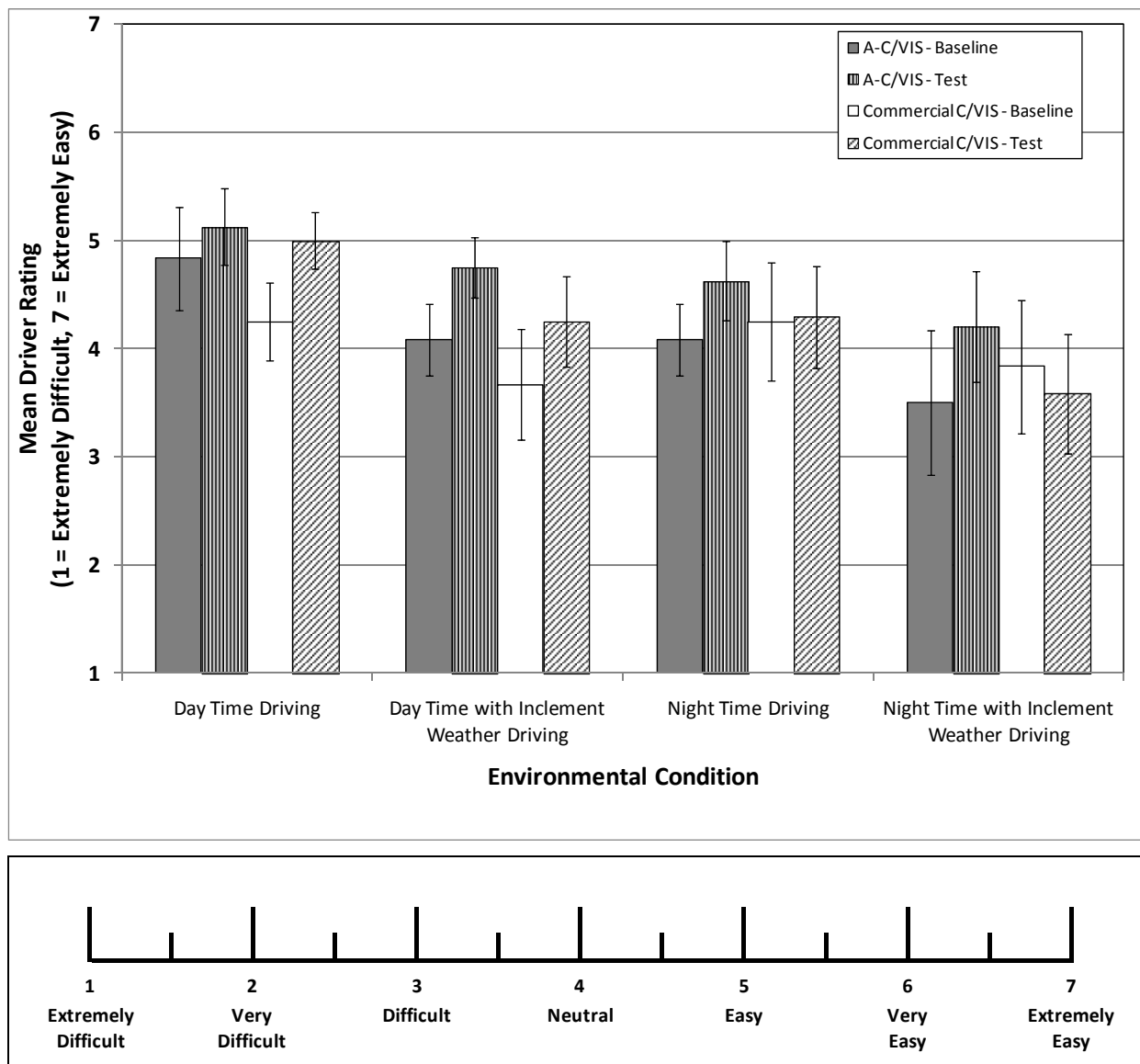


Figure 206. Comparison of Driver Responses to the Question, "How Difficult is it to Determine Whether there is Clearance between the Back Edge of the Trailer and the Front of a Vehicle Traveling Beside the Truck?"

Assessment of Adjacent Vehicle Type

Figure 207 presents drivers' mean ratings to the question, "How difficult is it to tell what kind of vehicle is traveling in the lane beside me?" across the four environmental conditions. Statistically significant differences were not present between drivers' mean ratings in the Baseline and Test conditions for any of the environmental conditions ($p > 0.05$). Drivers' mean ratings across each month in the study were analyzed, and no significant differences were found, regardless of the environmental condition ($p > 0.05$).

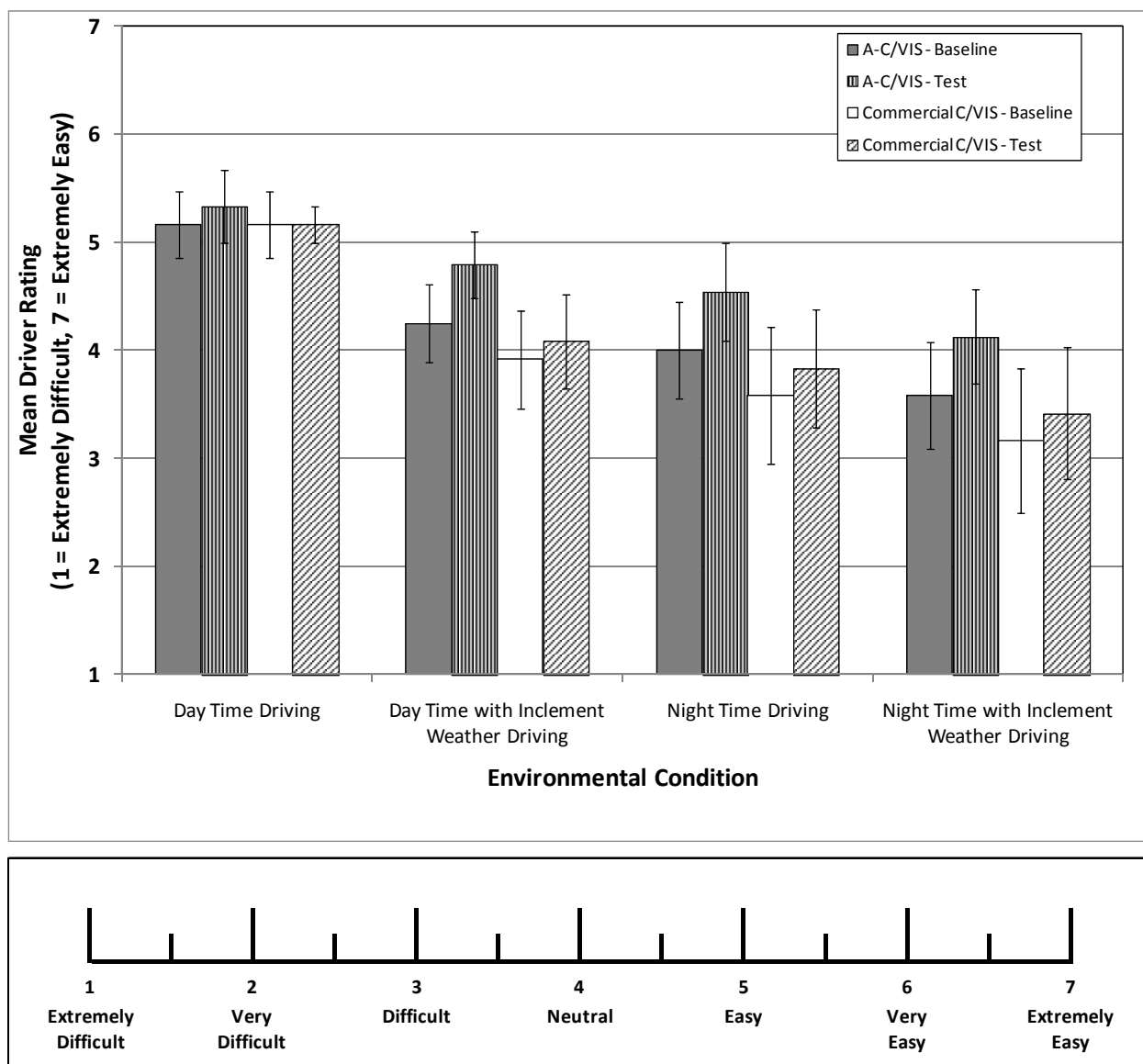


Figure 207. Comparison of Driver Responses to the Question, "How Difficult is it to Tell What Kind of Vehicle is Traveling in the Lane beside Me?"

Assessment of Adjacent Vehicle Approach Rate

The drivers' mean ratings in response to the question, "How difficult is it to tell how fast a vehicle in the lane beside me is approaching me?" are shown in Figure 208. Drivers' mean ratings in the Baseline and Test conditions did not significantly vary in any of the environmental conditions ($p > 0.05$).

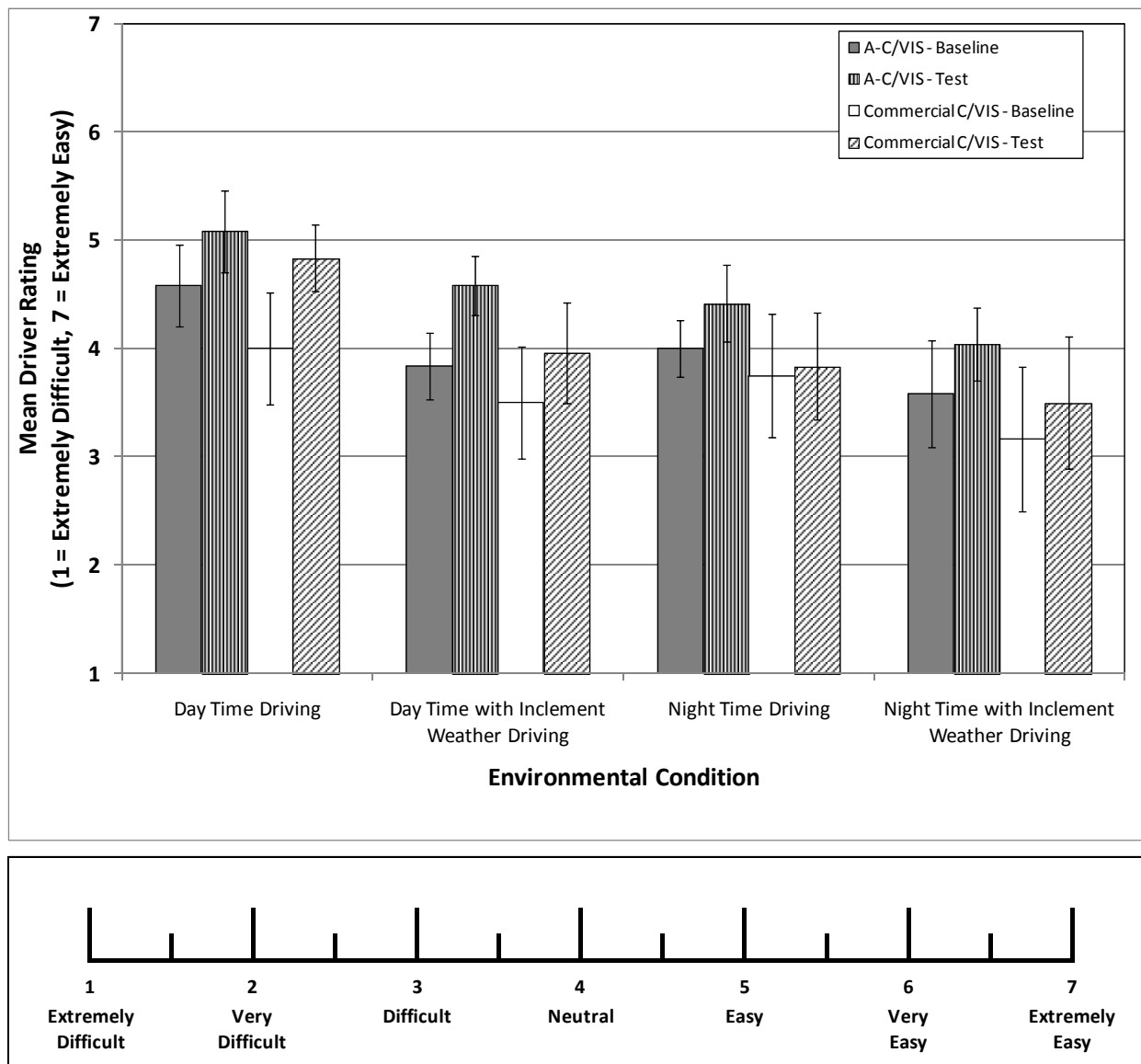


Figure 208. Comparison of Driver Responses to the Question, "How Difficult is it to Tell How Fast a Vehicle in the Lane beside Me is Approaching Me?"

A significant Month in Study effect was found for drivers of A-C/VIS-equipped trucks when using data related to inclement daytime conditions ($\chi^2 = 8.93$, $p = 0.0303$). Drivers of A-C/VIS equipped trucks indicated that during daytime inclement weather it became easier to determine the approach rate of a vehicle in an adjacent lane when the A-C/VIS was present (Figure 209). A

statistically significant pairwise comparison between drivers' mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$).

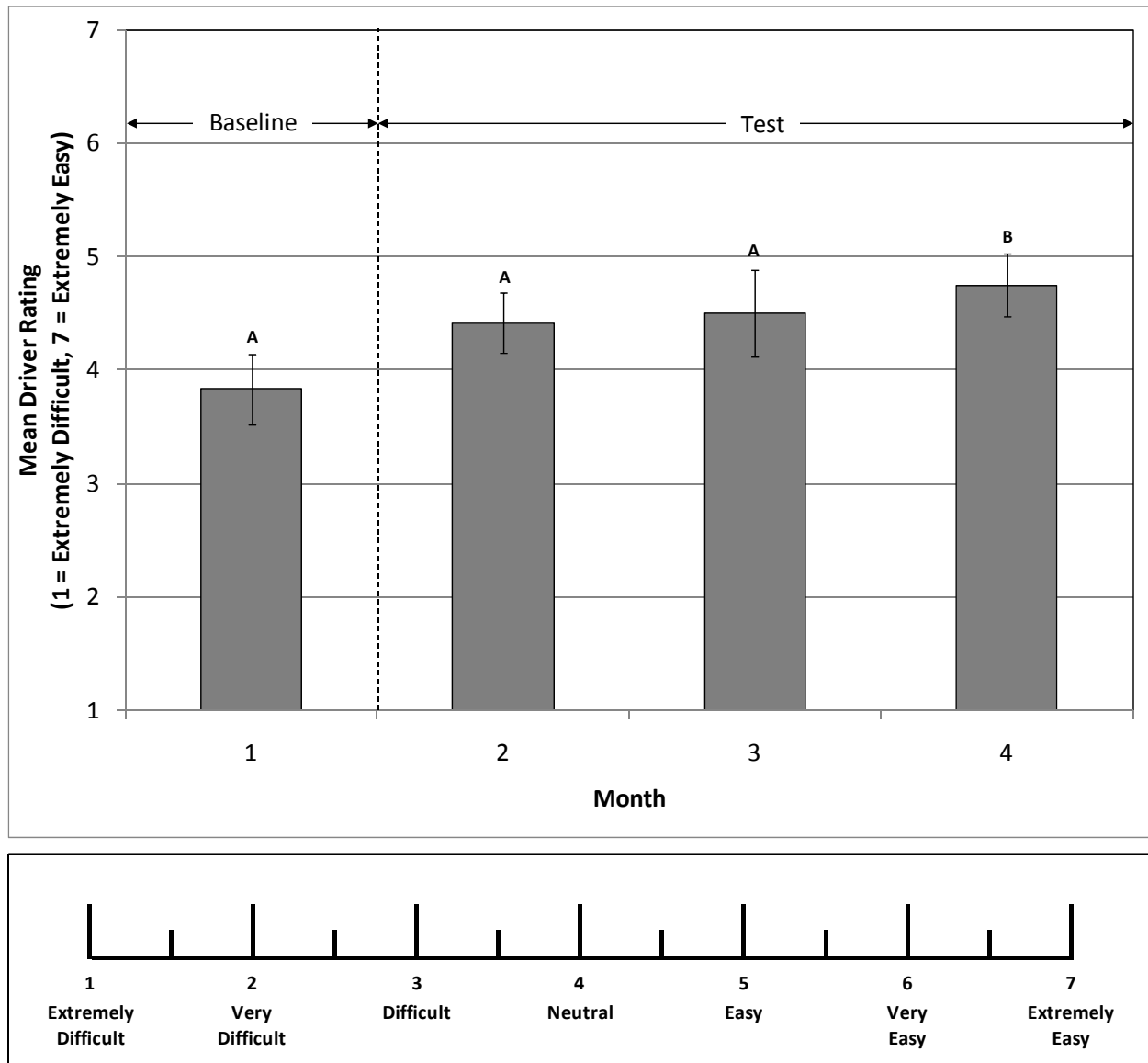


Figure 209. Comparison of A-C/VIS Drivers' Mean Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Question, "During the Day and When There is Inclement Weather, How Difficult is it to Tell How Fast a Vehicle in the Lane Beside Me is Approaching Me?" (D = number of drivers; R = number of responses)

Ease of Merging in Traffic

Drivers' mean ratings for the four environmental conditions in response to the question, "How difficult is it to merge into traffic?" are presented in Figure 210. Statistically significant differences between the mean ratings of drivers of A-C/VIS-equipped and commercial C/VIS-equipped trucks in the Baseline and Test conditions were not found for any environmental condition ($p > 0.05$).

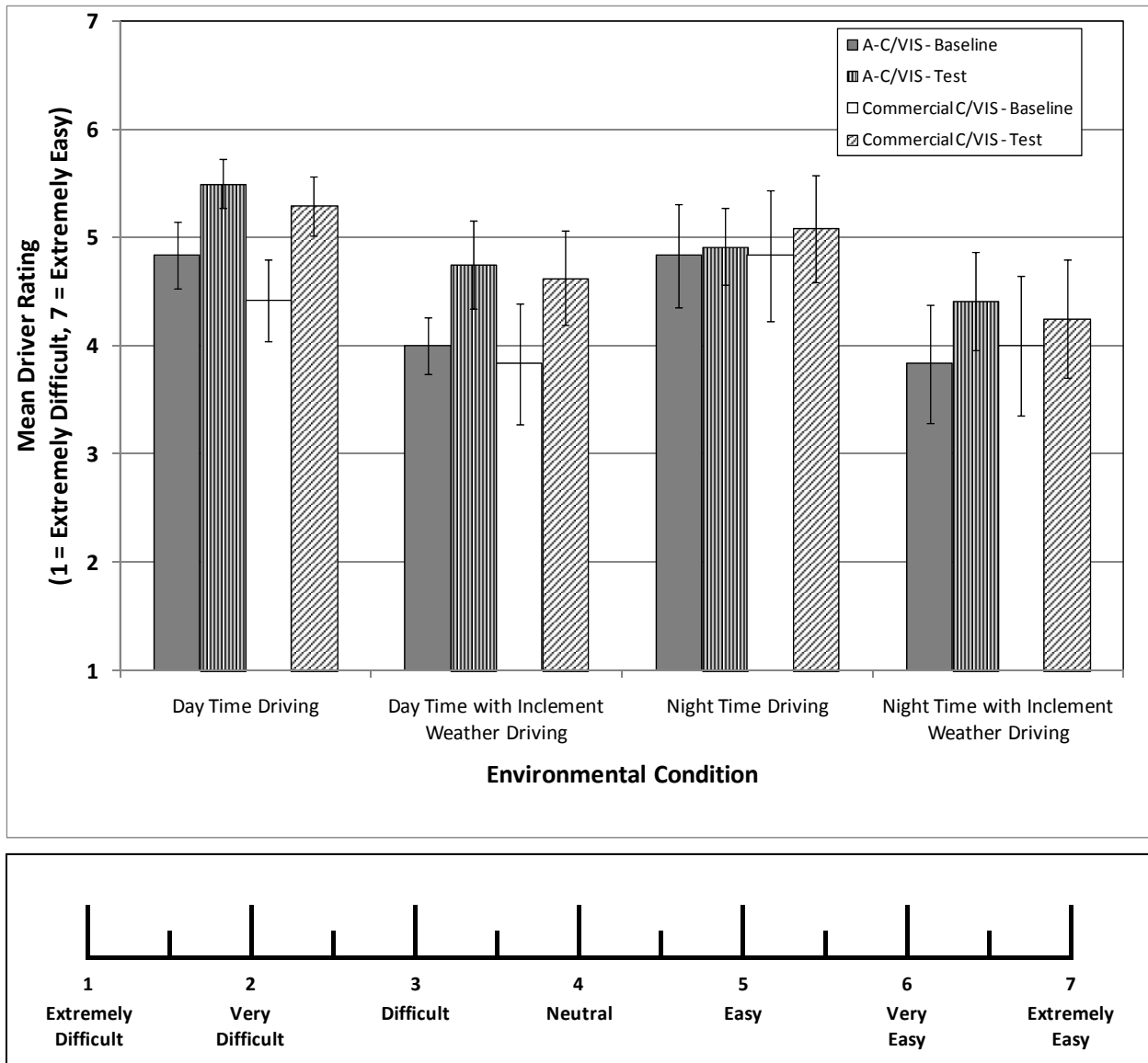


Figure 210. Comparison of Driver Responses to the Question, “How Difficult is it to Merge into Traffic?”

In investigating the data pertaining to inclement daytime conditions, a significant Month in Study effect was found for drivers of A-C/VIS equipped trucks ($\chi^2 = 8.41, p = 0.0382$). Drivers of A-C/VIS-equipped trucks found it easier to merge into traffic when the A-C/VIS was present (Figure 211). Significant differences between drivers’ mean ratings in each month were not found ($p > 0.05$).

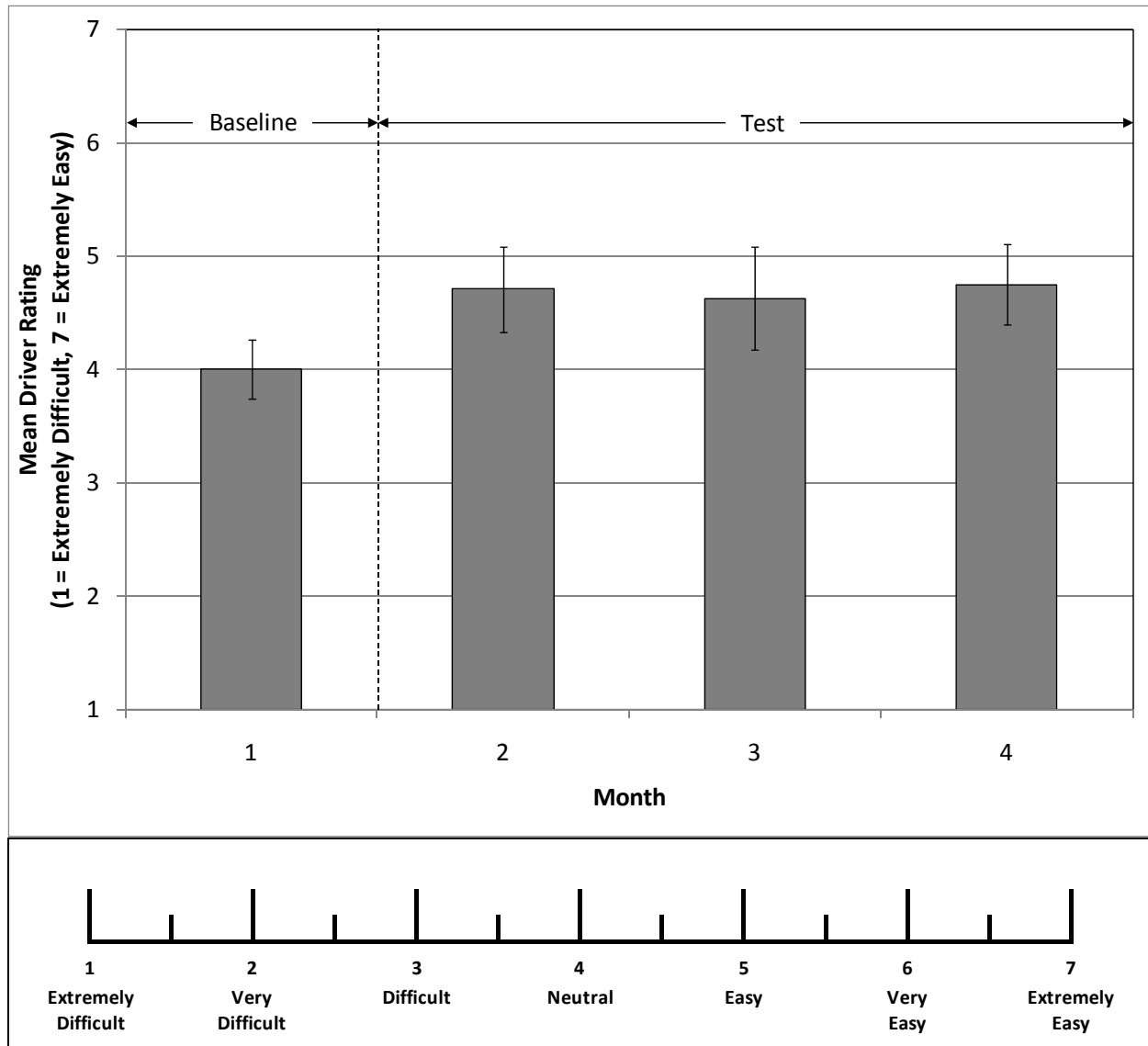


Figure 211. Comparison of A-C/VIS Drivers’ Mean Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Question, “During the Day and When There is Inclement Weather, How Difficult is it to Merge into Traffic?” (D = number of drivers; R = number of responses)

For drivers of commercial C/VIS-equipped trucks, a significant Month in Study effect was found when using the rating data that pertained to clear daytime conditions ($\chi^2 = 9.24$, $p = 0.0262$). Drivers of commercial C/VIS-equipped trucks indicated that, during clear daytime conditions, it became easier to merge into traffic when the C/VIS was available (Figure 212). Significant differences between drivers’ mean ratings in each month were not found ($p > 0.05$).

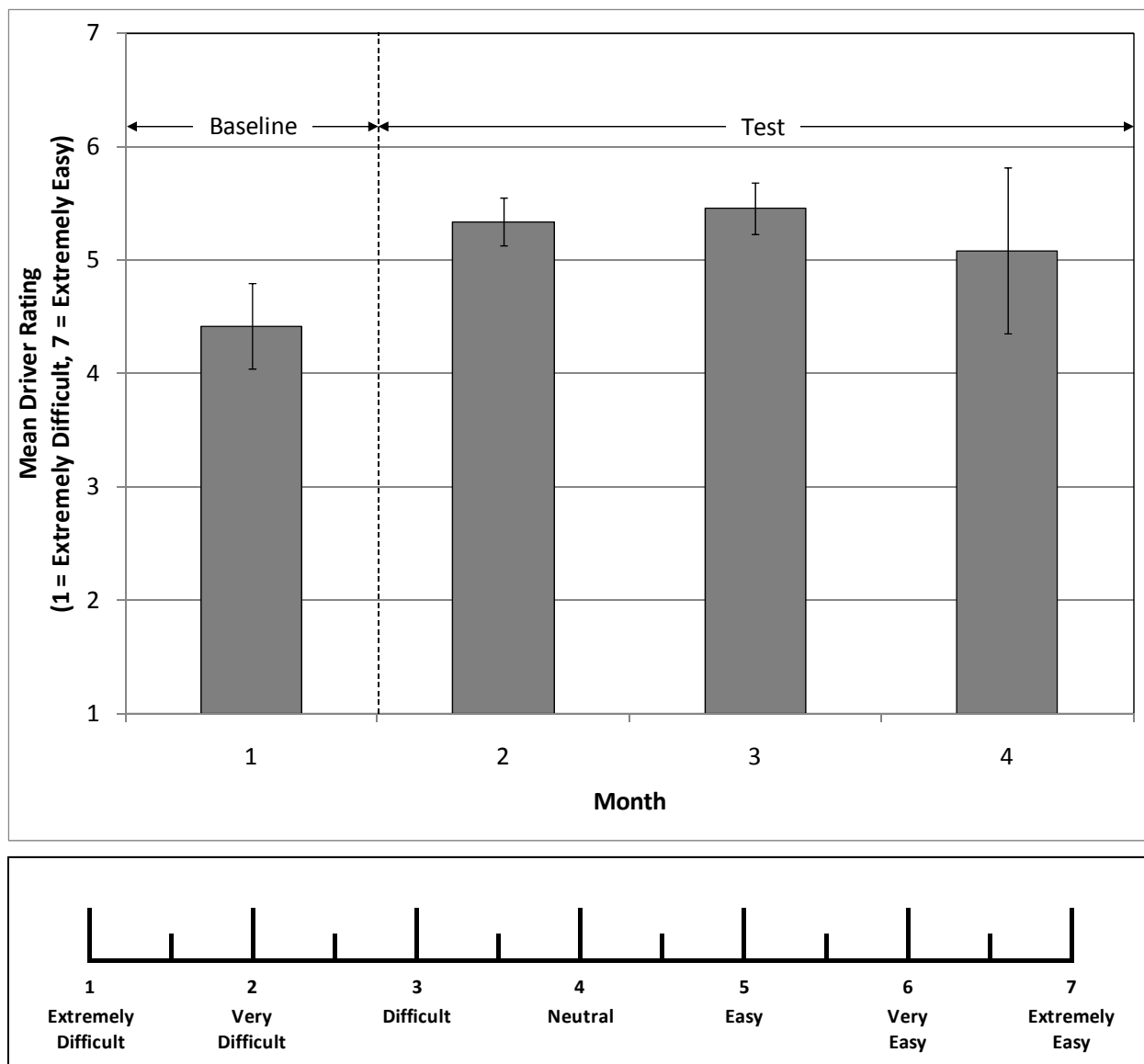


Figure 212. Comparison of the Commercially Available C/VIS Drivers' Mean Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Question, "During the Day, How Difficult is it to Merge into Traffic?" (D = number of drivers; R = number of responses)

Confidence when Merging into Traffic

Figure 213 presents drivers' mean ratings across the four environmental conditions to the question "How confident are you that you will not hit an adjacent vehicle when merging into traffic?" Statistically significant differences between mean ratings in the Baseline and Test conditions were not found for drivers of A-C/VIS-equipped or commercial C/VIS-equipped trucks ($p > 0.05$). Significant differences between drivers' mean ratings in each month were not found ($p > 0.05$).

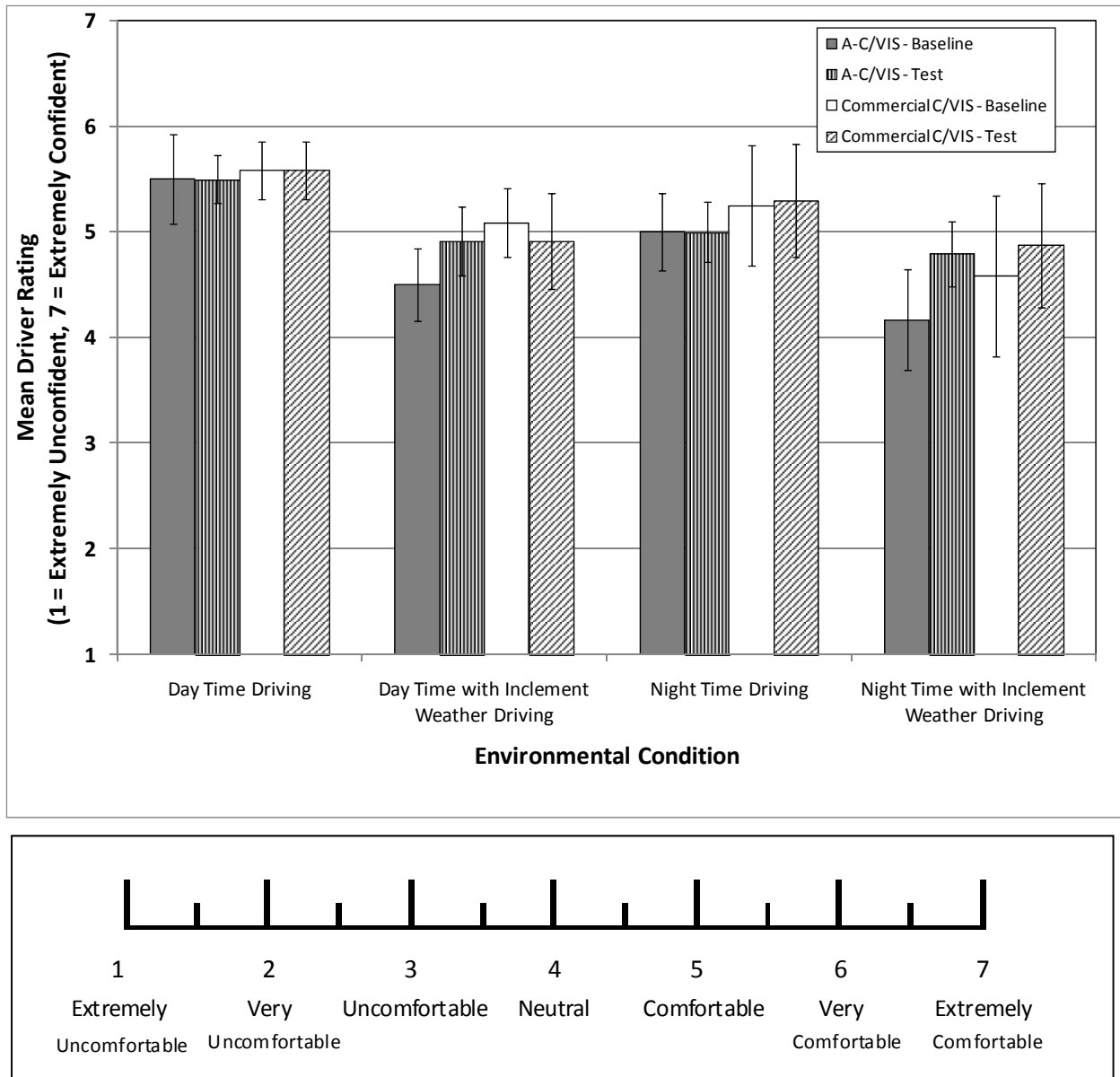


Figure 213. Comparison of Driver Responses to the Question, “How Confident are you that you will not Hit an Adjacent Vehicle When Merging into Traffic?”

Ease of Backing Up to an Object

Drivers’ mean ratings in each of the four environmental conditions in response to the question, “How difficult is it to back up to an object?” are presented in Figure 214. Across the four environmental conditions, statistically significant differences in drivers’ mean ratings in the Baseline and Test conditions were not found ($p > 0.05$). Significant differences between drivers’ mean ratings in each month were not found ($p > 0.05$).

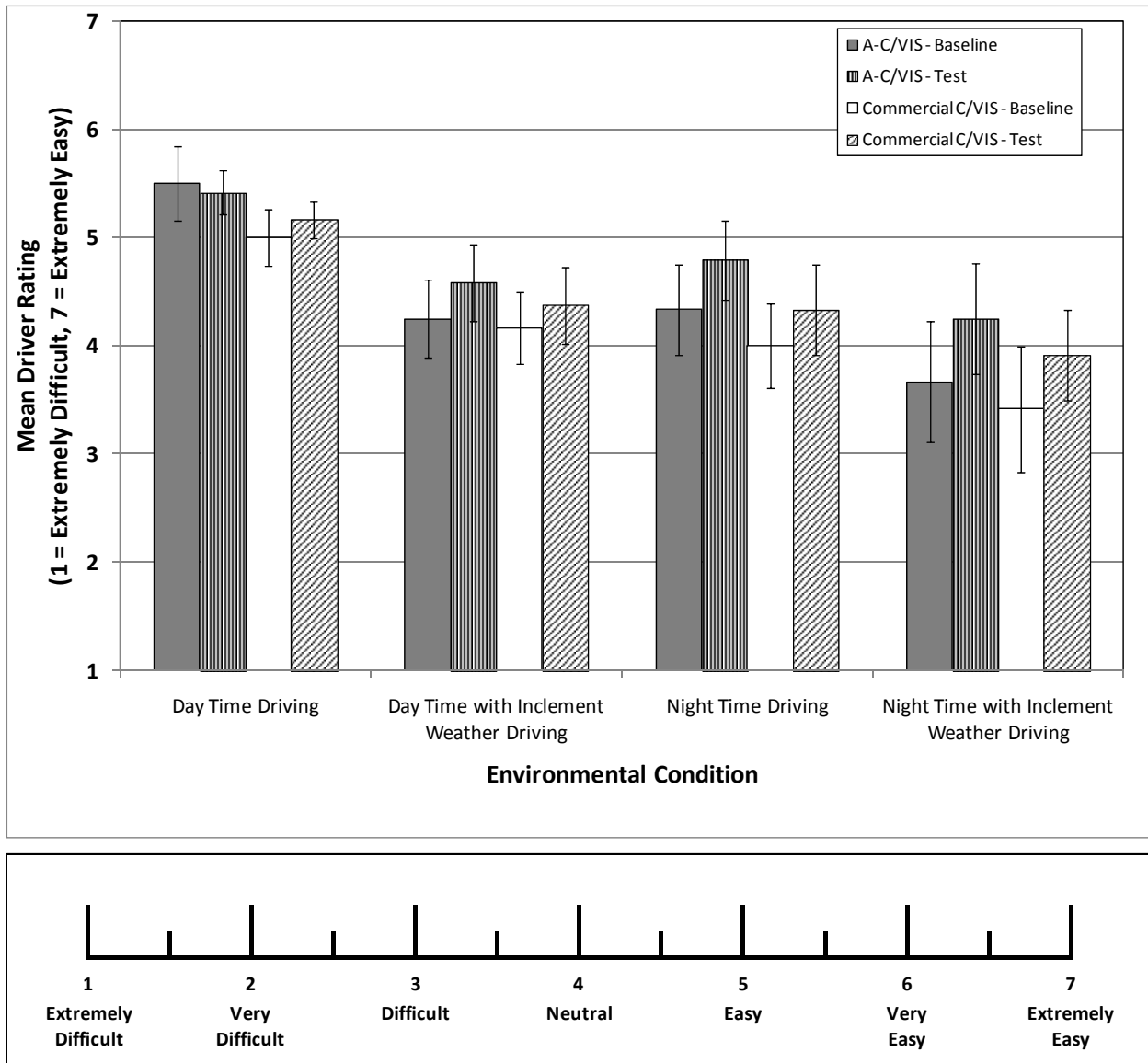


Figure 214. Comparison of Driver Responses to the Question, “How Difficult is it to Back up to an Object?”

Ranking of Lane-Change Difficulty by Direction

Drivers were asked to respond to the following statement: “For cases when you must figure out where a car is beside your truck and how fast it is traveling before changing lanes, please indicate which type of lane change is harder to perform by checking one of the two boxes in the diagram below (Figure 215).” All drivers ranked right lane changes as being harder to perform than left lane changes in both the Baseline and Test conditions. When asked to clarify their rankings, they indicated this was because the blind spot on the right side of the truck is larger. One driver also indicated right lane changes were harder than left lane changes because he had to take his eyes off the forward roadway longer to check his right west coast mirror.

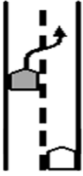
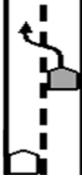
A <u>right</u> lane change in which you enter the right lane in front of a vehicle travelling in that lane	A <u>left</u> lane change in which you enter the left lane in front of a vehicle travelling in that lane
	

Figure 215. Figure of Lane-Change Direction

Analysis of Driver Comments

Favorite Features of the C/VIS

Throughout the Test condition, drivers were asked the following question at every meeting, “What are your top two most favorite features of the system?” The majority of the comments were related to the benefit of increased visibility (Figure 216).

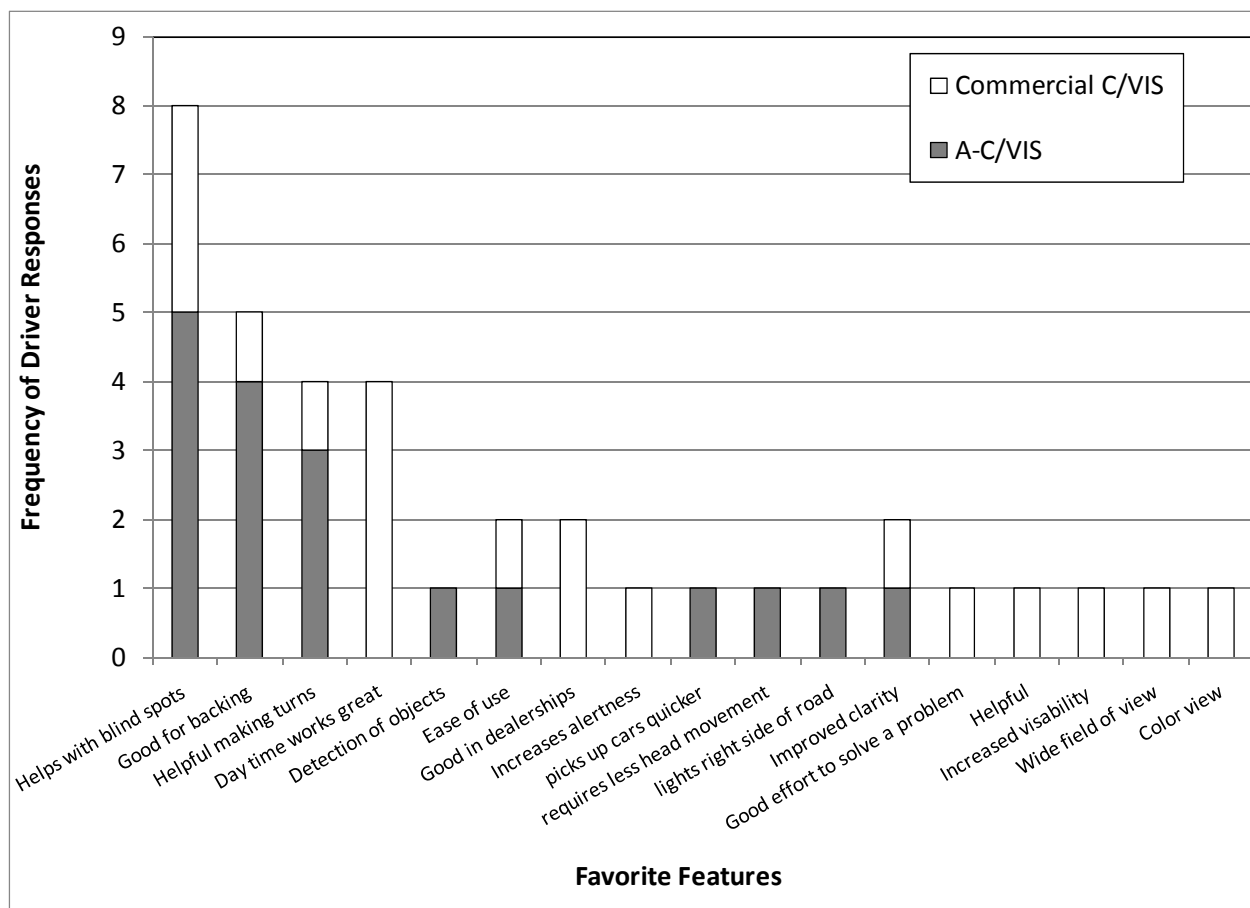


Figure 216. Frequency of Drivers' Comments in the Test Condition Regarding their Favorite Features of the C/VIS

Least Favorite Features of the C/VIS

During the Test condition, drivers were also asked the following question at every meeting, “What are your top two least favorite features of the system?” The majority of the comments pertained to the C/VIS producing glare at night. Comments were also frequently made regarding the placement of monitors inside the truck (Figure 217).

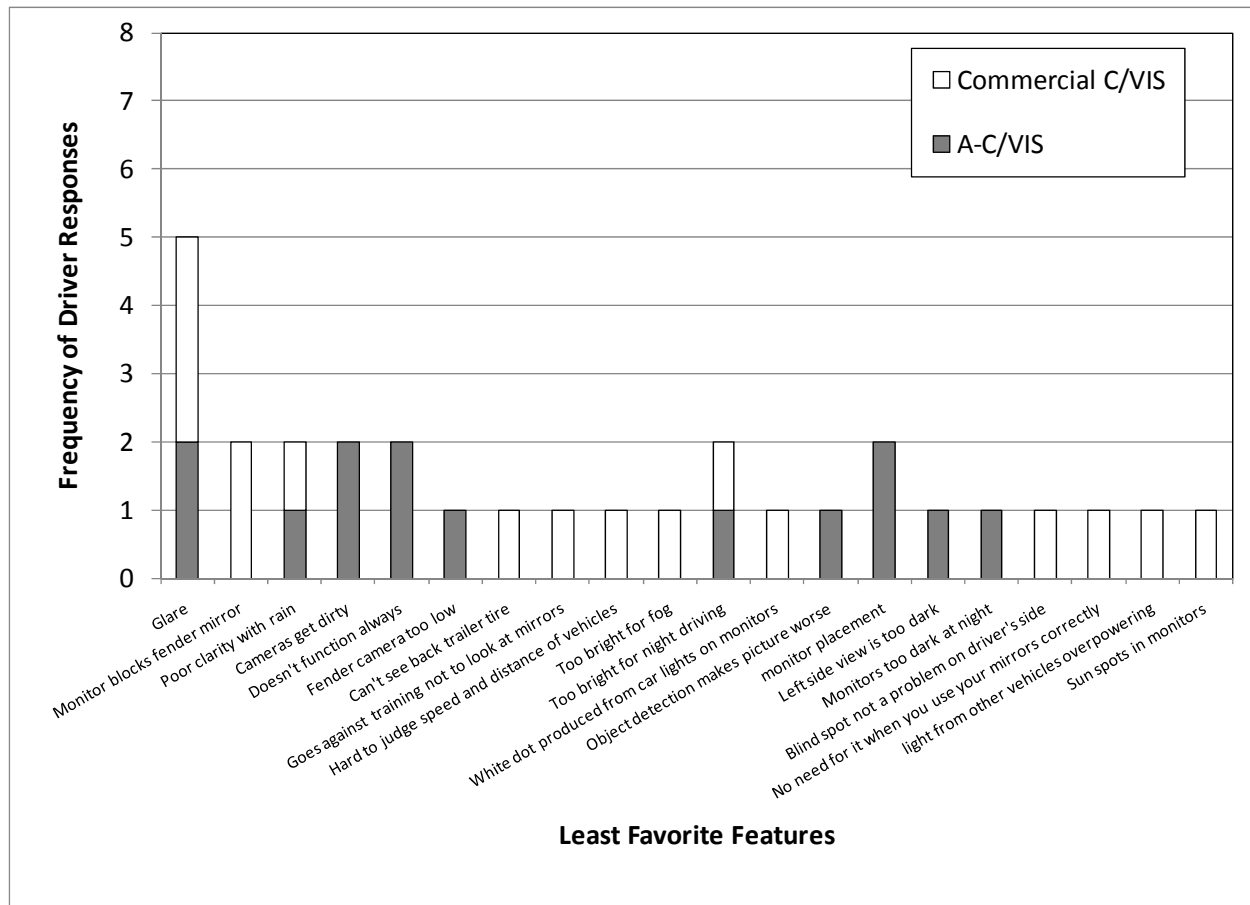


Figure 217. Frequency of Drivers' Comments in the Test Condition Regarding their Least Favorite Features of the C/VIS

Additional Comments Regarding the C/VIS

Drivers were asked “Are there any additional comments you would like to make regarding the video system?” The responses are shown in Figure 218. A driver of a commercial C/VIS-equipped truck indicated that the commercial C/VIS' left monitor should be repositioned to not block the left fender mirror. A driver of an A-C/VIS-equipped truck indicated that the right monitor currently positioned on the right A-pillar should be moved closer so he does not have to turn his head as far to view it. A driver of a commercial C/VIS-equipped truck also requested that light diffusers be used to prevent blooming from the turn signals on the monitors.

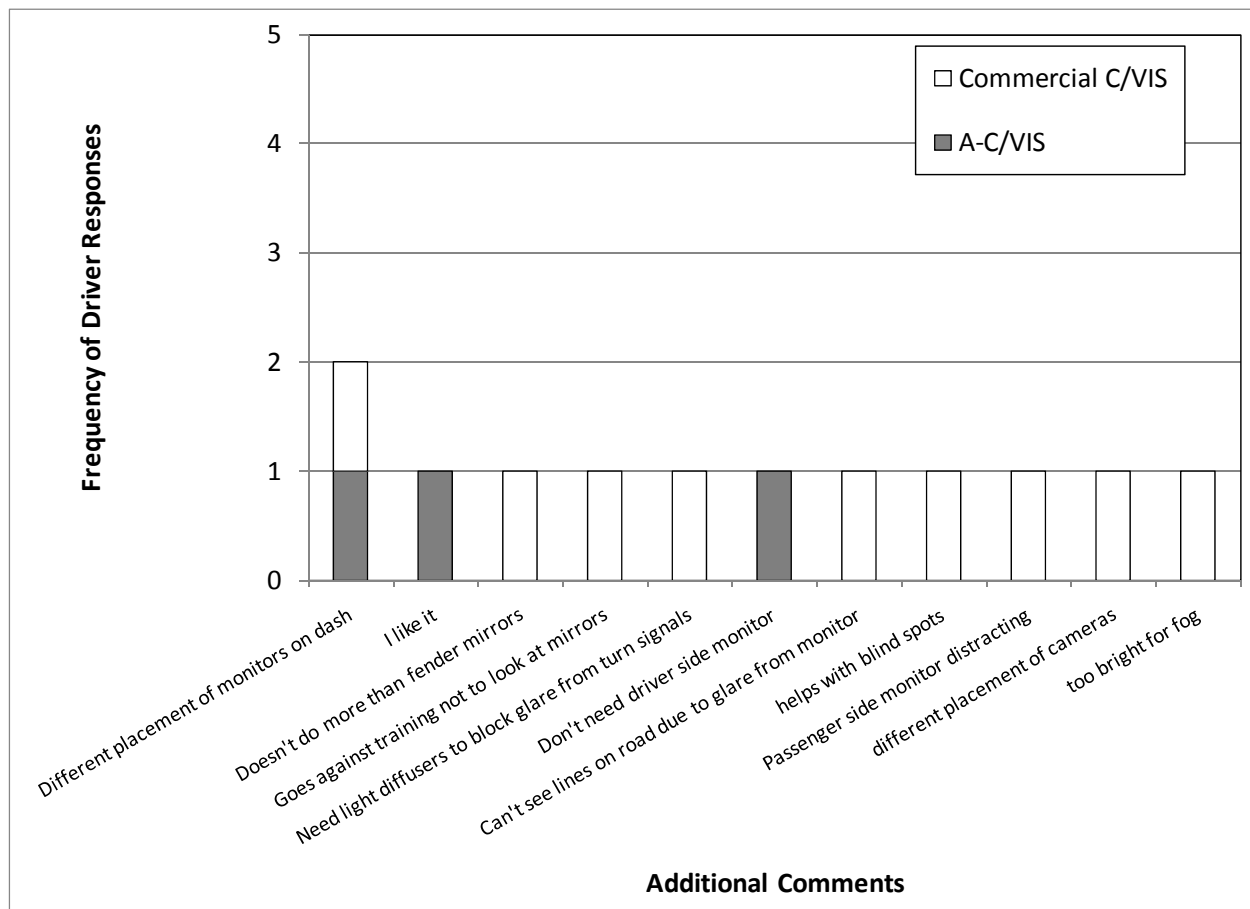


Figure 218. Frequency of Drivers' Additional Comments in the Test Condition Regarding the C/VIS

Drivers' Impressions of the Other C/VIS

Initial research planning indicated that comparison tasks would not be possible at the trucking operation being studied. However, as the researchers and trucking operation personnel became more familiar with each other's operational constraints, an opportunity to perform a short comparison task was identified. As a result, partway into data collection a modification to the experimental protocol was made and approved by the IRB. The modification involved the following procedure: Upon completing the fourth month of driving in the study, drivers were instructed to experience the other C/VIS by driving a truck equipped with the other C/VIS used in the TFD. Drivers drove a truck equipped with the other C/VIS for 10 minutes around the Schneider Winchester, Virginia operation. The experimenter sat in the passenger seat during this trial. Drivers then completed a questionnaire on their opinions of this C/VIS.

Additionally, it was determined that follow-up data concerning drivers' opinions of the C/VIS, one month after completing the study, would be desirable. The experimental protocol was again modified and approved by the IRB. This modification included contacting drivers via phone one month after they had completed the 4-month study to gauge whether drivers' opinions and driving behaviors had changed as a result of using a C/VIS. These two tasks went beyond the

statement of work, but were believed to provide valuable information when determining the effectiveness and desirability of each C/VIS system. Because the protocol modifications were made after the first eight drivers began the study, these drivers were not required to complete this comparison task. Table 46 displays which drivers were required to complete these additional tasks and which drivers optionally completed these tasks. Furthermore, Table 46 provides reasoning why the drivers did not complete these additional tasks.

Table 46. Summary of Drivers Completing Comparison Task and Follow-up Interview

Driver ID	C/VIS Experienced	Completed 4 months of driving	Required to Complete Comparison Task and Follow-up Interview?	Completed Comparison Task?	Completed Follow-up Interview?
1	A-C/VIS	Yes	No	Declined	Declined
3	A-C/VIS	Yes	No	Yes	Yes
13	A-C/VIS	Yes	No	Yes	Yes
4	A-C/VIS	Yes	Yes	No - terminated	No - terminated
5	A-C/VIS	Yes	Yes	Yes	Yes
15	A-C/VIS	No (completed 3 months)	Yes	No - quit before being terminated	No - quit before being terminated
7	Commercial C/VIS	Yes	No	Declined	Declined
8	Commercial C/VIS	Yes	No	Declined	Declined
9	Commercial C/VIS	Yes	No	Declined	Declined
10	Commercial C/VIS	Yes	No	Declined	Declined
12	Commercial C/VIS	Yes	No	Yes	Yes
14	Commercial C/VIS	Yes	Yes	Yes	No - quit

Of the five drivers that completed the comparison task, three were drivers of A-C/VIS-equipped trucks and two were drivers of commercial C/VIS-equipped trucks. Therefore, the three drivers that had A-C/VIS-equipped trucks for the four months of the study performed the comparison task with a commercial C/VIS-equipped truck. Similarly, the two drivers that had a commercial C/VIS-equipped truck for the four months of the study performed the comparison task with an A-C/VIS-equipped truck. It is important to note that the drivers who completed the comparison task and follow-up interview may have had significantly different opinions of the two C/VISs compared to the drivers that did not complete these two tasks.

To determine how drivers' opinions of the two C/VISs differed, drivers responded to some of the same questions they answered throughout the study. Interesting findings from the comparison task are presented below:

- The original drivers of commercial C/VIS-equipped trucks preferred to have the A-C/VIS on their trucks over the commercial C/VIS, while the original drivers of A-C/VIS-equipped trucks did not indicate a difference in preference.

- The original drivers of A-C/VIS-equipped trucks found the A-C/VIS to be more useful than the commercially available C/VIS. Likewise, the original drivers of commercial C/VIS-equipped trucks found the A-C/VIS system to be more useful.
- The original drivers of commercial C/VIS-equipped trucks indicated the A-C/VIS' FOV was better than that of the commercial C/VIS, while the original drivers of A-C/VIS-equipped trucks did not indicate a difference in the two C/VISs.
- The original drivers of commercial C/VIS-equipped trucks indicated that the commercially available C/VIS blocked their view of the road more, while the original drivers of A-C/VIS-equipped trucks did not rate a difference.
- The original drivers of commercial C/VIS-equipped trucks indicated that the A-C/VIS eliminated more blind spots than did the commercially available C/VIS, while the original drivers of A-C/VIS-equipped trucks did not suggest a difference.

One month after completing the 4-month study, each driver was contacted for the follow-up interview. Drivers that agreed to participate in the interview were asked six questions regarding their experiences since completing the study. These questions were designed to ascertain if the drivers' opinions of the C/VISs changed after completing the study. Notable findings from the follow-up interview are presented below:

- All four drivers that completed the follow-up interview indicated that they wished the C/VISs were available on their current vehicles. Three drivers stated that they desired the C/VIS because it helped with right hand maneuvers. Two drivers stated that they desired having the rear camera. One driver stated the following: "I have to look for blind spots and do a double or triple take to make sure a car isn't there instead of just checking once [in the monitor]."
- All four drivers preferred to drive a truck with a C/VIS. One driver reported being able to see cars farther away at night with the C/VIS. One driver indicated the C/VIS made him a safer driver, "I think I am a safer driver [with the C/VIS], and on sharp turns you don't need to keep [the] trailer in traffic longer."
- Three of the four drivers indicated that they would want the right monitor if they could only have one because of the large blind spot on the passenger side of the truck. One driver reported to want the left side monitor, "I would want the left monitor because I get lazy when I have to look that way. Instead of looking and leaning over into the mirror the monitor is like a cheat."
- Two of the four drivers indicated that their awareness of surrounding vehicles without a C/VIS is the same as when they were driving with a C/VIS. One driver said he now had to be more alert because the monitors were not there to help. One driver reported that driving with the C/VIS did not improve his awareness of his surroundings, but the C/VIS did help decrease the stress associated with being aware of his surroundings while driving.
- Two drivers indicated that the C/VIS helped when making right lane changes because it provided extra visibility in the passenger-side blind spot.

Summary

Overall, drivers' ratings of their driving performance with and without a C/VIS indicate that the C/VISs had a beneficial effect. Statistically significant effects were found for drivers of both A-

C/VIS-equipped and commercial C/VIS-equipped trucks. A summary of all statistically significant results are presented below:

- Drivers of A-C/VIS-equipped trucks indicated that it was easier to identify objects located around their truck during inclement night conditions with the C/VIS ($p = 0.0455$).
- Drivers of A-C/VIS-equipped trucks indicated that the C/VIS helped eliminate blind spots around their truck more so than the drivers of the commercial C/VIS-equipped trucks indicated ($p = 0.0225$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to merge into traffic during inclement daytime conditions with the C/VIS ($p = 0.0382$).
- Drivers of commercial C/VIS-equipped trucks indicated that it was easier to merge into traffic during clear daytime conditions with the C/VIS ($p = 0.0262$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to determine the approach rate of adjacent vehicles in daytime inclement weather with the C/VIS ($p = 0.0303$).
- Drivers' ratings of how much they desired the A-C/VIS significantly strengthened as their time in the study progressed ($p = 0.0068$).
- Drivers indicated that the A-C/VIS was more likable than they expected it to be before the system was turned on ($p = 0.0049$), while drivers of commercial C/VIS-equipped trucks indicated the system was less likable than they expected it to be before the system was turned on ($p = 0.0441$).

Reasons why drivers liked the A-C/VIS included the availability of the rear wide-angle look-down camera, the placement of the monitors, the low amount of glare produced at night, and the object detection feature. Drivers of A-C/VIS-equipped trucks also found it easy to use and clean.

Drivers of the commercial C/VIS-equipped trucks indicated that the system was useful, easy to use, and easy to keep clean. These drivers did indicate, however, that the monitors were too bright at night and when driving in rain or fog. Drivers also indicated that the position of the left monitor could block the left fender mirror. One driver complained that the headlights from adjacent vehicles could bloom (create large white spots) on the display. Another driver requested that the plastic light diffusers used on the A-C/VIS-equipped trucks be used to prevent blooming from the turn signals on the commercial C/VIS's monitors.

Despite the differences in the two C/VISs, drivers did indicate they preferred to drive a truck equipped with a C/VIS. Major reasons for this preference were the improved visibility of the passenger-side blind spot when performing maneuvers to the right, and the decrease in workload pertaining to maintaining spatial awareness. Overall, drivers' ratings suggest that the C/VISs were more beneficial than harmful.

CHAPTER 8. DISCUSSION

Previous test-track studies demonstrated the potential benefits that C/VISs could offer CMV drivers (Wierwille et al., in press; Wierwille, Schaudt, Spaulding, et al., 2008). The TFD took a formidable step forward by investigating whether C/VISs installed on 48-ft tractor-trailers helped CMV drivers perform their daily employment duties. The effects of C/VISs on drivers' involvement in SCEs, lane-change performance, and opinions of their driving performance are discussed in this chapter. The potential disbenefits of C/VISs are also discussed.

IMPACT OF C/VISs ON DRIVER INVOLVEMENT IN SCEs

Drivers' Involvement in SCEs

Whether CMV operators' driving performance changed when using a C/VIS was investigated primarily by analyzing their involvement in SCEs. It was hypothesized that the C/VIS would allow drivers to make fewer mirror checks, spend more time looking forward, and therefore encounter fewer SCEs. However, a reduction in the mean SCE rate was not observed. Drivers' mean SCE rate was 5.2 SCEs per 100 hrs of driving in both the Baseline and Test conditions ($p > 0.05$). Drivers' performance pertaining to the two C/VISs also did not change. The mean SCE rate for drivers of A-C/VIS-equipped trucks went from 5.9 to 5.7 when driving with a C/VIS ($p > 0.05$), while the mean SCE rate for drivers of commercial C/VIS-equipped trucks went from 4.5 to 4.7 when driving with a C/VIS ($p > 0.05$). Drivers' mean SCE rate by fault assignment was also investigated. Drivers' mean SCE rate for SCEs that were their fault was not found to differ across the four months in the study ($p > 0.05$). It is important to note that drivers' performance did not worsen when using a C/VIS.

Drivers' Visual Behavior Prior to SCEs

A concern with placing visual displays inside a vehicle is that they take drivers' visual attention away from the forward roadway and may increase drivers' crash risk. An earlier study had shown that allocating visual attention to adjust the instrument panel (an existing visual display) increases drivers' crash risk by 1.25 times (Olson et al., In Press). Drivers' visual behavior during the 8 s leading up to an SCE was measured by manually reducing video footage of the driver's face on a frame-by-frame basis. Obtrusive eye glance measurement equipment was not used in this study, allowing drivers' natural eye glance patterns to be observed. Four cameras were used to capture video of the driver's face to increase the accuracy of the eye glance reduction. It was found that drivers' mean probability of looking forward did not significantly change when driving with a C/VIS; their mean probability of looking forward was 0.86 in the Baseline condition and 0.87 in the Test condition ($p > 0.05$). This finding suggests that the C/VISs did not compel drivers to look away from the forward roadway. Drivers' mean probability of looking at the west coast/convex mirrors or fender mirrors also did not significantly change when driving with a C/VIS. A reason why drivers' visual behavior did not significantly change may be because the probability that drivers directly looked at the monitors prior to an SCE was 0.005. Drivers looked at least once at the left and right monitors in 4.5 percent of the SCEs, and at the center monitor in 2 percent of the SCEs.

SCEs Involving Lane Changes

Six of the 265 SCEs arose while the SV driver executed a lane change (four occurred in the Baseline condition). Two SCEs arose from another vehicle aggressively passing the SV on the right as the SV executed a right lane change (both were in the Baseline condition). Two SCEs arose from a vehicle making a right lane change into the center lane as the SV executed a left lane change into the same center lane (both were in the Baseline condition). These SCEs occurred because the SV driver inadequately scanned the surrounding environment and because the other vehicle's lane change was conducted rapidly. Another SCE arose because the SV driver made a left lane change in front of a rapidly approaching vehicle (this SCE occurred in the A-C/VIS Test condition). This SCE occurred because the SV driver inadequately scanned the environment prior to changing lanes. A crash was avoided because the SV quickly returned to the right lane after the error was realized. The final SCE occurred when a lead vehicle made a left lane change into the same lane that the SV was changing into (this SCE occurred in the A-C/VIS Test condition). The SV was travelling at a faster rate and was forced to brake.

Despite their rare occurrence, lane-change-related SCEs are not overlooked by the trucking industry. For instance, the Smith System "Keys to Safe Lane Changing and Merging" training program teaches that collisions caused by improper lane changes and merges are frequent, costly, and often deadly. They state that risky lane changes are the most common complaint from aggravated motorists that call in to the SmithSAFE fleet monitoring service. This study did find a reduction in the percentage of lane changes initiated with the trailer overlapping an adjacent vehicle when a C/VIS was available. It is important to note that although the clearance was low, these maneuvers did not constitute SCEs. Nevertheless, this result suggests that the visibility enhancements offered by C/VISs stand to reduce lane changes initiated close to an adjacent vehicle.

Avoidable Tire Strike SCEs

An interesting type of SCE that is worth discussing is the occurrence of avoidable tire strikes. Avoidable tire strikes predominantly occurred when drivers made left or right turns and their back tires struck a curb. This study did not find a decrease in the rate of avoidable tire strikes when the C/VIS was available. It is possible that, despite the enhanced visibility, the tire strikes simply occurred because the driver was rushed or did not want to perform the turn maneuver with the required precision. Drivers did not use the C/VISs in these SCEs. It should be noted that, although this type of event is less severe, it imposes a toll on the transportation infrastructure due to curb damage, and on the carrier due to tire damage. It also results in an automatic failure of the CDL test.

IMPACT OF C/VISs ON DRIVER LANE-CHANGE PERFORMANCE

C/VISs are designed to assist drivers see objects around their vehicles and execute lane-change maneuvers. Previous test-track research showed that CMV drivers were able to better judge whether there was clearance between the trailer and an adjacent vehicle, as well as better assess the magnitude of this clearance, when provided with a C/VIS (Fitch et al., 2008; Wierwille et al., in press; Wierwille, Schaudt, Spaulding, et al., 2008). This research also showed that drivers shifted their visual attention from the west coast/convex mirrors to the C/VISs when the C/VISs

were provided, while the amount of visual attention allocated to the forward roadway did not change. At the same time, it was also found that the clearance between the tractor-trailer and an adjacent vehicle decreased from 6.1 m to 4.2 m when a C/VIS was provided (tests were performed at 40 km/h), presumably because drivers were able to more accurately determine when there was sufficient clearance with the C/VISs (Wierwille, Schaudt, Spaulding, et al., 2008).

The TFD analyzed various aspects of drivers' lane-change performance to investigate whether similar changes in driver behavior would be observed when drivers used a C/VIS during their daily employment duties. These aspects of lane-change maneuvers are discussed below.

Clearance to Adjacent Vehicle

Drivers' mean clearance to an adjacent vehicle was not found to significantly change when driving with a C/VIS. The mean clearance to an adjacent vehicle for drivers of A-C/VIS-equipped trucks was 36.91 m in the Baseline condition, and 35.81 m in the Test condition ($p > 0.05$). The mean clearance to an adjacent vehicle for drivers of commercial C/VIS-equipped trucks was 37.86 m in the Baseline condition, and 37.32 m in the Test condition ($p > 0.05$). Furthermore, drivers' mean clearance when using the A-C/VIS was not found to be significantly different from drivers' mean clearance when using the commercially available C/VIS system ($p > 0.05$).

Given that drivers were observed to decrease their mean clearance when driving with a C/VIS in the earlier E-C/VIS-prototype studies, it is interesting that this performance measure did not change when using a C/VIS in the TFD. The data indicate that drivers did not abuse the enhanced visibility offered by the C/VIS by cutting in closer to adjacent vehicles when changing lanes. It is worth noting that the training administered to drivers using the A-C/VIS specifically warned of vehicles appearing closer in the center monitor than they really are. It also showed drivers how the distance to objects was skewed and how to use the monitor when changing lanes (Figure 219). It should be noted that the red and orange lines shown in Figure 219 were not present on the monitor.

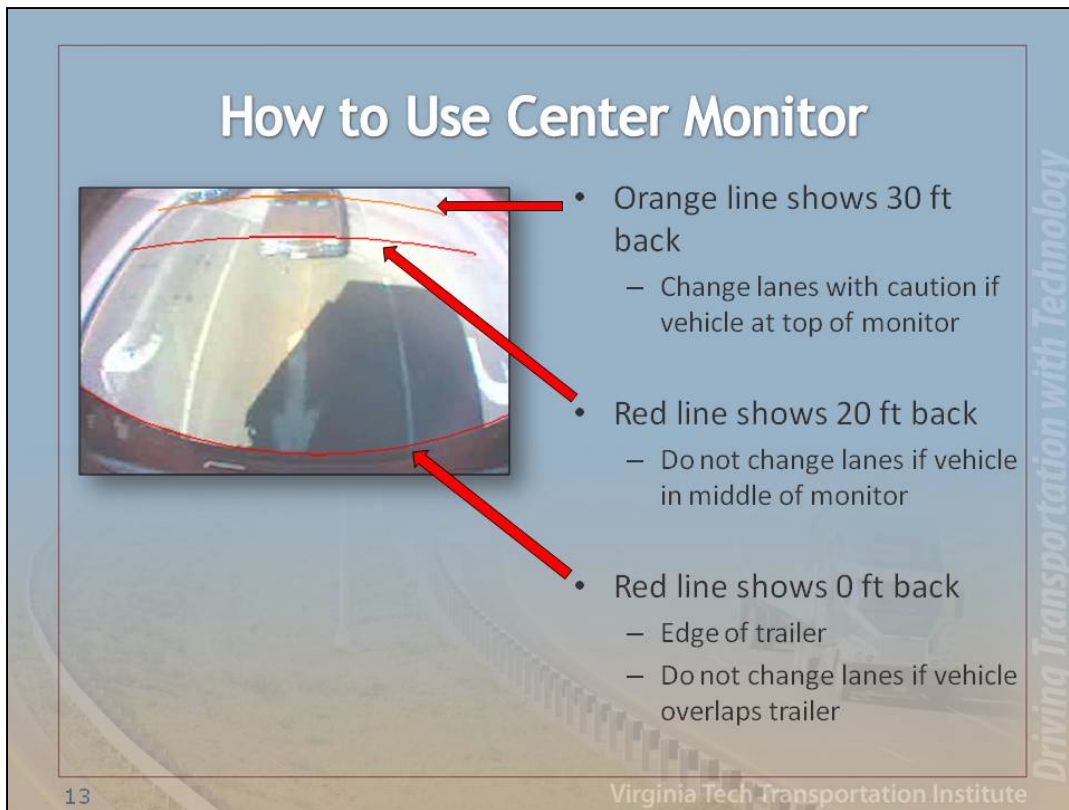


Figure 219. Excerpt from A-C/VIS Training Manual on Proper Use of the Center Monitor

Drivers' mean clearance was found to significantly differ based on lane-change direction ($p < 0.0001$). Drivers' mean clearance to an adjacent vehicle was 53.31 m when making left lane changes, while it was 31.63 m when making right lane changes. The majority of left lane changes arose from drivers initiating a pass of a slow lead vehicle, while the majority of right lane changes were drivers returning to the right lane after passing a lead vehicle. Drivers' clearance data were binned into five clearance categories for left and right lane changes: 1) overlapping, 2) less than 6 m, 3) less than 12 m, 4) less than 18 m, and 5) greater than or equal to 18 m. However, the relative frequency of lane changes in each of these clearance categories was not found to significantly differ when driving with a C/VIS ($p > 0.05$). Overall, the data suggest that drivers did not abuse the enhanced views provided by the C/VISs when making either left or right lane changes.

When making right lane changes, drivers' mean clearance during clear nighttime conditions was found to be significantly longer than their clearance during clear daytime conditions ($p = 0.0117$). However, drivers were not found to change their clearance to an adjacent vehicle when driving with a C/VIS across the environmental conditions ($p > 0.05$).

Drivers' Visual Behavior

Drivers did not look at the C/VIS during all of the sampled lane changes. When considering the percentage of lane changes in which drivers looked at least once at the monitors, drivers of A-

C/VIS-equipped trucks looked at the right monitor in 11 percent of the right lane changes, at the center monitor in 20 percent of the right lane changes, and at the left monitor in 2 percent of the right lane changes. Drivers of commercial C/VIS-equipped trucks looked at the right monitor in 20 percent of the right lane changes, and at the left monitor in 2 percent of the right lane changes. Additionally, drivers of A-C/VIS-equipped trucks looked at the left monitor in 8 percent of the left lane changes, at the center monitor in 5 percent of the left lane changes, and at the right monitor in 3 percent of the left lane changes. Drivers of commercial C/VIS-equipped trucks looked at the left monitor in 14 percent of the left lane changes, and at the right monitor in 3 percent of the left lane changes.

Lane changes in which drivers looked at least once at the monitors were compared to lane changes in which drivers did not look at the monitors. Drivers were more likely to look at the monitors during clear nighttime conditions compared to clear daytime, inclement daytime, and inclement nighttime conditions (Odds Ratio = 1.4119, LCL = 1.1055, UCL = 1.8031). This was likely because drivers found the C/VIS worthwhile when their visibility was reduced at night. Drivers were significantly more likely to use the monitors during right lane changes compared to left lane changes (Odds Ratio = 1.7322, LCL = 1.26502, UCL = 2.37135). This was likely because drivers found that the C/VIS helps them detect objects in the large No-Zone on the right side of the truck. Importantly, drivers that looked at the C/VIS were not found to exhibit different clearances from drivers that did not look at the C/VIS, indicating that drivers did not abuse the enhanced views.

The C/VISs were not found to divert drivers' visual attention away from the forward roadway when changing lanes; drivers' mean probability of looking forward was 0.66 in both the Baseline and Test conditions. Drivers also did not reduce their probability of looking at the west coast/convex mirrors when changing lanes with a C/VIS ($p > 0.05$). However, drivers of commercial C/VIS-equipped trucks looked at the left fender mirror less frequently when making left lane changes with a C/VIS ($p = 0.0099$), and drivers of A-C/VIS-equipped trucks looked at the right fender mirror less frequently when making right lane changes with a C/VIS ($p < 0.0001$). These findings suggest that drivers substituted the visual information provided by the fender mirrors with the visual information provided by the C/VIS.

Eye glances to the C/VIS monitors were relatively quick. When making right lane changes, drivers' mean glance duration was 0.73 s when looking at the right monitor, 0.75 s when looking at the center monitor, and 0.63 s when looking at the left monitor. To compare, drivers' mean glance duration when looking at the right west coast/convex mirror was 1.16 s (1.5 times longer). The data indicate that drivers were able to quickly obtain visual information from the displays.

Unlike the test-track studies, drivers in the TFD in general did not substantially look at the monitors when changing lanes in front of an adjacent vehicle. To compare, the probability that drivers used the C/VIS when making a right lane change in front of a confederate vehicle on the Smart Road was found to be 0.36 (Wierwille, Schaudt, Gupta, et al., 2008), while the mean probability that drivers looked at the monitors in the TFD when making right lane changes in front of an adjacent vehicle was 0.01. It should be noted that the sampled time interval used to determine the eye glance probabilities for both studies was unequal; the TFD used a 15-second sample for each lane change, while the sample used in Wierwille, Schaudt, Gupta, et al. (2008)

depended on the point in time the driver initiated the lane change (and was likely shorter). Nevertheless, the C/VIS monitor eye glance probabilities were markedly lower in the TFD. It is possible that drivers only consulted the monitors when there was some uncertainty regarding the location of adjacent vehicles.

The test-track studies showed that drivers were more likely to use the rear wide-angle look-down monitor relative to the left and right monitors when estimating the clearance to an adjacent confederate vehicle (Wierwille et al., in press). Similarly, the TFD found that drivers were more likely to use the rear wide-angle look-down monitor than the left or right monitors when making right lane changes. This result is interesting as most commercially available C/VISs do not offer a trailer-mounted camera, typically because there are over two trailers for every tractor (American Trucking Associations, 2010), and such an option would increase implementation costs. Nevertheless, the TFD indicates that this view is useful to drivers. Driver ratings support this objective finding. Drivers of A-C/VIS-equipped trucks ranked the center monitor as more useful than the left or right monitors. Drivers also increased their ratings of how much they liked the A-C/VIS over the course of the study ($p = 0.0049$), while drivers' affinity towards the commercially available C/VIS did not increase. It is worth noting that trailer-mounted functionality—such as a rear camera and IR lights—that demand drivers make an additional wired connection between the tractor and trailer is not believed to substantially increase driver workload. This is because some drivers who had to disconnect the trailer from their tractor during the TFD indicated that reattaching the C/VIS connection was not bothersome since they already had to make a connection for the trailer lights.

Reasons why drivers may have looked at the monitors less in the TFD than in the test-track studies are as follows:

- The majority of the driving in the TFD was performed on roads with a low traffic density. Drivers may not have used the C/VIS monitors if they felt confident that there were no vehicles in their blind spots. This is supported by the fact that drivers' confidence that they would not hit an adjacent vehicle when merging into traffic was rated high in both the Baseline and Test conditions.
- CMV drivers are professionals. They find new technologies designed to assist them perform the driving task as beneficial, but do not find them essential since they have been operating a tractor-trailer without them for an extended period of time. As a result, their driving habits (e.g., where they look prior to changing lanes) are hard to break. One driver addressed this issue by commenting that perhaps he would have used the monitors more if he had been trained to use them when getting his CDL.
- Drivers may not have used the monitors less often in the TFD because an experimenter was not present in the test vehicle. Drivers brought in for the test-track studies may have focused on the C/VIS in the one-hour time interval more so than when performing their employment duties over the 3-month Test condition.

The opinion results discussed further on indicate that drivers benefited from the C/VIS. Therefore, it is worth considering that drivers may have looked at the monitors with their peripheral vision while they looked forward. Such behavior is not captured in the eye glance reduction because it assumes that each glance location is independent (i.e., drivers only look in

one location at a time). However, at night, when the majority of the driving in this study was performed, the headlights from an adjacent vehicle are pronounced on the C/VIS monitors, and may have been perceived by drivers in their periphery. It is possible that drivers indirectly used the monitors to acquire spatial awareness. Based on this hypothesis, drivers were specifically asked through the questionnaires whether they looked at the monitors out of the corners of their eyes. The majority of both the A-C/VIS and commercial C/VIS drivers reported that they did. The C/VISs may therefore have been used more readily than the eye glance analysis suggests.

Eye glances to the monitors are not expected to increase drivers' crash risk. This is because the information presented by the monitors is relevant to the driving task and the formulation of spatial awareness. Klauer, Dingus, Neale, Sudweeks, & Ramsey (2006) found that light-vehicle drivers that looked away from the forward roadway to view their mirrors actually improved their driving performance (i.e., they had a crash risk less than 1). It is possible that looking at the C/VIS monitors may provide a similar benefit to CMV drivers since the monitors and mirrors display similar information that supports drivers' development of spatial awareness.

Lane-Change Execution

The time that elapsed from drivers initiating a lane change to crossing the lane markings was found to significantly shorten from 2.22 s to 1.96 s when driving with a C/VIS ($p = 0.0078$). Although drivers' confidence in not striking an adjacent vehicle during a lane change was rated high in both Baseline and Test conditions, it is believed that the reduction in this time interval is a reflection of drivers having better situation awareness when driving with a C/VIS. In knowing ahead of time whether there is sufficient clearance to change lanes, drivers no longer need to slowly cross the lane markings out of concern that a vehicle could be hidden in their no-zone.

Evidence of Lane-Change Difficulty

Driver ratings indicated that right lane changes are harder to make than left lane changes, predominantly because the blind spot on the right side of the truck is larger than the blind spot on the left side of the truck. Furthermore, if drivers need to check their left blind spot, they are able to rotate their head and look back, while this is not possible when inspecting the right adjacent lane. The TFD observed significant differences between drivers' left and right lane-change performance. The clearance given when making right lane changes was found to be half of the clearance given when making left lane changes. Furthermore, drivers of A-C/VIS-equipped trucks were more likely to use the center monitor when making right lane changes than they were when making left lane changes, possibly because the rear wide-angle look-down camera assisted drivers in determining the position of right adjacent vehicles.

A reason why the clearance for right lane changes was half of that for left lane changes is that 94 percent of the right lane changes sampled consisted of the tractor-trailer returning to the right lane after passing a lead vehicle. When passing a vehicle, the CMV driver can track the vehicle's trajectory and assess its speed. In these cases, tractor-trailer drivers may believe that their speed is greater than the adjacent vehicle's speed, and that a closer cut-in distance is less likely to create a conflict if the gap separating the vehicles is expanding. In contrast, 2 percent of the sampled left lane changes consisted of drivers returning to the left lane after passing a vehicle on the right. Instead, drivers performed left lane changes to pass a slow lead vehicle, or out of

preference for driving in the left lane. Drivers in these cases must rely on visual cues perceived through the mirrors and monitors (e.g., visual angle and rate of change of visual angle) to assess the approach speed of an adjacent vehicle. It was hypothesized that because an adjacent vehicle's headlights can mask these visual cues, drivers would rate the execution of left lane changes as harder than right lane changes. However, drivers' opinion data, as well as the low eye glance probabilities to the left monitors when making left lane changes, indicate that they found it harder to make right lane changes. C/VISs that cater to the safe execution of right lane changes would be perceived as useful to CMV drivers.

There were cases where the adjacent vehicle flashed its headlights twice, or turned its headlights off for a second, when the SV was preparing to make a right lane change. Discussion with the drivers confirmed that this was the adjacent vehicle drivers' way of informing the tractor-trailer driver that there was sufficient clearance to enter the right lane. The drivers indicated that the adjacent-vehicle driver was likely a CMV driver, or was aware of the issues CMV drivers face when making right lane changes, because they knew that it was helpful to provide feedback to the driver when it was safe to change lanes. On the other hand, there were cases where the adjacent vehicle repeatedly flashed its headlights in a rapid manner after the heavy vehicle made a right lane change in front of it. Sample video footage was shown to a CMV driving instructor (employed by the institution performing the current study) to gauge his opinion on the interaction. The driver indicated that it seemed as if the adjacent vehicle driver was angered by having to slow down to let the heavy vehicle in front. The manner in which the headlights are flashed can therefore mean different things to the drivers. Multiple rapid flashes indicate anger, while two slow flashes or turning the headlights off indicate cooperation. Despite how the headlights are flashed, the existence of this light-vehicle/heavy-vehicle sign language is further evidence that drivers have difficulty perceiving objects around their tractor-trailers.

Drivers' Use of the Object Detection Feature

An investigation of drivers' use of the A-C/VIS's object detection feature revealed that it was turned on for 37 percent of the sampled lane changes from the A-C/VIS Test condition. The feature was turned on during 43 percent of the lane changes made in the first month of Test mode, 46 percent of the lane changes made in the second month of Test mode, and 19 percent of the lane changes made in the final month of Test mode. The feature was used more readily during clear daytime conditions compared to clear nighttime conditions. Drivers were observed to use the feature in over a third of the lane changes made in inclement weather conditions; however, few lane changes in these conditions were available in the final sample. Drivers' opinion data indicated that they liked the feature and that it was useful. Drivers also did not indicate that the feature negatively impacted their driving.

DRIVER OPINIONS OF C/VISS

An investigation of drivers' ratings of the driving task revealed the following:

- Drivers indicated that it was easier to merge into traffic with a C/VIS in certain conditions.
 - Drivers of A-C/VIS-equipped trucks indicated that it was easier to merge into traffic during inclement daytime conditions with the C/VIS ($p = 0.0382$).

- o Drivers of commercial C/VIS-equipped trucks indicated that it was easier to merge into traffic during clear daytime conditions with the C/VIS ($p = 0.0262$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to identify objects located around their truck during inclement night conditions with the C/VIS ($p = 0.0455$).
- Drivers of A-C/VIS-equipped trucks indicated that it was easier to determine the approach rate of adjacent vehicles in daytime inclement weather with the C/VIS ($p = 0.0303$).

Drivers' opinions towards the C/VISs are summarized in Table 47.

Table 47. Summary of Drivers' Opinions towards C/VISs

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Likeability of the C/VIS	• Drivers liked the A-C/VIS, but were neutral regarding commercial C/VIS	• Drivers indicated that the A-C/VIS was more likable than they expected it to be before the system was turned on ($p = 0.0049$)	• Drivers indicated the commercial C/VIS was less likable than they expected it to be before the system was turned on ($p = 0.0441$)
How Useful is the C/VIS	• Drivers found the C/VISs to be useful	• Drivers rated the A-C/VIS to be useful. Rear-camera view ranked as more useful than left and right camera views	• Drivers were neutral. Although, right-camera view ranked as more useful than left camera view.
How Irritating is the C/VIS	• Overall, drivers did not find the C/VISs to be irritating. Yet, some drivers did complain about glare from the commercial C/VIS.	• Drivers rated the A-C/VIS to be likeable	• Drivers were neutral. However, some drivers did complain about glare from the commercial C/VIS
How Desirable is the C/VIS	• Drivers did not find the C/VISs to be undesirable	• Drivers' desire of the A-C/VIS increased over the course of the study ($p = 0.0068$)	• Drivers' ratings were neutral

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Elimination of Blind Spots	Drivers of A-C/VIS-equipped trucks indicated that the C/VIS helped eliminate blind spots around their truck more so than the drivers of the commercial C/VIS-equipped trucks indicated ($p = 0.0225$)	Drivers agreed that the A-C/VIS eliminated blind spots, pointing out that the rear-view camera helped them see the area behind their trailer	Drivers were neutral, pointing out that the C/VIS did not offer any views that were different from the existing fender mirrors
Usefulness of the Object Detection Feature		Drivers rated the A-C/VIS's object detection feature as useful throughout their time in the study	N/A
Glare from Monitors at Night	Drivers' ratings of the glare from the monitors was dependent on how much the brightness of the monitors could be reduced at night	Drivers rated the brightness of the A-C/VIS monitors to be comfortable at night. This was because the brightness of the A-C/VIS monitors could be substantially reduced	Drivers rated the glare from the commercial C/VIS's monitors to be uncomfortable at night. This was because the brightness of the commercial C/VIS's monitors could not be substantially reduced
Degree to which Monitor Glare Reduces Ability to See the Road	Drivers' ratings were dependent on the degree to which the monitors could be dimmed	Drivers indicated that the glare from the A-C/VIS monitors slightly reduced their ability to see detail in the road	- Drivers indicated that the glare from the commercial C/VIS's monitors reduced their ability to see detail in the road - One driver indicated that the glare made it difficult to see the lane markings on the road - Drivers reported that they had to turn the monitors off when driving in fog - One driver consistently turned the monitors off at night

Dimension	General Opinion	Opinion of A-C/VIS	Opinion of Commercial C/VIS
Degree to which Monitor Blocks View of Roadway	• Drivers' ratings were dependent on the placement of the monitors	• Drivers indicated that the A-C/VIS monitors, which were mounted on the left and right A-pillars, as well as the top center of the windshield, less than slightly blocked the view of the road	• Drivers indicated that the commercial C/VIS's monitors, which were mounted on the left and right side of the steering wheel on the dash, somewhat blocked their view of the road. This was because the left monitor could block the driver's view of the left fender mirror if the driver's head was in a certain position
Effort to Clean Camera Lens	• Drivers indicated that the C/VIS cameras were easy to clean	• Drivers indicated that the left and right A-C/VIS fender-mounted cameras were very easy to clean. Drivers were not asked to clean the rear camera on the trailer.	• Drivers indicated that the commercial C/VIS's left and right fender-mounted cameras were extremely easy to clean.
Turn Signal Light Diffuser Effectiveness at Reducing Blooming on Monitors		• Drivers liked the A-C/VIS turn signal diffusers (i.e., the translucent plastic caps that blocked the turn signal light from reaching the fender cameras) as they substantially reduced the blooming produced on the monitors when the turn signals were activated.	• The commercial C/VIS drivers complained that the turn signals were too bright on the monitors (commercial C/VIS-equipped trucks did not have turn signal diffusers). • Turn signal light diffusers were later installed on commercial C/VIS trucks to uphold participant safety

Overall, drivers appreciated being able to use the C/VISs. Drivers indicated that the C/VISs helped them see objects around the tractor-trailer, helped them perform lane-change maneuvers in front of an adjacent vehicle, and made the lane change task easier. Therefore, provided that C/VISs:

- do not create new blind spots,
- can be substantially dimmed to avoid glare,
- do not produce large white spots on the monitors when the turn signal lights are activated, and

- ensure that the light reflected off the windshield and windows does not block the drivers' view of the road,

then the CMV driving population should be accepting of C/VISs on their tractor-trailers.

DISBENEFITS OF C/VISs

Observed Disbenefits

Drivers' opinion data revealed the following disbenefits of C/VISs. It should be noted that these disbenefits do not apply to all C/VISs. For instance, the design of the A-C/VIS purposefully guarded against the identified system shortcomings.

Uncomfortable Monitor Glare

The brightness of the C/VIS monitors is a crucial component to its overall usability. This is due to the fact that if the monitor brightness cannot be substantially dimmed, drivers' vision can be impaired and their ability to perceive objects in the road can degrade. This was considered during the development of the A-C/VIS and the TFD. Monitors that could be substantially dimmed were incorporated into the A-C/VIS's design. Both a training session and manual were used to show drivers how to lower the A-C/VIS monitor brightness. On the other hand, the commercial C/VIS's monitors were tested as they were out of the box. No modifications were made to how they presented information to drivers. A training session and manual, designed and implemented by the research team, were used to show drivers how to lower the commercial C/VIS's monitor brightness using the "brightness" and "contrast" settings. However, it should be noted that the A-C/VIS monitors could be dimmed substantially more than could those of the commercially available C/VIS.

During the TFD, drivers indicated that the glare produced from the commercial C/VIS's monitors was too bright and affected their ability to see details in the forward roadway. Drivers had a particularly hard time seeing the forward roadway with the commercial C/VIS's monitors turned on when driving at night in foggy conditions.

Based on drivers' ratings, it can be said that a C/VIS that does not allow the monitors to be substantially dimmed to near darkness can negatively affect their opinion of the C/VIS, and possibly affect their driving performance if the monitor brightness prevents them from seeing details in the roadway.

Designers must also consider that the light from the monitors can reflect off the windshield and windows, and block the drivers' view of the roadway. For example, when mounted on the bottom of the A-pillars, the E-C/VIS prototype's monitors produced a cross-reflection on the opposite side window that could block the driver's view of the west coast mirror. Because of this, the monitors were relocated to the top of the windshield to move the cross reflection out of the way. Drivers using the commercially available C/VIS also reported that the reflected light off the windshield blocked their view of the lane markings and made it difficult to track the direction of the lane. It is believed that this would still occur if the monitors were mounted lower in front of the dash.

Monitors Can Obstruct Drivers' View of Fender Mirror

The placement of the C/VIS monitors may negatively impact drivers' opinions of the C/VIS if their position obstructs the driver's view of the fender mirror. The A-C/VIS monitors were purposefully positioned at the top of the left and right A-pillars, and top center of the windshield, so they would not block the driver's view of the road or fender mirrors (Figure 220). In fact, the monitors did not occupy any more vertical real estate on the windshield than did the sun visor. On the other hand, the commercial C/VIS's monitors were installed on the dash on the left and right side of the steering wheel according to a specification sent by VTECH USA, LLC. The monitors came with a stand designed to stick the monitors to the dash. After installing the commercial C/VIS's monitors on the dash, it was found that the left monitor could block the driver's view of the left fender mirror if his head was in a certain location (Figure 221). After sending a picture of the installation to VTECH USA, LLC, it was recommended that the monitors be drilled into the dash so that their position was lower. However, in doing so, elements of the instrument panel, as well as the left window defroster, would be covered (Figure 222). In addition, the vehicle's dash would be permanently damaged. The Schneider National fleet company manager indicated that he did not want to install the monitors in a fashion that would cover the instrument panel and window defroster. This issue was presented to VTECH USA to determine how they would have installed the monitor had the research team not been involved. The option of fabricating a custom bracket for the Freightliner C-120 trucks was suggested to VTECH USA, LLC, but they indicated that such work would not be possible without permanently damaging the dashboard. As such, the commercial C/VIS's monitors were installed according to the specification and stand that came with the system.



Figure 220. Placement of A-C/VIS Monitors in Truck Cab



Figure 221. Placement of Commercial C/VIS's Left Monitor According to VTECH USA, LLC Specification



Figure 222. Potential Placement of Commercial C/VIS's Left Monitor to Avoid Potential Obstruction of Left Fender Mirror; Elements of the Instrument Panel and Window Defroster are Obstructed

Over the course of the TFD, some drivers did indeed indicate that the left monitor could block their view of the left fender mirror if their head was in a certain position. As a result, the left and right monitors of the commercially available C/VIS were folded down during the Baseline condition. The monitors were then flipped up during the Test condition. When leaning to the left, drivers had to look around the monitor in order to use the left fender mirror. Although drivers were still able to use the left fender mirror, their opinions of the monitors may have been negatively affected by this obstruction. It should be noted that drivers indicated that the monitors provided the same view as the fender mirrors did when they were enabled.

When installing a C/VIS, the placement of the monitors should consider the layout of the vehicle's interior. Brackets that allow more flexibility for installing the C/VIS should be provided. If drivers are assigned to specific trucks, their input should be consulted regarding their preferred placement of the monitors. Overall, the findings from the TFD suggest that placing the monitors at the top of the A-pillars and top center of the windshield is the best solution.

Potential Disbenefits

The following disbenefits were not observed in the TFD. They are discussed here as potential issues to consider should C/VISs be implemented.

C/VIS May Allow Close Lane Changes

Although there is no evidence to suggest that this is the case, it is possible that drivers could misuse the enhanced visibility offered by the C/VISs by cutting in closer to adjacent vehicles when changing lanes. In dense traffic conditions, drivers constantly vie for position on the road. A driver that might otherwise stay in the right, slow-travel lane when uncertain about the clearance to an adjacent vehicle may decide to change into the left, faster-travel lane in front of a closely located adjacent vehicle if a C/VIS indicates that there is sufficient clearance to do so. Such a behavior could generate negative reactions—such as rapid braking—by surrounding traffic or lead to crashes if the CMV driver does not fully understand how to perceive gaps with the C/VIS.

Potential for Driver Distraction

It is possible that allocating visual attention to the monitors can increase drivers' crash risk, particularly if the glances to the monitors exceed 2 s in duration. This is because eye glances away from the forward roadway lasting more than 2 s increase crash risk (Klauer et al., 2006). Fortunately, drivers' probability of looking forward when driving with a C/VIS was not found to decrease in the TFD. Furthermore, the glances to the monitors were shorter than 1 s. Provided that glances to the monitors are short, it is expected that C/VISs will not increase crash risk because information presented on the monitors is relevant to the formulation of spatial awareness. Klauer et al. (2006) found that drivers who looked away from the forward roadway to check their side-view and rear-view mirrors actually had a crash risk less than 1 (i.e., monitoring one's mirrors had a protective effect). It is therefore hypothesized that regular, short eye glances to the monitors will provide a similar benefit to drivers since they will become more aware of their surroundings.

At the same time, there is another concern that selecting C/VIS functions through an on-screen menu can also take drivers' visual attention away from the forward roadway and negatively impact driving performance. C/VISs that demand that drivers navigate deep on-screen menus to adjust features (such as brightness) should only be operated when the vehicle is stationary. It is worth noting that the A-C/VIS's interface was designed to allow drivers to toggle between features with one button press. No on-screen menus were used.

STUDY LIMITATIONS

The following limitations should be considered when using the results from the TFD.

Number of Drivers

There were 12 drivers who participated in the TFD. Six drivers were assigned to the A-C/VIS-equipped trucks, and six were assigned to the commercial C/VIS-equipped trucks. There was an attempt to increase the number of drivers in the study, but the following constraints prevented this from occurring:

- To minimize data loss, there was a study requirement to keep the tractor-trailers permanently coupled throughout the study. Schneider was one of a few trucking operations willing to meet this requirement.
- There were only six routes available at Schneider's Winchester, Virginia operation that could support 48-ft trailers. Additional drivers could therefore not participate during the pre-determined data collection time interval.

As such, the findings are based on 12 drivers who were employed by Schneider, a safety-conscious company that has stringent hiring criteria for its employees.

Low Traffic Density

The majority (95 percent) of the sampled lane changes occurred in low traffic density (Level of Service A), where there are fewer vehicles on the road and therefore fewer opportunities to encounter vehicle-to-vehicle SCEs. Drivers' interaction with the C/VIS may have differed had they operated their tractor-trailers in rush-hour traffic when traffic density is higher.

Eye Glance Analysis Assumes Independence

The eye glance reduction assumes that drivers can only look in one location at a time. That is, if a driver is looking forward, then any glances to adjacent locations with their peripheral vision are not recorded. However, drivers indicated in their questionnaire responses that they did sometimes look at the monitors using their peripheral vision while they looked down the forward roadway. As such, the probability of looking at the monitors that was computed in this report could be greater than what is reported. Conversely, it may also be possible that a driver looking at a monitor can also look forward with his/her peripheral vision. Therefore, the time spent not looking forward may be less than what was reported when the monitors were added.

CHAPTER 9. CONCLUSIONS

CMV drivers must account for large blind spots when operating a tractor trailer. An analysis performed at the onset of this study found that crashes resulting from: 1) improper lane changes, 2) turning across the path of another vehicle, 3) improperly backing the vehicle, and 4) making a blind-spot-related driver error accounted for 20,311 crashes per year. Interviews with fleet safety managers also revealed that trucking companies would invest in a countermeasure technology provided that the ROI was less than 2.5-3 years. In addressing this issue, the U.S. DOT initiated an Indirect Visibility Research program that set out to investigate low-cost C/VISs that could be easily implemented in a commercial trucking operation. The initial research that was performed demonstrated that within specific contexts, C/VISs were able to assist CMV drivers in operating heavy vehicles. Based on these positive findings, a TFD was performed to investigate CMV drivers' performance with a C/VIS in a real-world context.

Prior to collecting data, a roadworthy version of the C/VIS prototype was developed. This advanced C/VIS, or A-C/VIS, possessed all the features of the previously validated E-C/VIS prototype (Wierwille et al., in press), while being compact and sufficiently rugged to withstand the substantial vibration generated by heavy-vehicle operation. A commercially available C/VIS was also selected for inclusion in the TFD using a trade study. To develop an understanding of the A-C/VIS and the commercially available C/VIS, both C/VISs were evaluated through a static object detection and recognition experiment that followed the static testing procedures used in the earlier E-C/VIS study. It was found that non-CMV-driver participants were able to detect objects positioned around the tractor-trailer in an unlit parking lot with the A-C/VIS equally as well as CMV drivers that used the E-C/VIS prototype in the earlier testing. It was also found that the non-CMV-driver participants detected fewer objects with the commercially available C/VIS than with the A-C/VIS system due to the commercial C/VIS's lack of a third rear-view camera and night vision capability. Yet, it should be mentioned that the objects that were missed consisted of a pedestrian, an unlit vehicle, and a stop sign, which are objects more likely to be found in a parking lot than on an open road. All participants detected a lit vehicle with the commercially available C/VIS.

The TFD consisted of installing the A-C/VIS on three tractor-trailers, and the commercially available C/VIS on another three tractor-trailers. Six CMV drivers from Schneider National, Inc. drove an A-C/VIS equipped truck, while another six drivers drove a commercial C/VIS-equipped truck. Participants drove one month with the C/VIS disabled, and three months with the C/VIS enabled. Video data, accelerometers, distance sensors, and yaw sensors were used to identify SCEs, while video data and rear-facing distance sensors were used to measure drivers' lane-change performance. Questionnaires administered to drivers every two weeks were used to measure drivers' opinions of their driving performance and the C/VISs. The objective of the TFD was to determine: 1) the effect of C/VISs on drivers' involvement in SCEs, 2) the effect of C/VISs on drivers' lane-change performance, and 3) drivers' opinions of C/VISs. Through these analyses, the potential disbenefits of C/VISs were concurrently investigated. The major conclusions from the data gathered from the conditions observed in the TFD are presented below.

IMPACT OF C/VISs ON DRIVER INVOLVEMENT IN SCEs

- Drivers' involvement in SCEs did not worsen when driving with a C/VIS.
- The severity of SCEs experienced did not change when driving with a C/VIS.
- Drivers' visual attention to the forward roadway did not degrade when driving with a C/VIS.

IMPACT OF C/VISs ON DRIVER LANE-CHANGE PERFORMANCE

- Drivers that looked at the C/VIS changed lanes with the same clearance to an adjacent vehicle as the drivers that did not look at the C/VIS.
- Drivers' visual attention to the forward roadway did not degrade when changing lanes with a C/VIS. However, drivers looked at the fender mirrors less frequently when changing lanes with a C/VIS.
- The time taken to cross the lane markings shortened when changing lanes with a C/VIS.
- Drivers were more likely to look at the C/VIS during clear nighttime conditions relative to the other environmental conditions examined. This was because the visibility of the road is reduced at night.
- Drivers were more likely to look at the C/VIS when making right lane changes compared to left lane changes. This was because there is a larger No-Zone on the right side of the truck compared to the left side.

DRIVERS' OPINIONS OF C/VISs

- Drivers indicated that the A-C/VIS made it easier to merge into traffic during inclement daytime conditions.
- Drivers indicated that the commercially available C/VIS made it easier to merge into traffic during clear daytime conditions.
- Drivers indicated that the A-C/VIS made it easier to identify objects located around the truck during inclement night conditions.
- Drivers indicated that the A-C/VIS made it easier to determine the approach rate of adjacent vehicles in daytime inclement weather.
- Drivers liked the A-C/VIS, but were neutral in rating the likeability of the commercially available C/VIS.
- Drivers indicated that the A-C/VIS helped eliminate blind spots around the truck, while drivers of the commercial C/VIS-equipped trucks were neutral in this regard.
- Drivers ranked the A-C/VIS's center monitor as more useful than the right or left monitors (although the ranking of the right monitor was a close second). Drivers ranked the commercial C/VIS's right monitor as more useful than the left monitor.
- Drivers liked the A-C/VIS turn signal diffusers (i.e., the translucent plastic caps that blocked the turn signal light from reaching the fender cameras) as they substantially reduced the blooming produced on the monitors when the turn signals were activated.
- All interviewed drivers indicated that they missed having a C/VIS on their truck one month after their participation in the study ended.

C/VIS DISBENEFITS

- Some drivers indicated that the glare from the commercial C/VIS's monitors is uncomfortable at night and can reduce their ability to see details in the roadway. Drivers found the A-C/VIS monitors' brightness to not be uncomfortable at night, likely because they can be substantially dimmed. Allowing the C/VIS monitors to be dimmed to near darkness is important. The use of turn signal light diffusers can also help reduce glare on the monitors by controlling blooming.
- Some drivers complained that the turn signals were too bright on the commercial C/VIS's monitors (commercial C/VIS-equipped trucks did not have turn signal light diffusers). Turn signal light diffusers were later installed on commercial C/VIS-equipped trucks to reduce discomfort glare.
- Some drivers did not like the placement of the left monitor on the commercially available C/VIS as it can obstruct their view of the left fender mirror. Most drivers liked the monitors placed at the top of the left and right A-pillars and the center of the windshield. Iterative user-centered design showed that mounting the monitors in these locations reduces cross-reflection on the windshield and windows, and reduces glare from reflected sunlight. If the monitors cannot be mounted along the top of the windshield, then the driver should be involved in selecting the monitor's placement on the dash.

CONCLUDING STATEMENTS

Overall, the TFD demonstrates that C/VISs, both an A-C/VIS and a commercially available C/VIS, benefit drivers by eliminating blind spots, improving drivers' spatial awareness, and easing the execution of lane changes in traffic. Furthermore, drivers' involvement in SCEs, their lane change performance, and their visual attention to the forward roadway were not found to worsen when driving with a C/VIS in the conditions tested. The observed disbenefits consisting of glare from the commercial C/VIS's monitor and placement of the commercial C/VIS's left monitor are also resolvable.

Because drivers find right lane changes harder to perform than left lane changes, a C/VIS that eliminates the right no-zone will be useful to drivers. Both the commercially available C/VIS and the A-C/VIS did this. However, drivers did find the trailer-mounted rear wide-angle look-down camera on the A-C/VIS to be very useful and were more likely to use this view compared to the other views when changing lanes. This view also helped drivers perform backing maneuvers and turning maneuvers, and when maneuvering the tractor-trailer in parking lots. There is, therefore, merit in adopting this advanced feature when implementing a C/VIS in a commercial trucking operation.

The use of trailer-mounted IR light to illuminate the areas around the tractor trailer may have supported drivers in maneuvering the tractor-trailer in unlit parking lots and making left and right turns on unlit streets. However, it likely did not assist drivers in perceiving an adjacent vehicle during highway driving as the adjacent vehicle's headlights served as the primary cue that a vehicle was present. Although the commercially available C/VIS does not have IR illumination, drivers can identify that a vehicle was traveling beside the truck if they see the vehicle's headlights.

Drivers indicated that the A-C/VIS's object detection feature was useful. Drivers used it more frequently during clear daytime conditions than in clear nighttime conditions. Although drivers did use the feature in over a third of inclement weather conditions, few lane changes were observed in these conditions.

The TFD also showed that there is a need to diffuse the light emanated from the turn signal lights so that blooming does not occur on the C/VIS monitors. By installing translucent plastic shields between the turn signal and the fender-mounted camera's vantage point, the amount of blooming on the monitors can be substantially reduced, leading to improved driver comfort with the C/VIS. It should be noted that drivers of the commercial C/VIS-equipped trucks appreciated this feature once they saw it implemented on the A-C/VIS at the end of the TFD.

Drivers' opinion data indicate that a C/VIS's monitors are best served if they are mounted at the top of the left and right A-pillars, and top center of the windshield if a rear-view is also provided. Iterative user-centered design also showed that mounting the monitors at these locations reduced cross-reflection on the windshield and windows, and reduced glare from reflected sunlight. Drivers did not indicate that the commercial C/VIS's right monitor was bothersome, but did not like the location of the commercial C/VIS's left monitor (positioned to specifications set forth by VTECH USA, LLC) as it could obstruct their view of the left fender. If the monitors cannot be positioned along the top of the windshield, drivers' preferences should be consulted when installing monitors on the dash as their height and professional training can help guide their ideal placement.

Finally, it is important that the C/VIS monitors can be substantially dimmed to prevent discomfort glare when driving at night. Dimming the monitors is also helpful when driving in fog, rain, or snow. The A-C/VIS, whose monitors could be substantially dimmed, was rated as comfortable to look at when driving at night, while the commercially available C/VIS, whose monitors could not be substantially dimmed, was rated as too bright when driving at night. Dimming the monitors allows drivers' vision to remain dark-adapted so they can perceive essential detail in the forward roadway.

To conclude, provided that C/VIS monitors allow for coverage of the right no-zone, can be sufficiently dimmed to not generate distraction glare, are positioned to not create new blind spots and cross-reflection in critical locations on the windshield and windows, do not have deep on-screen menus, and diffuse the light emanated from the turn signals, then drivers should be widely accepting of this driver-assistance technology.

C/VIS DESIGN GUIDELINES

The following are offered as C/VIS design guidelines:

- Ensure C/VIS monitors can be substantially dimmed to avoid discomfort glare and to allow drivers to remain dark-adapted when driving at night.
- Position monitors at the top of the left and right A-pillars, and top center of the windshield (if a rear-view is provided), to avoid:
 - Obstructing fender-mounted mirrors
 - Producing cross reflection on the windshield and side windows

- o Producing glare on the monitors from sunlight during the day
 - o Obstructing the driver's view of the adjacent lanes
- If a trailer-mounted C/VIS is used and needs to be connected to the tractor, design the C/VIS cable into the existing trailer light cable. Drivers will then only have one cable to attach. Furthermore, the attachment should provide feedback to drivers when the connection is properly made (e.g., snapping into place, or the alignment of two markings on either side of the connector).
- Deep on-screen menus should not be used for the selection of C/VIS settings. Allow drivers to save settings and toggle between their saved settings with one button press. For instance, the C/VIS should provide a day mode with a high brightness setting, and a night mode with a low brightness setting.
- Attach translucent plastic light diffusers between the turn signal lights and the fender-mounted C/VIS camera's vantage point to reduce blooming on the monitors at night. It should be noted that the amount of light shined in all other directions by the turn signal light was not reduced by the guards. The side turn signal lights are used to alert adjacent vehicle drivers of the truck's intent to change lanes. The turn signal light diffusers did not prevent the turn signal lights from being seen by adjacent vehicles. The side turn signal lights could also still be seen when directly facing the front of the truck because the plastic guards were translucent. The mandatory turn signal lights positioned on the front of the truck were not guarded and could be clearly seen.
- Ensure that the C/VIS turns on automatically with the ignition. Drivers should not have to turn the C/VIS on after starting the truck.
- Ensure that a training program is developed and used to instruct drivers on how to properly use the C/VIS when implementing them in a commercial trucking operation. For example, ensure that drivers are instructed that objects are closer than they appear in the monitors, particularly for views obtained with cameras with large FOVs (i.e., greater than 55 degrees).

FUTURE RESEARCH

The following areas of research could be performed in the future to extend our understanding of C/VISs:

- Baseline driving epochs could be sampled from the Test condition and reduced. Whether looking at the C/VIS monitors increases the likelihood of an SCE could be investigated by computing the odds ratio associated with the probability of looking at the monitors prior to an SCE and during a Baseline driving epoch.
- The naturalistic driving data collected from the TFD could be analyzed to identify the time of day and conditions that were present in which the SCEs occurred. Whether driving with a C/VIS has an effect on the time of day in which SCEs occur could be investigated.
- Investigate the use of augmented reality to help drivers perceive the clearance between the trailer and adjacent vehicle. A trick currently used by drivers is to determine whether an adjacent vehicle is touching the trailer's shadow. If contact exists, then the driver

knows that the trailer overlaps the vehicle. The use of graphics on top of the video image (referred to as augmented reality) could provide the same information to drivers regardless of the sun's position or presence.

- An optimal driver training program could be developed that instructs drivers how to operate a heavy vehicle with a C/VIS. Care would be given to the safe execution of lane changes, turning maneuvers, backing maneuvers, and maneuvering in parking lots.
- It would be worth investigating whether a combination of enhanced views and collision avoidance warnings, made possible by the fusion of C/VISs with distance-sensing radar or machine vision algorithms, improves drivers' performance.
- The Vehicle Safety Communications initiative seeks to accelerate the introduction of vehicle-to-vehicle (V2V) technologies into surface transportation. It is currently unknown whether the C/VIS monitors could also be used to present V2V information to drivers.
- It is also unknown whether there is merit in installing C/VISs on 28-ft local short haul trucks. Because such trucks are typically exposed to dense traffic conditions, drivers may benefit from the enhanced visibility. The investigation of using C/VISs on transit buses would be equally worthwhile for the same reason.
- The utility of C/VISs on light vehicles could be investigated, particularly to assess whether drivers with restricted head mobility benefit from the enhanced views.
- Finally, given the initiative to improve the sustainability of surface transportation, the use of C/VIS surrogates that replace the existing mirror system should be further investigated. It is estimated that eliminating the mirrors on trucks would improve their fuel efficiency owing to the reduction in drag. However, additional research is required to determine the optimal way to present the information gathered from the mirrors through C/VIS monitors.

APPENDIX A. SOLICITATION SCRIPTS

E-mail Script:

Hello, my name is _____ and I am a researcher at the Virginia Tech Transportation Institute. We are performing a study for the Federal Motor Carrier Safety Administration (FMCSA) examining the use of video cameras to reduce and eliminate the blind spots around tractor-trailers. As part of this research we are talking with fleet managers, safety officials, and maintenance directors regarding their professional opinions regarding these types of systems.

We are asking for your participation by allowing us to interview you regarding your professional opinions. This is voluntary, and we will not release your name or your company's name to anyone, including the FMCSA. The interview will be by telephone, and should last under one hour.

If you are interested in being interviewed for this project, please reply to this e-mail with your preferred contact time and telephone number. I will write back to confirm this.

I certainly appreciate your time today.

Name,
Title
Telephone and E-mail Address
Virginia Tech Transportation Institute

Response E-mail Script:

Thank you for agreeing to participate in the interview. You indicated that your preferred time was _____ at the telephone number of _____. I will be sure to only call during this time.

To ensure that you are aware of what the interview involves, could you please review the attached Informed Consent document when you have a moment? This document outlines your rights as a participant and describes what will happen during your participation in this research. It also states that although the interview is recorded for transcription and note-taking purposes, the recording and information such as your name and your company's name will not be released to anyone else, including the FMCSA.

Additionally, I am attaching a short description of the technology we will be discussing during the interview. We will refer to this document during the beginning of the interview. Both this and the Informed Consent document are Adobe Acrobat PDF files. Please let me know if you have trouble with either attachment.

We will be in contact shortly. Again, thank you for your time,

Name,
Title
Telephone and E-mail Address
Virginia Tech Transportation Institute

APPENDIX B. INTERVIEW SCRIPT

Hello, my name is _____ and I am a researcher at the Virginia Tech Transportation Institute. We spoke earlier and had scheduled a brief interview for this time. Is this still a convenient time for you?

As I mentioned before, we are performing a study for the Federal Motor Carrier Safety Administration, or FMCSA, examining the use of video cameras to reduce and eliminate the blind spots around tractor-trailers. We are seeking your professional opinion as an official of a trucking company regarding these systems. This interview will be recorded. However, your name and your company's name will not be released to anyone else – including the Federal Motor Carrier Safety Administration. The entire interview should take under one hour. Will this be okay?

Before we begin, I need to read you the Informed Consent information. Another employee of Virginia Tech will be present while I read this to you in order to serve as a witness. Once we finish the informed consent process, the witness will leave and we will begin the recorded interview. This is done to keep your and your company's name separate from your interview. We will also avoid using names during the interview, as further protection of your privacy. Are you ready to begin?

Read Informed Consent. Gain verbal approval by having participant state full name when form prompts for signatures. At conclusion of consent process, inform participant and dismiss witness.

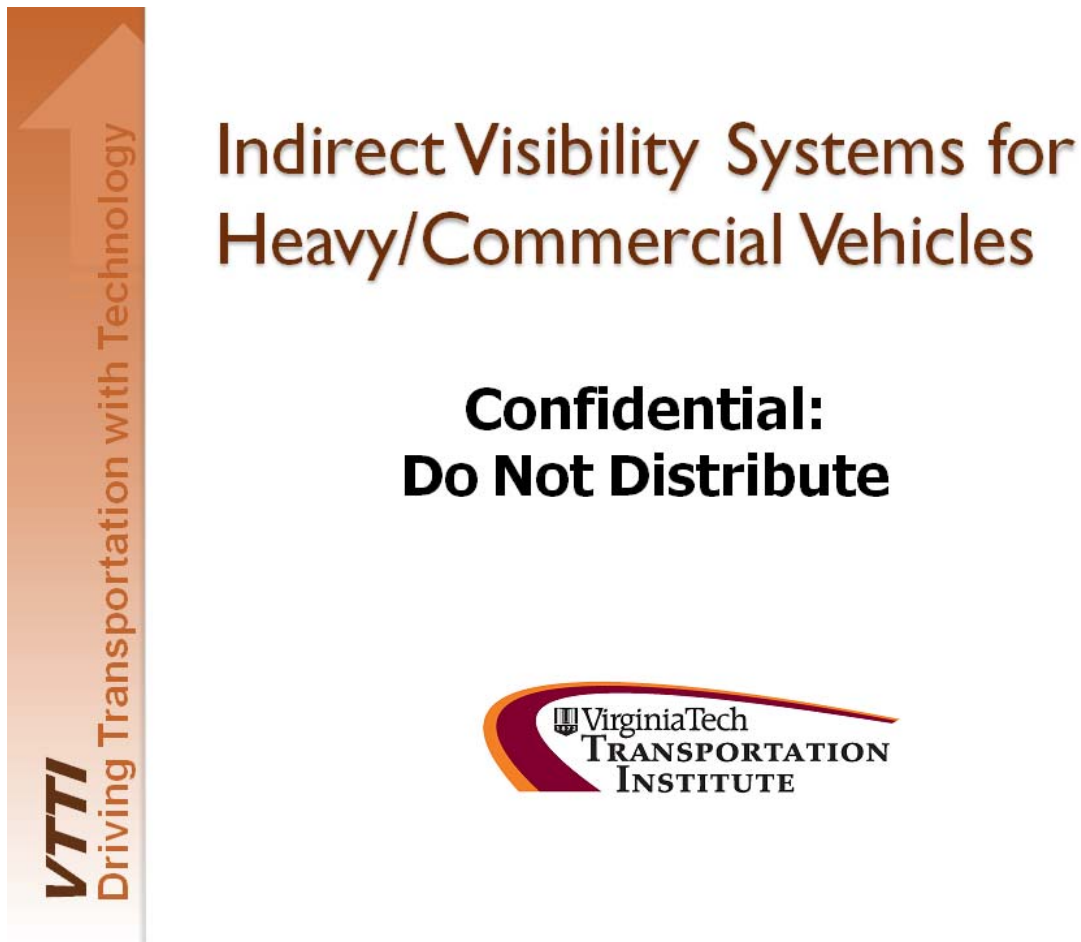
Thank you. We are now ready to begin the interview. Keep in mind that this will be recorded, so we will avoid using your name and your company's name. At any time, you may ask me to stop recording. Are you ready to begin?

Signal to participant when recording begins. Proceed through questions. At conclusion, ask if participant has any further comments or statements, then end recording and notify participant that recording has ceased.

Again, we thank you for your time today. Your professional opinion is valuable to transportation safety researchers, and we certainly appreciate the help you have given us. If you have any questions or need to reach me, I can be contacted by phone at (540) 231-XXXX, or by e-mail at XXXX@vti.vt.edu. Thank you. <Terminate call>

APPENDIX C. BRIEFING ON THE C/VIS TECHNOLOGY

The following images are slides which were given to the interviewee for review prior to the interview. Before the interview began, the interviewer briefed the participant on the C/VIS using these slides. Each slide's accompanying narrative, which was read by the interviewer, is below the accompanying slide.



Slide 1

Slide 1: No narrative provided to participant.

Description

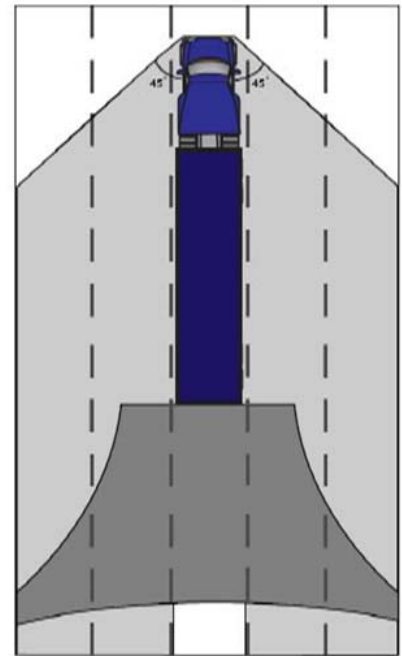
- Indirect Visibility Systems (IVS) use video cameras to show vehicles traveling in a Truck's No-Zone.
- The IVS shown in these slides is designed to help Commercial Motor Vehicle drivers drive safely.

Slide 2

Slide 2: Today I am going to ask you about a technology referred to as indirect visibility systems. Indirect visibility systems use cameras and monitors to provide video images of a heavy vehicle's No-Zone blind spots to the driver.

Cameras

- The IVS uses a 3-camera system:
 - Front right fender
 - Front left fender
 - Rear top of trailer



Camera Coverage

Slide 3

Slide 3: The system I would like to talk to you about has cameras mounted on the side front fenders of the tractor, and on the center rear position of the trailer near the top.

Cameras

- The cameras are:
 - Wide angle (rear camera only)
 - Housed in a weather and shock resistant casing



Example of a commercially available camera housing (image courtesy of SideTracker, a division of V-Tech, USA)

Slide 4

Slide 4: The cameras provide a wide angle picture, and are housed in a weather- and shock-resistant casing.

Monitors

- There are 3 in-cab video monitors
- Driver/Passenger side placed on A-pillars
- Rear view placement in center of windshield



Slide 5

Slide 5: These camera images are displayed on three monitors inside the cab. Monitors are placed in the same general line of sight as the west coast mirrors on the A pillars. The rear view monitor is placed in the top center of the windshield, similar to the rearview mirror in a car.

Image

- Monitors show a color image during day and black and white (infrared) image at night
- The image switches automatically based on external lighting conditions



Daytime Image



Nighttime Image

Slide 6

Slide 6: The cameras provide a color image during the day. At night the cameras use an infrared technology to provide a black and white image. Please keep in mind that this system is not intended to replace existing west coast mirrors. Instead, this indirect visibility system seeks to fill in the blind spots which the mirrors cannot reach.

Right Fender-Mounted Camera



Slide 7

Slide 7: This page, and the next two pages, show actual indirect visibility system images of areas around the truck. Please spend some time looking at the images. Think about whether this C/VIS helps drivers see their No-Zone, and consider which driving maneuvers this system would be helpful with, and which driving maneuvers this system would make more difficult.

Rear Top-Center Look-Down Camera



Slide 8

Slide 8: No narrative provided to participant.

Left Fender-Mounted Camera



Slide 9

Slide 9: No narrative provided to participant.

APPENDIX D. INTERVIEW QUESTIONS

Safety Benefits

1. Do you think drivers using an indirect visibility system would change their on-road driving?
 1. If yes: why/in what ways?
 2. If no: why?
2. Do you think having an indirect visibility system would change how drivers drive at terminals and other loading/unloading points?
3. In your experience, how common are collisions where forward visibility from the cab was a contributing factor?
 1. Do you think that an additional camera view of the area in front of the truck would solve this problem?
 2. Would this camera view be more useful to the driver in certain scenarios, such as operating in yards or terminals?
4. What types of routes does your company primarily operate? (***IF company runs different route types***) Would an indirect visibility system help local/regional, line, and long haul drivers differently?
 1. If so, why
 2. If not, why?
5. If the indirect visibility system was being tested in revenue generating runs, what would tell you that it was working well?
 1. What would tell you that it wasn't working well?
6. We are about to conduct a study on indirect visibility systems which will look at how drivers using the device we described may alter the way they change lanes and merge in traffic.
 1. What results from this study would interest you?
 2. Are there any specific driving behaviors we should investigate while drivers have the indirect visibility system?
 3. What other questions regarding this system would it be important for you to have answers for?

Company/Driver Acceptance

7. Does your company offer or give any type of training to CDL drivers?
 1. If so, please briefly describe. (e.g., new driver training, fuel economy training, etc.)
 2. (***IF company offers driver training***) Would indirect visibility technology change driver training within your company.
 1. If so, how?
8. If your company decided to install these systems in all of their trucks, would you record the video displayed by this device?

1. If yes: are there any specific reasons why?
2. If no: why?
9. Do you think that the possibility your company could record the video output from this system would affect drivers' acceptance?
10. What do you think Class-A CDL drivers' initial reaction to an indirect visibility system will be?
11. Has your company previously implemented any aftermarket safety technologies?
 1. If so, which ones?
 2. How have drivers reacted to each?
 3. What safety benefits of these technologies have you experienced?

Fleet Implementation

12. How much interaction should this system require from a driver?
 1. How should the driver turn the system on and off?
 2. How should the driver adjust settings such as screen brightness?
13. Would you prefer an indirect visibility system to come pre-installed, or be installed after delivery?
14. Are there any other features you would want to see in this device?
 - a. If yes, what are they? Why?
 - b. How much additional cost per unit would your company be willing to pay for this/these features?
15. What maintenance concerns do you have regarding this system?

Economic Issues

16. If possible, could you please estimate the costs associated with lane change/merge crashes your company incurs each year?
17. If possible, could you please estimate the costs associated with backing/maneuvering crashes your company incurs each year?
18. How much would you be willing to pay for this system in your fleet per truck?
19. What would factor into your company's cost-benefit analysis of this system?
 1. What are the possible economic benefits?
 2. What are the possible economic risks and liabilities?
20. In your opinion, would the additional cost of a full 360° camera view around the vehicle be economically justified?
21. Would federal or insurance incentives influence the decision on whether or not your company would adopt an indirect visibility system?
22. Would liability issues, such as video recordings of a crash, affect your decision?
23. What is the biggest issue or issues you see in using this technology?
24. In general, do you feel this indirect visibility system would be useful in your company?

Thank you for answering these questions. I have two more questions about your company.

Company Information

25. Approximately how many Class-A CDL drivers does your company employ or contract?
26. How many power units are in your company's fleet?

APPENDIX E. COMPARISON OF A-C/VIS SPECIFICATIONS TO E-C/VIS SPECIFICATIONS

Specifications	E-CVIS			A-CVIS		
Camera						
Type of Camera (Purpose)	Wide-Angle Trailer Rear Multipurpose Look-Down Enhancement	Left Side Blind-Spot Enhancement	Right Side Blind-Spot Enhancement	Wide-Angle Trailer Rear Multipurpose Look-Down Enhancement	Left Side Blind-Spot Enhancement	Right Side Blind-Spot Enhancement
Location	Rear top center of the trailer/cargo box	Left front fender mount	Right front fender mount	Rear top center of the trailer/cargo box	Left front fender mount above centerline of axle	Right front fender mount above centerline of axle
Angle of Coverage (Field of View)	102 Degrees Horizontally	45 Degrees Horizontally	45 Degrees Horizontally	Approx. 102 Degrees Horizontally	Approx. 45 Degrees Horizontally	Approx. 45 Degrees Horizontally
Image Presentation	Reversed Scan	Reversed Scan	Reversed Scan	Reversed Scan	Reversed Scan	Reversed Scan
Horizontal Aim Direction	0 deg on axis of trailer/cargo box	Camera is aimed so right edge of camera view is tangent to the tractor or cargo box	Camera is aimed so left edge of camera view is tangent to the tractor or cargo box	Aimed downward so that the bottom edge of the camera view includes the rear vertical surface of the trailer box.	Camera is aimed so left edge of camera view is tangent to the tractor or cargo box	Camera is aimed so right edge of camera view is tangent to the tractor or cargo box
Vertical Aim Direction	Aimed downward so that the bottom edge of the camera view includes the rear vertical surface of the trailer box.	Camera level with horizon appearing in upper half of the view based on review of previously collected video data	Camera level with horizon appearing in upper half of the view based on review of previously collected video data	Aimed downward so that the bottom edge of the camera view includes the rear vertical surface of the trailer box.	Camera level with horizon appearing in upper half of the view based	Camera level with horizon appearing in upper half of the view based
Depth of Field (Focus Range)	min 6 ft /max 80 ft or greater	min 10 ft /max 150 ft or greater	min 10 ft /max 150 ft or greater	min 6 ft /max 80 ft or greater	min 10 ft /max 150 ft or greater	min 10 ft /max 150 ft or greater
Waterproof	Yes, Waterproof housings with sun shades	Yes, Waterproof housings with sun shades	Yes, Waterproof housings with sun shades	Yes.	Yes.	Yes.
Camera Operating Temperature Range	-10 to 120° F (-23.3 to 48.9° C)	-10 to 120° F (-23.3 to 48.9° C)	-10 to 120° F (-23.3 to 48.9° C)	-10 to 120° F (-23.3 to 48.9° C)	-10 to 120° F (-23.3 to 48.9° C)	-10 to 120° F (-23.3 to 48.9° C)

Camera Storage (Exposure)Temperature Range	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)
Exterior Illumination Operating Range	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)	All cameras should be capable of providing a usable image for objects with luminance in the range from 0.02 to 20,000 cd/m2 (0.0058 to 5831 ft.l.)
Switch from Day to Night (automatic, manual, both?)	Automatic. All three cameras should switch modes simultaneously. A crossover threshold with sufficient hysteresis was determined empirically.	Automatic. All three cameras should switch modes simultaneously. A crossover threshold with sufficient hysteresis was determined empirically.	Automatic. All three cameras should switch modes simultaneously. A crossover threshold with sufficient hysteresis was determined empirically.	Automatic. All three cameras will switch modes simultaneously. A crossover threshold with sufficient hysteresis will be determined empirically.	Automatic. All three cameras will switch modes simultaneously. A crossover threshold with sufficient hysteresis will be determined empirically.	Automatic. All three cameras will switch modes simultaneously. A crossover threshold with sufficient hysteresis will be determined empirically.
Minimum Image Resolution	350 Horizontal TV lines or 540 Horizontal Pixels	350 Horizontal TV lines or 540 Horizontal Pixels	350 Horizontal TV lines or 540 Horizontal Pixels	350 Horizontal TV lines or 540 Horizontal Pixels	350 Horizontal TV lines or 540 Horizontal Pixels	350 Horizontal TV lines or 540 Horizontal Pixels
Image Frame Rate	NTSC (29.97 Frames/Second). (Updated from previous report)	NTSC (29.97 Frames/Second). (Updated from previous report)	NTSC (29.97 Frames/Second). (Updated from previous report)	NTSC (29.97 Frames/Second). (Updated from previous report)	NTSC (29.97 Frames/Second). (Updated from previous report)	NTSC (29.97 Frames/Second). (Updated from previous report)
Monitor						

Signal Interface	VGA monitors were used because unacceptable lag was created by conversion of machine vision processing output to NTSC signal	VGA monitors were used because unacceptable lag was created by conversion of machine vision processing output to NTSC signal	VGA monitors were used because unacceptable lag was created by conversion of machine vision processing output to NTSC signal	NTSC	NTSC	NTSC
Monitor Location	Upper center of windshield. It must not block any horizontal portion of driver's forward view. Monitor should be turned toward driver so that his/her view is almost perpendicular to the monitor.	Base of driver side A-pillar. (When installed, any overlap should be toward the rear so that the windshield is not blocked. Views of side mirrors should not be blocked. Monitor should be turned toward driver so that his/her view is almost perpendicular to the monitor. If side mirror reflections become a problem, another location might be needed.	Base of passenger side A-pillar. (When installed, any overlap should be toward the rear so that the windshield is not blocked. Views of side mirrors should not be blocked. Monitor should be turned toward driver so that his/her view is almost perpendicular to the monitor. If side mirror reflections become a problem, another location might be needed.	Upper center of windshield. It does not block any horizontal portion of driver's forward view. Monitor turned toward driver so that his/her view is almost perpendicular to the monitor.	Due to side mirror and window reflections, monitor is located at the top front portion of A-pillar (only position available to reduce reflections and stable installation availability). Monitor is turned toward driver so that his/her view is almost perpendicular to the monitor.	Due to side mirror and window reflections, monitor is located at the top front portion of A-pillar (only position available to reduce reflections and stable installation availability). Monitor is turned toward driver so that his/her view is almost perpendicular to the monitor.
Monitor Size	Size 2 as defined in the original CVIS study	Size 2 as defined in the original CVIS study	Size 2 as defined in the original CVIS study	5" (Diagonal)	5" (Diagonal)	6.4" (Diagonal)
Monitor Operating Temperature Range	0 to 110° F (-17.8 to 43.3° C)	0 to 110° F (-17.8 to 43.3° C)	0 to 110° F (-17.8 to 43.3° C)	0 to 110° F (-17.8 to 43.3° C)	0 to 110° F (-17.8 to 43.3° C)	0 to 110° F (-17.8 to 43.3° C)
Monitor Storage (Exposure)Temperature Range	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)	-30 to 150° F (-34.3 to 65.6° C)

Monitor Luminance	Monitor screen should range from 5 to 5000 lux (0.46 to 465 foot candles (fc) depending on incident illumination level	Monitor screen should range from 5 to 6000 lux (0.46 to 557 fc) depending on incident illumination level	Monitor screen should range from 5 to 6000 lux (0.46 to 557 fc) depending on incident illumination level	Monitor screen should range from 5 to 5000 lux (0.46 to 465 fc) depending on incident illumination level	Monitor screen should range from 5 to 6000 lux (0.46 to 557 fc) depending on incident illumination level	Monitor screen should range from 5 to 6000 lux (0.46 to 557 fc) depending on incident illumination level
Monitor Luminance & Contrast Adjustment	Automatic adjustment over suggested range	Automatic adjustment over suggested range	Automatic adjustment over suggested range	Automatic adjustment over suggested range	Automatic adjustment over suggested range	Automatic adjustment over suggested range
Response to Activation	400 ms	400 ms	400 ms	400 ms	400 ms	400 ms
Glare Shades (Monitor Hoods), or monitor glare reduction filters	Glare shades should be developed to minimize off-axis incident light. Careful not to present a hazard to the driver or front seat passenger when entering or exiting the vehicle or in case of a crash.	Glare shades should be developed to minimize off-axis incident light. Careful not to present a hazard to the driver or front seat passenger when entering or exiting the vehicle or in case of a crash.	Glare shades should be developed to minimize off-axis incident light. Careful not to present a hazard to the driver or front seat passenger when entering or exiting the vehicle or in case of a crash.	Glare shades not necessary due to monitor placement.	Glare shades not necessary due to monitor placement.	Glare shades not necessary due to monitor placement.
Image Aspect Ratio	Aspect ratio of 3 units of height to 4 units of width.	Aspect ratio of 3 units of height to 4 units of width.	Aspect ratio of 3 units of height to 4 units of width.	Aspect ratio of 3 units of height to 4 units of width.	Aspect ratio of 3 units of height to 4 units of width.	Aspect ratio of 3 units of height to 4 units of width.
Overall System						
Maximum Image Processing Latency	50 ms from image acquisition to display.	50 ms from image acquisition to display.	50 ms from image acquisition to display.	50 ms from image acquisition to display.	50 ms from image acquisition to display.	50 ms from image acquisition to display.
Day/Night Mode	Simultaneous switching from nighttime to daytime including monitor brightness control	Simultaneous switching from nighttime to daytime including monitor brightness control	Simultaneous switching from nighttime to daytime including monitor brightness control	Simultaneous switching from nighttime to daytime including monitor brightness control	Simultaneous switching from nighttime to daytime including monitor brightness control	Simultaneous switching from nighttime to daytime including monitor brightness control
IR Illuminators						

Description	IR Illuminators (140 LED white rectangular units)	IR Illuminators (140 LED white rectangular units)	IR Illuminators (140 LED white rectangular units)	IR Illuminators (140 LED white rectangular units)	IR Illuminators (140 LED white rectangular units)	IR Illuminators (140 LED white rectangular units)
Predominant Wavelength	940 nm (determined from test on an actual unit)	940 nm (determined from test on an actual unit)	940 nm (determined from test on an actual unit)	940 nm (determined from test on an actual unit)	940 nm (determined from test on an actual unit)	940 nm (determined from test on an actual unit)
Tractor - Mounting Locations	Lower rear portion of front right and left fenders	Lower rear portion of front right and left fenders	Lower rear portion of front right and left fenders	Lower rear portion of front right and left fenders	Lower rear portion of front right and left fenders	Lower rear portion of front right and left fenders
Tractor - Horizontal Angle with Respect to Centerline of Vehicle	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)	22.5 deg. Horizontal center aim (aimed with edge tangent to edge of tractor or cargo box)
Tractor - Vertical Elevation	6 degrees	6 degrees	6 degrees	6 degrees	6 degrees	6 degrees
Trailer - Mounting Locations (E_CVIS 53 feet Trailer / VIS 48 feet Trailer)	2 IR Illuminators placed on both the right and left sides of trailer 10 ft back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 20 ft forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.	2 IR Illuminators placed on both the right and left sides of trailer 10 ft back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 20 ft forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.	2 IR Illuminators placed on both the right and left sides of trailer 10 ft back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 20 ft forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.	2 IR Illuminators placed on both the right and left sides of trailer 22.7 in back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 21.6 in forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.	2 IR Illuminators placed on both the right and left sides of trailer 22.7 in back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 21.6 in forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.	2 IR Illuminators placed on both the right and left sides of trailer 22.7 in back from front of trailer; 2 IR Illuminators placed on both the right and left sides of trailer and 21.6 in forward from back of trailer; 2 IR Illuminators placed on both the right and left sides of the trailer rear.

Trailer - Horizontal Angle with Respect to Centerline of Vehicle	All four illuminators mounted on the side of the trailer should be 22.5 deg. Horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer should be 15 deg. Horizontal center aim (aimed with edge tangent to extended edge of cargo box).	All four illuminators mounted on the side of the trailer should be 22.5 deg. Horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer should be 15 deg. Horizontal center aim (aimed with edge tangent to extended edge of cargo box).	All four illuminators mounted on the side of the trailer should be 22.5 deg. Horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer should be 15 deg. Horizontal center aim (aimed with edge tangent to extended edge of cargo box).	All four illuminators mounted on the side of the trailer at 22.5 deg. horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer at 15 deg. horizontal center aim (aimed with edge tangent to extended edge of cargo box).	All four illuminators mounted on the side of the trailer at 22.5 deg. horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer at 15 deg. horizontal center aim (aimed with edge tangent to extended edge of cargo box).	All four illuminators mounted on the side of the trailer at 22.5 deg. horizontal center aim (aimed with edge tangent to edge of cargo box). Two illuminators mounted to rear of trailer at 15 deg. horizontal center aim (aimed with edge tangent to extended edge of cargo box).
Trailer - Vertical Elevation	6 degrees	6 degrees	6 degrees	6 degrees	6 degrees	6 degrees
Horizontal Beam Width	60 deg	60 deg	60 deg	60 deg	60 deg	60 deg
Visible Output Under Nighttime Conditions	No visible output	No visible output	No visible output	No visible output	No visible output	No visible output
Image Processing						
Description	Changes in contrast in raw video image and use for "outlining". Outlined processed video would be superimposed over original image. Also, suppression of headlight bloom was performed to show all but the edges of the bloom as dark grey.	Changes in contrast in raw video image and use for "outlining". Outlined processed video would be superimposed over original image. Also, suppression of headlight bloom was performed to show all but the edges of the bloom as dark grey.	Changes in contrast in raw video image and use for "outlining". Outlined processed video would be superimposed over original image. Also, suppression of headlight bloom was performed to show all but the edges of the bloom as dark grey.	Object detection feature accentuates lines in the video image by overlaying computer-generated white lines over the detected edges.	Object detection feature accentuates lines in the video image by overlaying computer-generated white lines over the detected edges.	Object detection feature accentuates lines in the video image by overlaying computer-generated white lines over the detected edges.

Processing Adjustment	The amount of processing could be adjusted by a weighting scheme, which was specified at a given level by consensus of developers.	The amount of processing could be adjusted by a weighting scheme, which was specified at a given level by consensus of developers.	The amount of processing could be adjusted by a weighting scheme, which was specified at a given level by consensus of developers.	The threshold for edge detection is adjustable. Lower thresholds translate into more edge detection, and more computer-generated white lines.	The threshold for edge detection is adjustable. Lower thresholds translate into more edge detection, and more computer-generated white lines.	The threshold for edge detection is adjustable. Lower thresholds translate into more edge detection, and more computer-generated white lines.
DVI						
Description	Driver was able to control the display brightness and image processing level. The DVI was mounted to the dash to the right of the steering wheel within reach of the driver and consisted of two rocker switches and a default setting.	Driver was able to control the display brightness and image processing level. The DVI was mounted to the dash to the right of the steering wheel within reach of the driver and consisted of two rocker switches and a default setting.	Driver was able to control the display brightness and image processing level. The DVI was mounted to the dash to the right of the steering wheel within reach of the driver and consisted of two rocker switches and a default setting.	The driver interacts with the IVS using 6 buttons located on the left monitor. The driver is able to switch between day and night modes, adjust the image brightness, turn the object detection on or off, and adjust the amount of object detection with the DVI buttons.	The driver interacts with the IVS using 6 buttons located on the left monitor. The driver is able to switch between day and night modes, adjust the image brightness, turn the object detection on or off, and adjust the amount of object detection with the DVI buttons.	The driver interacts with the IVS using 6 buttons located on the left monitor. The driver is able to switch between day and night modes, adjust the image brightness, turn the object detection on or off, and adjust the amount of object detection with the DVI buttons.
Miscellaneous						

Marker Lights	Tractor and Trailer marker lamps (small visible lights located on both the tractor and trailer) that were located near the camera height had a divider shade applied in order to reduce the addition of bright spots on the displays. However, the rear trailer marker lights are used by some drivers for reference in driving maneuvers, and covering them should be taken into account in any future efforts.	Tractor and Trailer marker lamps (small visible lights located on both the tractor and trailer) that were located near the camera height had a divider shade applied in order to reduce the addition of bright spots on the displays. However, the rear trailer marker lights are used by some drivers for reference in driving maneuvers, and covering them should be taken into account in any future efforts.	Tractor and Trailer marker lamps (small visible lights located on both the tractor and trailer) that were located near the camera height had a divider shade applied in order to reduce the addition of bright spots on the displays. However, the rear trailer marker lights are used by some drivers for reference in driving maneuvers, and covering them should be taken into account in any future efforts.			

Suggested						
Activation and Deactivation of the System	At ignition and/or a driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.	At ignition and/or a driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.	At ignition and/or a driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.	Activation at ignition. Driver will have control over day/night mode, brightness, and image processing level.	Activation at ignition. Driver will have control over day/night mode, brightness, and image processing level.	Activation at ignition. Driver will have control over day/night mode, brightness, and image processing level.

APPENDIX F. C/VIS SPECIFICATIONS

C/VIS SPECIFICATION TEMPLATE

The template used to identify C/VIS specifications is presented below.

System Information:

1. What is the name of the system?
2. What are the product components? Please identify the components using the product numbers and provide a brief description.
Camera 1:
Camera 2:
Camera 3:
Camera 4:
Monitor 1:
Monitor 2:
Monitor 3:
Additional Components:
3. Who manufactures the system?
4. Who distributes the system?
5. How is the system activated and deactivated (push button, when vehicle is put in reverse, etc.)?
6. Do the cameras switch from day mode to night mode? If so, are all done simultaneously?
7. What is the initial cost of the system?
8. Has it been industry tested?
9. How many units have you sold of this type of system?

Camera Information:

10. What is the purpose of the camera (rear, left, right)?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

11. What is the location of the camera mounting?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

12. What is the angle of coverage or field of view of the camera?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

13. What is the aim direction of the camera? See figures 1 and 2 for letter assignments.

Camera 1:

Camera 2:

Camera 3:

Camera 4:

14. What is the focus range (in feet) of the camera?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

15. What is the image presentation (i.e. standard [un-reversed] scan)?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

16. Is the camera waterproof?

Camera 1:

Camera 2:

Camera 3:

Camera 4:

17. What is the temperature range in which the exterior components can operate?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
18. What is the temperature range that the exterior components can be exposed to?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
19. What is the exterior illumination operating range?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
20. Does the camera have night vision?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
21. How does the camera switch from day mode to night mode (automatic, manual, etc.)?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
22. Is the camera VGA or NTSC?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
23. Where does the horizon appear in the video image (in relation to the vertical angle used to aim the camera)?
- Camera 1:
 - Camera 2:
 - Camera 3:
 - Camera 4:
24. Does your system use infrared (IR) illuminators? If so, are they attached to the camera, or are they attached elsewhere on the truck?

Camera 1:
Camera 2:
Camera 3:
Camera 4:

Monitor Information:

25. Where is the mounting location for the monitor? See Figure 3 for mountings at the A-Pillars or Figure 4 for other mountings.

Monitor 1:
Monitor 2:
Monitor 3:

26. What is the size of the monitor?

Monitor 1:
Monitor 2:
Monitor 3:

27. What is the temperature range in which the interior components can operate?

Monitor 1:
Monitor 2:
Monitor 3:

28. What is the temperature range that the interior components can be exposed to?

Monitor 1:
Monitor 2:
Monitor 3:

29. What is the cab interior illumination operating range (lux)?

Monitor 1:
Monitor 2:
Monitor 3:

30. What is the monitor minimum and maximum luminance and contrast adjustment?

Monitor 1:
Monitor 2:
Monitor 3:

31. What is the minimum system image resolution?

Monitor 1:
Monitor 2:
Monitor 3:

32. What is the rate that the system refreshes?

Monitor 1:
Monitor 2:
Monitor 3:

33. What is the maximum system image delay?

Monitor 1:
Monitor 2:
Monitor 3:

34. How fast is the response to activation (How long does it take to turn on after being touched)?

Monitor 1:
Monitor 2:
Monitor 3:

35. How many camera views are displayed in the monitor (number of screens)?

Monitor 1:
Monitor 2:
Monitor 3:

36. What is the image aspect ratio?

Monitor 1:
Monitor 2:
Monitor 3:

SAFETY VISION®'S ON-BOARD CAMERA SYSTEM (PRODUCT: SV-CLCD-70)

Specifications pertaining to the Safety Vision® SV-CLCD-70 system are presented in Table 48.

Table 48. Safety Vision® On-board Camera System

SYSTEM	
Product Components	
Camera 1 (Right Side)	Not Applicable
Camera 2 (Left Side)	Not Applicable
Camera 3 (Rear)	Color SV-620A
Monitor 1	LCD SV-LCD70
Monitor 2	Not Applicable
Additional Components	Control Box (SV-LCD70-CBQKIT), Monitor bracket (SV-LCDBRKT), 65 foot cable (SV-523B)
Manufacturer	Safety Vision®, LP
Distributor	Safety Vision®, LP
System Activation/Deactivation	User Configurable
Simultaneous Day/Night Mode	Automatic
Initial Cost	\$995.00
Industry Tested	On market since 2005
Units Sold	10,000 (including construction and mining applications)
CAMERA	
Purpose:	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Rear View
Location of Camera Mounting	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Rear Top of Vehicle
Angle of Coverage/Field of View	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	130 Degrees
Aim Direction	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	G
Focus Range	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	2' to Infinity
Image Presentation	
Camera 1	Not Applicable

Camera 2	Not Applicable
Camera 3	Selectable [Standard (un-reversed) or Mirror (reversed)]
Waterproof	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Yes
Operation Temperature	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	-22 to 122 Degrees F
Exposure Temperature	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	-40 to -122 Degrees F
Exterior Illumination Range	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Minimum of 0 lux
Night Vision	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Yes
Switch Day/Night Mode	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Automatic
VGA or NTSC	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	NTSC
Horizon	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Adjustable
Infrared Illuminators	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Yes, integrated into camera
MONITOR	
Monitor Mounting Location	
Monitor 1	Rear view mirror or on top of dashboard in center of windshield
Monitor 2	Not Applicable
Monitor Size	
Monitor 1	7"
Monitor 2	Not Applicable
Operation Temperature	
Monitor 1	14 to 122 Degrees F

Monitor 2	Not Applicable
Exposure Temperature	
Monitor 1	-13 to 176 Degrees F
Monitor 2	Not Applicable
Cab Interior Illumination Operating Range	
Monitor 1	0 lux to direct sunlight
Monitor 2	Not Applicable
Min/Max Luminance and Contrast Adjustment	
Monitor 1	Auto dimmer, user switch or sensor
Monitor 2	Not Applicable
Minimum System Image Resolution	
Monitor 1	1440 x 234 pixels
Monitor 2	Not Applicable
Refresh Rate	
Monitor 1	59.94 hertz
Monitor 2	Not Applicable
Maximum System Image Delay	
Monitor 1	Approximately none
Monitor 2	Not Applicable
Response to Activation	
Monitor 1	< .5 seconds
Monitor 2	Not Applicable
Number of Views Displayed	
Monitor 1	Up to 4
Monitor 2	Not Applicable
Image Aspect Ratio	
Monitor 1	16:09
Monitor 2	Not Applicable

V-TECH USA LLC'S SIDETRACKER SYSTEM

Specifications pertaining to the Sidetracker C/VIS are presented below in Table 49.

Table 49. V-TECH USA's Sidetracker System

SYSTEM	
Product Components	
Camera 1 (Right Side)	1
Camera 2 (Left Side)	1
Camera 3 (Rear)	Not Applicable
Monitor 1	5.6"
Monitor 2	Not Applicable
Additional Components	Not Available
Manufacturer	Vtech USA
Distributor	Vtech USA
System Activation/Deactivation	Push Button
Simultaneous Day/Night Mode	No
Initial Cost	\$650.00
Industry Tested	Yes
Units Sold	8,000+
CAMERA	
Purpose:	
Camera 1	Right Side View
Camera 2	Not Applicable
Camera 3	Not Applicable
Location of Camera Mounting	
Camera 1	Front Right Fender
Camera 2	Not Applicable
Camera 3	Not Applicable
Angle of Coverage/Field of View	
Camera 1	90 Degrees
Camera 2	Not Applicable
Camera 3	Not Applicable
Aim Direction	
Camera 1	Aimed outward towards the rear of the trailer
Camera 2	Not Applicable
Camera 3	Not Applicable
Focus Range	
Camera 1	Approx 1'
Camera 2	Not Applicable
Camera 3	Not Applicable
Image Presentation	
Camera 1	Mirror (reversed)

Camera 2	Not Applicable
Camera 3	Not Applicable
Waterproof	
Camera 1	Yes
Camera 2	Not Applicable
Camera 3	Not Applicable
Operation Temperature	
Camera 1	-47 to 176 Degrees F
Camera 2	Not Applicable
Camera 3	Not Applicable
Exposure Temperature	
Camera 1	-20 to 120 Degrees F
Camera 2	Not Applicable
Camera 3	Not Applicable
Exterior Illumination Range	
Camera 1	1 lux to sunlight
Camera 2	Not Applicable
Camera 3	Not Applicable
Night Vision	
Camera 1	No
Camera 2	Not Applicable
Camera 3	Not Applicable
Switch Day/Night Mode	
Camera 1	Not Applicable
Camera 2	Not Applicable
Camera 3	Not Applicable
VGA or NTSC	
Camera 1	NTSC
Camera 2	Not Applicable
Camera 3	Not Applicable
Horizon	
Camera 1	40% from top
Camera 2	Not Applicable
Camera 3	Not Applicable
Infrared Illuminators	
Camera 1	Not Used
Camera 2	Not Applicable
Camera 3	Not Applicable
MONITOR	
Monitor Mounting Location	
Monitor 1	In the center of the dashboard on the lip
Monitor 2	Not Applicable
Monitor Size	
Monitor 1	5.6"
Monitor 2	Not Applicable
Operation Temperature	
Monitor 1	-4 to 176 Degrees F
Monitor 2	Not Applicable

Exposure Temperature	
Monitor 1	-4 to 176 Degrees F
Monitor 2	Not Applicable
Cab Interior Illumination Operating Range	
Monitor 1	Not Available
Monitor 2	Not Applicable
Min/Max Luminance and Contrast Adjustment	
Monitor 1	Not Available
Monitor 2	Not Applicable
Minimum System Image Resolution	
Monitor 1	380
Monitor 2	Not Applicable
Refresh Rate	
Monitor 1	33 milliseconds
Monitor 2	Not Applicable
Maximum System Image Delay	
Monitor 1	33 milliseconds
Monitor 2	Not Applicable
Response to Activation	
Monitor 1	1 second
Monitor 2	Not Applicable
Number of Views Displayed	
Monitor 1	1
Monitor 2	Not Applicable
Image Aspect Ratio	
Monitor 1	5.6 diagonal inches
Monitor 2	

WINSTED PRODUCTS DUAL CAMERA SYSTEM LEFT/RIGHT SIDE VIEWS (PRODUCT: CCH-P70C1TTX2)

Specifications pertaining to the Winsted Products C/VIS are presented below in Table 50.

Table 50. Winsted Products Dual Camera System

SYSTEM	
Product Components	
Camera 1 (Right Side)	Right Provix Camera, 70 Degree
Camera 2 (Left Side)	Left Provix Camera, 70 Degree
Camera 3 (Rear)	Not Applicable
Monitor 1	LCD 7"
Monitor 2	LCD 7"
Additional Components	Cables, mounts and 24v/12v power supply (regulated)
Manufacturer	Winsted Products
Distributor	www.mobilesafety.net www.rearviewcamera.net www.provix.net
System Activation/Deactivation	System is activated by a key on circuit: operational at all times when vehicle is on
Simultaneous Day/Night Mode	Automatic
Initial Cost	\$815
Industry Tested	On market since 2001
Units Sold	1,000+
CAMERA	
Purpose:	
Camera 1	Right Side View
Camera 2	Left Side View
Camera 3	Not Applicable
Location of Camera Mounting	
Camera 1	Right West Coast Mirror Arm
Camera 2	Left West Coast Mirror Arm
Camera 3	Not Applicable
Angle of Coverage/Field of View	
Camera 1	70 Degrees Horizontal
Camera 2	70 Degrees Horizontal
Camera 3	Not Applicable
Aim Direction	
Camera 1	Outward towards right rear of trailer
Camera 2	Outward towards left rear of trailer
Camera 3	Not Applicable
Focus Range	

Camera 1	Infinite
Camera 2	Infinite
Camera 3	Not Applicable
Image Presentation	
Camera 1	Mirror (reversed)
Camera 2	Mirror (reversed)
Camera 3	Not Applicable
Waterproof	
Camera 1	Yes
Camera 2	Yes
Camera 3	Not Applicable
Operation Temperature	
Camera 1	-22 to 140 Degrees F
Camera 2	-22 to 140 Degrees F
Camera 3	Not Applicable
Exposure Temperature	
Camera 1	-40 to 176 Degrees F
Camera 2	-40 to 176 Degrees F
Camera 3	Not Applicable
Exterior Illumination Range	
Camera 1	10 meters
Camera 2	10 meters
Camera 3	Not Applicable
Night Vision	
Camera 1	IR Illuminators
Camera 2	IR Illuminators
Camera 3	Not Applicable
Switch Day/Night Mode	
Camera 1	Automatic
Camera 2	Automatic
Camera 3	Not Applicable
VGA or NTSC	
Camera 1	NTSC
Camera 2	NTSC
Camera 3	Not Applicable
Horizon	
Camera 1	1cm from top
Camera 2	1cm from top
Camera 3	Not Applicable
Infrared Illuminators	
Camera 1	Integrated into camera

Camera 2	Integrated into camera
Camera 3	Not Applicable
MONITOR	
Monitor Mounting Location	
Monitor 1	Rear view mirror, on top of dashboard in center, in dashboard in center, or along the A Pillars supporting the roof of the cab
Monitor 2	Rear view mirror, on top of dashboard in center, in dashboard in center, or along the A Pillars supporting the roof of the cab
Monitor Size	
Monitor 1	7"
Monitor 2	7"
Operation Temperature	
Monitor 1	-22 to 176 Degrees F
Monitor 2	-22 to 176 Degrees F
Exposure Temperature	
Monitor 1	-40 to 176 Degrees F
Monitor 2	-40 to 176 Degrees F
Cab Interior Illumination Operating Range	
Monitor 1	400 nit
Monitor 2	400 nit
Min/Max Luminance and Contrast Adjustment	
Monitor 1	300:1 Contrast
Monitor 2	300:1 Contrast
Minimum System Image Resolution	
Monitor 1	480 x 234 RGB
Monitor 2	480 x 234 RGB
Refresh Rate	
Monitor 1	NTSC Standard
Monitor 2	NTSC Standard
Maximum System Image Delay	
Monitor 1	NTSC Standard
Monitor 2	NTSC Standard
Response to Activation	
Monitor 1	.5 seconds
Monitor 2	.5 seconds
Number of Views Displayed	
Monitor 1	1
Monitor 2	1
Image Aspect Ratio	
Monitor 1	9:16
Monitor 2	9:16

MOBILE AWARENESS – PRODUCT: VISIONSTAT™ TRIPLE SIDE VIEW CAMERA SYSTEM

Specifications pertaining to the Mobile Awareness Visionstat™ camera system are presented below in Table 51.

Table 51. Mobile Awareness VisionStat™ Camera System

SYSTEM	
Product Components	
Camera 1 (Right Side)	1/3 CCD, 9 Infrared LED Night Vision, IP67 Rated, Side Mount Color Camera (MA-SMS-IR9)
Camera 2 (Left Side)	1/3 CCD, 9 Infrared LED Night Vision, IP67 Rated, Side Mount Color Camera (MA-SMS-IR9)
Camera 3 (Rear)	1/3 CCD, 18 Infrared LED Night Vision, IP67 Rated, Audio Enabled, Color Rear Backing (MA-BCS-IR18)
Monitor 1	7" Color TFT LCD Monitor w/ integrated Control Interface, Audio Capability and Backlit Buttons (MA-LCDS-7.0)
Monitor 2	Not Applicable
Additional Components	21 meter cable, two 10 meter cables, power and interface cable, sun visor, three mounting options
Manufacturer	Mobile Awareness, LTD and its affiliates
Distributor	Mobile Awareness, LLC
System Activation/Deactivation	Cameras are activated when vehicle is placed in reverse (rear camera) or when turn signals are used (left/right cameras)
Simultaneous Day/Night Mode	Automatic - based on available light
Initial Cost	\$795.00
Industry Tested	Not Available
Units Sold	1,000 Wired and Wireless Systems Combined
CAMERA	
Purpose:	
Camera 1	Right Side View
Camera 2	Left Side View
Camera 3	Rear View
Location of Camera Mounting	
Camera 1	Right side of cab
Camera 2	Left side of cab
Camera 3	Rear of cab at top, rear of trailer either on top or on bottom
Angle of Coverage/Field of View	
Camera 1	92 Degrees
Camera 2	92 Degrees

Camera 3	120 Degrees
Aim Direction	
Camera 1	Outward towards right rear of trailer
Camera 2	Outward towards left rear of trailer
Camera 3	Outward towards back of trailer
Focus Range	
Camera 1	Not Available
Camera 2	Not Available
Camera 3	Not Available
Image Presentation	
Camera 1	Standard (un-reversed) but can be mirror (reversed)
Camera 2	Standard (un-reversed) but can be mirror (reversed)
Camera 3	Standard (un-reversed) but can be mirror (reversed)
Waterproof	
Camera 1	Yes
Camera 2	Yes
Camera 3	Yes
Operation Temperature	
Camera 1	-4 to 158 Degrees F
Camera 2	-4 to 158 Degrees F
Camera 3	-4 to 158 Degrees F
Exposure Temperature	
Camera 1	-40 to 185 Degrees F
Camera 2	-40 to 185 Degrees F
Camera 3	-40 to 185 Degrees F
Exterior Illumination Range	
Camera 1	up to 10 meters
Camera 2	up to 10 meters
Camera 3	up to 15 meters
Night Vision	
Camera 1	Yes
Camera 2	Yes
Camera 3	Yes
Switch Day/Night Mode	
Camera 1	Automatic
Camera 2	Automatic
Camera 3	Automatic
VGA or NTSC	
Camera 1	NTSC
Camera 2	NTSC
Camera 3	NTSC

Horizon	
Camera 1	Not Available
Camera 2	Not Available
Camera 3	Not Available
Infrared Illuminators	
Camera 1	Embedded in camera
Camera 2	Embedded in camera
Camera 3	Embedded in camera
MONITOR	
Monitor Mounting Location	
Monitor 1	In the dashboard, on the dashboard, or on the windshield
Monitor 2	Not Applicable
Monitor Size	
Monitor 1	7"
Monitor 2	Not Applicable
Operation Temperature	
Monitor 1	-4 to 158 Degrees F
Monitor 2	Not Applicable
Exposure Temperature	
Monitor 1	-22 to 185 Degrees F
Monitor 2	Not Applicable
Cab Interior Illumination Operating Range	
Monitor 1	0 lux to direct sunlight
Monitor 2	Not Applicable
Min/Max Luminance and Contrast Adjustment	
Monitor 1	Contrast - 400:1 Brightness - 350cd/m ²
Monitor 2	Not Applicable
Minimum System Image Resolution	
Monitor 1	480 x 234 (RGB)
Monitor 2	Not Applicable
Refresh Rate	
Monitor 1	Not Available
Monitor 2	Not Applicable
Maximum System Image Delay	
Monitor 1	Approximately 1 second
Monitor 2	Not Applicable
Response to Activation	
Monitor 1	Approximately 1 second
Monitor 2	Not Applicable
Number of Views Displayed	

Monitor 1	1 unless Adapters are purchased
Monitor 2	Not Applicable
Image Aspect Ratio	
Monitor 1	16:9 or 4:3 (user selectable)
Monitor 2	Not Applicable

ASA ELECTRONICS' VOYAGER SYSTEM

Specifications pertaining to the ASA Electronics' Voyager System are presented below in Table 52.

Table 52. ASA Electronics' Voyager System

SYSTEM	
Product Components	
Camera 1 (Right Side)	Side Body VCMS36RCM
Camera 2 (Left Side)	Side Body VCMS36LCM
Camera 3 (Rear)	Rear Color VCCS150
Monitor 1	7" Multi-Screen Color LCD AOM7694HD
Monitor 2	Not Applicable
Additional Components	VOSBHC2K (Bulkhead Trailer Connect Harness), CEC75 (75 ft Cable), CEC25 x2 (25 ft Cable), CEC34 (34 ft Cable), 31100014 (Adapter Cable), 72704 (Monitor Mount)
Manufacturer	ASA Electronics/Voyager
Distributor	Kingston Distribution (Kingston Mobile)
System Activation/Deactivation	By a reverse trigger or manual push button
Simultaneous Day/Night Mode	Yes
Initial Cost	\$1,200.00
Industry Tested	Yes, in many commercial markets
Units Sold	Several Hundred
CAMERA	
Purpose:	
Camera 1	Right Side View
Camera 2	Left Side View
Camera 3	Rear View
Location of Camera Mounting	
Camera 1	Front right side of cab
Camera 2	Front left Side of cab
Camera 3	Rear of trailer either on top or bottom
Angle of Coverage/Field of View	
Camera 1	118° W x 95° H x 75° V
Camera 2	118° W x 95° H x 75° V

Camera 3	150° Wide x 120° High x 90° Vertical
Aim Direction	
Camera 1	On right side pointing back, angled outward
Camera 2	On left side pointing back, angled outward
Camera 3	Outward towards back of trailer
Focus Range	
Camera 1	30-35 feet
Camera 2	30-35 feet
Camera 3	30-35 feet
Image Presentation	
Camera 1	Reversed (mirror)
Camera 2	Reversed (mirror)
Camera 3	Mirror Default (Selectable)
Waterproof	
Camera 1	Yes
Camera 2	Yes
Camera 3	Yes
Operation Temperature	
Camera 1	-40 to 185 Degrees F
Camera 2	-40 to 185 Degrees F
Camera 3	-4 to 149 Degrees F
Exposure Temperature	
Camera 1	-40 to 185 Degrees F
Camera 2	-40 to 185 Degrees F
Camera 3	-22 to 158 Degrees F
Exterior Illumination Range	
Camera 1	Excellent low light & high bright performance
Camera 2	Excellent low light & high bright performance
Camera 3	Excellent low light & high bright performance
Night Vision	
Camera 1	Yes
Camera 2	Yes
Camera 3	Yes
Switch Day/Night Mode	
Camera 1	Automatic
Camera 2	Automatic
Camera 3	Automatic
VGA or NTSC	
Camera 1	NTSC
Camera 2	NTSC
Camera 3	NTSC

Horizon	
Camera 1	Top of image
Camera 2	Top of image
Camera 3	Top of image
Infrared Illuminators	
Camera 1	Yes, attached to camera
Camera 2	Yes, attached to camera
Camera 3	Yes, attached to camera
MONITOR	
Monitor Mounting Location	
Monitor 1	At the A-pillar on the driver's side, near the rearview mirror, on top of or in the dash in the center
Monitor 2	Not Applicable
Monitor Size	
Monitor 1	7"
Monitor 2	Not Applicable
Operation Temperature	
Monitor 1	-4 to 149 Degrees F
Monitor 2	Not Applicable
Exposure Temperature	
Monitor 1	-40 to 176 Degrees F
Monitor 2	Not Applicable
Cab Interior Illumination Operating Range	
Monitor 1	500 nit
Monitor 2	Not Applicable
Min/Max Luminance and Contrast Adjustment	
Monitor 1	0 to 500 nit luminance and 300:1 contrast ratio
Monitor 2	Not Applicable
Minimum System Image Resolution	
Monitor 1	336,960 pixels
Monitor 2	Not Applicable
Refresh Rate	
Monitor 1	No Delay
Monitor 2	Not Applicable
Maximum System Image Delay	
Monitor 1	No Delay
Monitor 2	Not Applicable
Response to Activation	
Monitor 1	Instant
Monitor 2	Not Applicable
Number of Views Displayed	

Monitor 1	Up to 4
Monitor 2	Not Applicable
Image Aspect Ratio	
Monitor 1	16:09
Monitor 2	Not Applicable

APPENDIX G. STATIC EVALUATION INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Preliminary Evaluation of Indirect Visibility Systems

Investigators: Greg Fitch, Myra Blanco, Jeanne Rice, Amy Wharton

I. The purpose of this Research/Project

The Virginia Tech Transportation Institute (VTTI) is currently developing a roadworthy Camera/Video Imaging System (C/VIS) for heavy trucks that assists drivers in detecting objects located in their blind spots. Both VTTI's C/VIS, as well as a commercially available C/VIS, will be evaluated through an eight-month long Technology Field Demonstration (TFD). However, prior to commencing the TFD, the researchers would like to determine the two C/VIS's ability to support users in detecting and recognizing objects located around a heavy vehicle. The results from this study will be compared to the object detection and recognition results obtained from a previous static evaluation of an enhanced C/VIS performed by VTTI under a National Highway Traffic Safety Administration (NHTSA) Task Order, titled "Enhanced Camera/Video Imaging Systems (E-C/VISs)." The findings will be used to determine how well the roadworthy C/VIS performs compared to the previously tested E-C/VIS prototype.

II. Procedures

During the course of this experiment you will be asked to perform the following tasks:

1) Read this Informed Consent Form and sign it if you agree to participate. 2) Complete a vision test. 3) Climb into the driver's seat of the heavy vehicle. This is similar to climbing up a five foot ladder. An experimenter will stand behind you for extra support. 4) Sit in the driver seat of a stationary heavy vehicle and look for an object around the heavy vehicle using the windows, mirrors, and C/VIS monitors. 5) Answer three questions posed by the experimenter for each object. 6) A video recording of your face will be made throughout the experiment.

It is important for you to understand that we are not evaluating you or your performance in any way. You are helping us evaluate new technology. Any tasks you perform, or opinions you have will only help us do a better job of designing the system. Therefore, we ask that you perform to the best of your abilities. The information and feedback that you provide is very important to this project. The experiment will last about 1 to 1 ½ hours.

III. Risks

There are risks or discomforts to which you may be exposed to in volunteering for this research. They include the following:

- 1) The risk of falling while climbing up to the driver seat.
- 2) The risk of tripping while walking to the test vehicle at night.
- 3) Possible fatigue due to the length of the experiment

The following precautions will be taken to ensure minimal risk to you:

- 1) You may take breaks or decide not to participate at any time
- 2) The experimenter will show you the safe way to climb into the heavy vehicle. Participants must maintain three points of contact with the vehicle at all times during ascent/descent (i.e., two hands and one foot, or two feet and one hand).
- 3) If you participate during the nighttime session, the experimenter will carry a flashlight to help light up the walkway and reduce the risk of tripping.

You are participating in this project in the course of your normal job. Should you become injured while participating in this project, you will be afforded the same protection and coverage from worker's compensation as is typically the case while you are on the job.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study may contribute to the improvement of in-vehicle systems.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). At no time will the researchers release data identifiable to an individual to anyone other than VTTI staff working on the project without your written consent. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation

You will complete the study as part of your job duties, thus you will be compensated by regular pay. A study fund number will be provided so that your time may be charged to this project.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of the page.

IX. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1) To follow the experimental procedures as well as you can. 2) To inform the experimenter if you have difficulties of any type. 3) To provide feedback to the experimenter based on how well you can see the objects placed around the heavy vehicle.

X. Participant's Permission

I have read and understood the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

Should I have any questions about this research or its conduct, I may contact:
Greg Fitch 231-1500 or Myra Blanco 231-1500

If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore, Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects, Telephone/email : (540) 231-4991/ moored@vt.edu; Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

APPENDIX H. STATIC EVALUATION QUESTIONS

Subject # _____

Date _____

1. Can you see the object?

YES

NO

2. If yes, what is it?

3. On a scale of 1 to 7, where 1 is extremely unclear and 7 is extremely clear, how would you rate the clarity of the object?

1	2	3	4	5	6	7
Extremely Unclear	Very Unclear	Unclear	Neutral	Clear	Very Clear	Extremely Clear

APPENDIX I. PRE-STUDY QUESTIONNAIRES

Demographic Questionnaire

1. What is your age?: _____ years
2. Gender (Check one): ☐ Male ☐ Female
3. Height: _____ feet _____ inches
4. Weight: _____ lbs
5. Build (check one): ☐ Small frame ☐ Medium frame ☐ Large frame
6. Do you wear glasses or contact lenses? ☐ No ☐ Yes
IF YES:
 - a. Do you wear contact lenses? (Check one) ☐ No ☐ Yes
 - b. Do you wear glasses at *night* when driving? ☐ No ☐ Yes
7. Which of the following groups is most representative of your background? (Check one)

☐ African American	☐ Asian or Pacific Islander	☐ Caucasian
☐ Hispanic	☐ Native American	☐ Caribbean
8. Is English your language of preference for: Reading? (check one) ☐ No ☐ Yes
Speaking? (check one) ☐ No ☐ Yes
9. How long have you been driving commercial vehicles? _____ years _____ months
10. How many hours a week do you drive? _____
11. How long is your typical shift? _____
12. From what time to what time does your typical shift last? Start: _____ End: _____
13. How many miles do you typically travel in a shift? _____
14. Do you typically travel alone? _____
15. Have you used any of the following in-vehicle technologies? Check all that apply.

☐ Qualcomm	☐ EOBR/Electronic Log Book
☐ Front Object Detection System (i.e. Vehicle On-Board Radar)	☐ Lane Departure Warning System
☐ Blind Spot Warning System	☐ On-Board Monitoring System
☐ Cell Phone (Voice/Texting)	☐ GPS/Route Navigation

O Other in-vehicle technology (please list): _____

16. How long have you been working for this company? _____ years _____ months

17. Were you working as a truck driver for your previous employer? ☐ No ☐ Yes

IF YES:

a. How long did you work for your previous employer? _____ years _____ months

18. Type of license and endorsements held: License: _____ Endorsements: _____

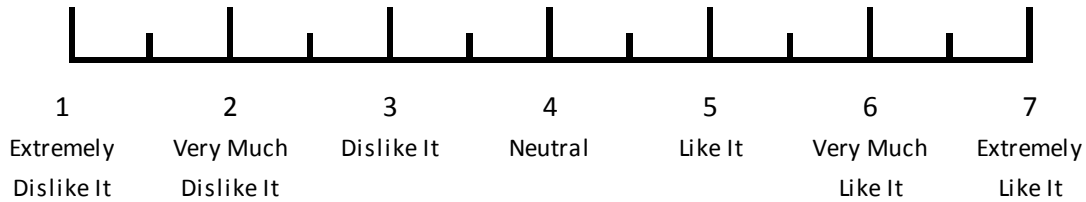
Pre-Study Questionnaire

Background

Camera/Video Imaging Systems (C/VISs) display video captured from cameras mounted on the truck to drivers using displays mounted inside the truck cabin. C/VISs may allow drivers to see objects not ordinarily visible by a typical mirror configuration.

1) How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?

Response: _____



2) I think a C/VIS is...(Please place an X on each line below that best matches your response)

useful | | | | | | | useless

pleasant | | | | | | | unpleasant

bad | | | | | | | good

nice | | | | | | | annoying

effective | | | | | | | superfluous

irritating | | | | | | | likeable

assisting | | | | | | | worthless

undesirable | | | | | | | desirable

raising alertness | | | | | | | sleep-inducing

3) What are two things you think you will like about the C/VIS?

1. _____

2. _____

4) What are two things you think you will dislike about the C/VIS?

1. _____

2. _____

APPENDIX J. DRIVING QUESTIONNAIRE

Instructions

Please answer the following questions by writing a number from the scale below them that best matches your response. Please write your answer on the line following the word “Response” as shown below.

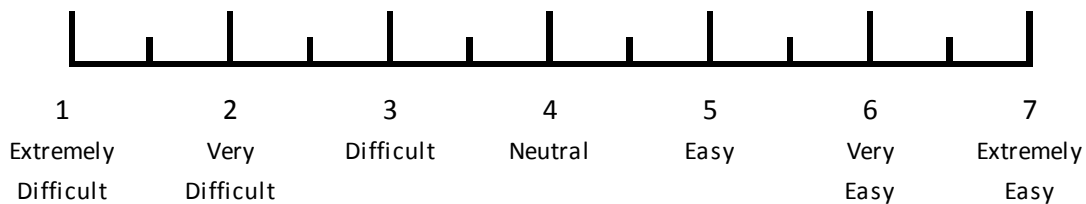
Response: 4

Half numbers such as 4.5 are allowed.

Day Time Driving

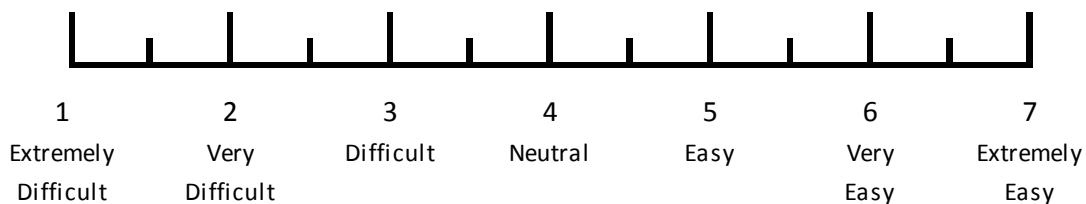
- 1. During the day, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind spots (no-zone) area.**

Response: _____



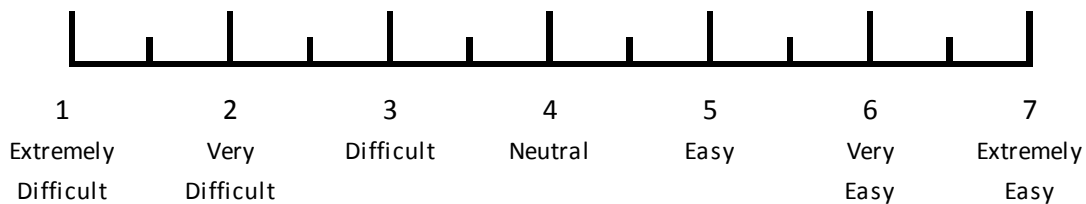
- 2. During the day, how difficult is it to determine whether there is clearance between the back edge of the trailer and the front of a vehicle traveling beside the truck?**

Response: _____



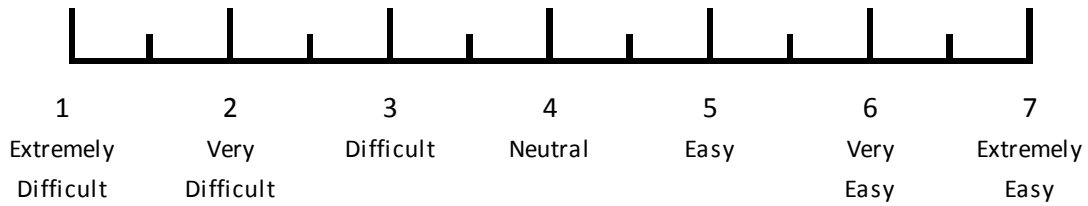
- 3. During the day, how difficult is it to tell what kind of vehicle is traveling in the lane beside me?**

Response: _____



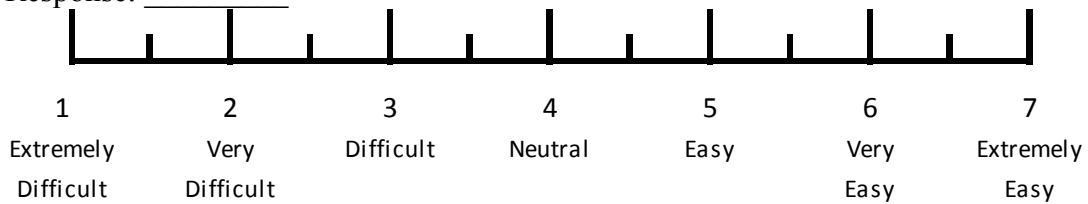
4. During the day, how difficult is it to tell how fast a vehicle in the lane beside me is approaching me?

Response: _____



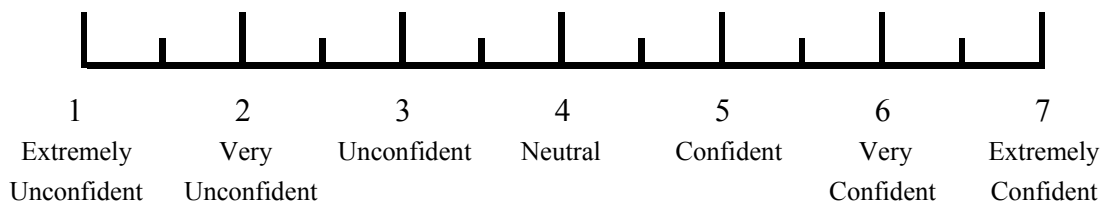
5. During the day, how difficult is it to merge into traffic?

Response: _____



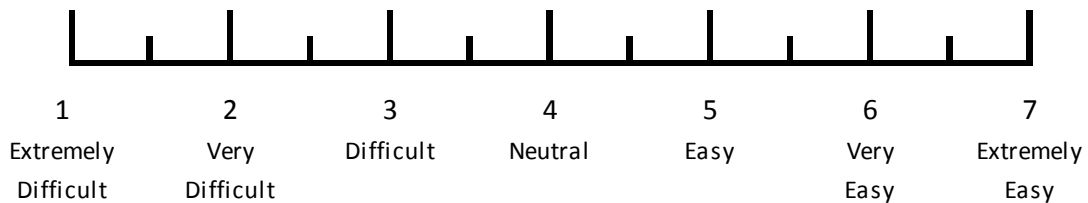
6. During the day, how confident are you that you will not hit an adjacent vehicle when merging into traffic?

Response: _____



7. During the day, how difficult is it to back up to an object?

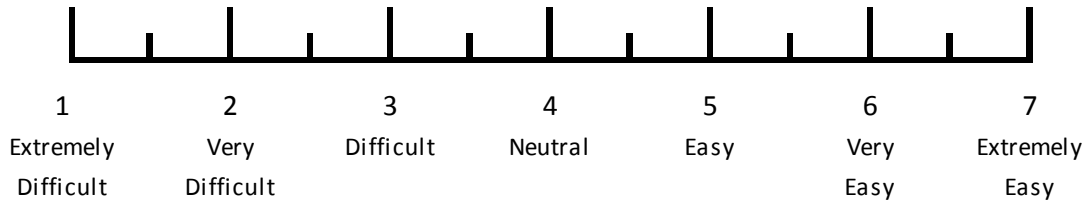
Response: _____



Day Time Inclement Weather Driving

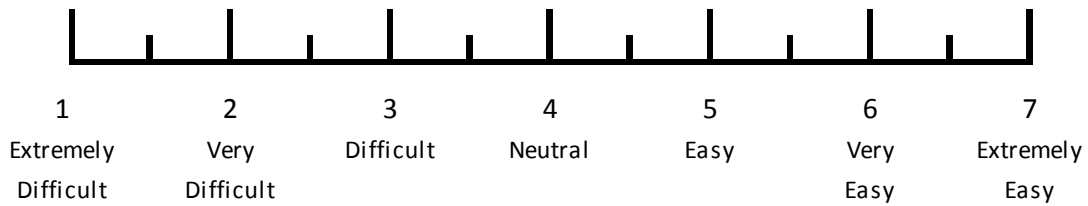
8. During the day and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind spots (no-zone) area.

Response: _____



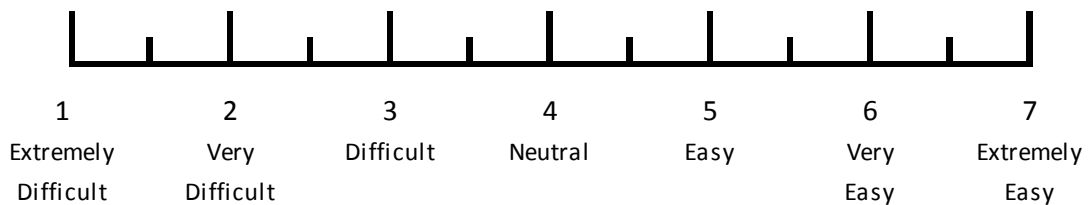
9. During the day and when there is inclement weather, how difficult is it to determine whether there is clearance between the back edge of the trailer and the front of a vehicle traveling beside the truck?

Response: _____



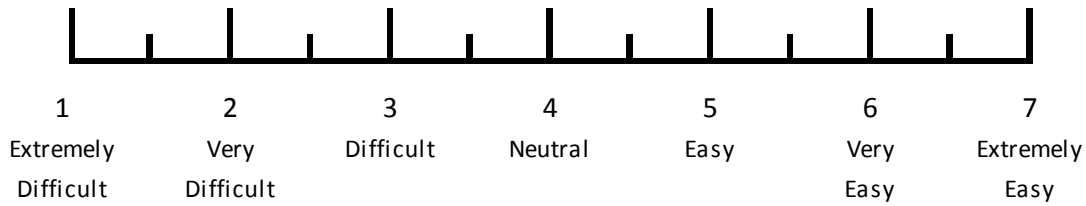
10. During the day and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside me?

Response: _____



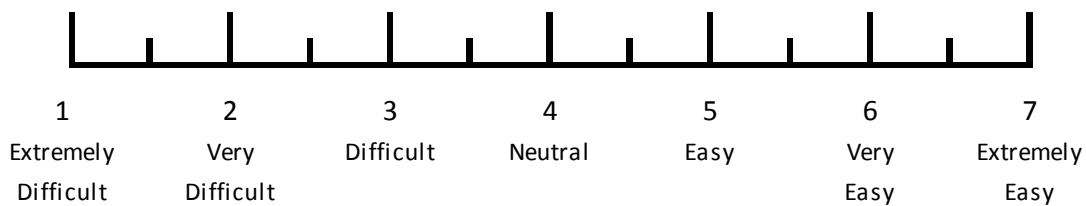
11. During the day and when there is inclement weather, how difficult is it to tell how fast a vehicle in the lane beside me is approaching me?

Response: _____



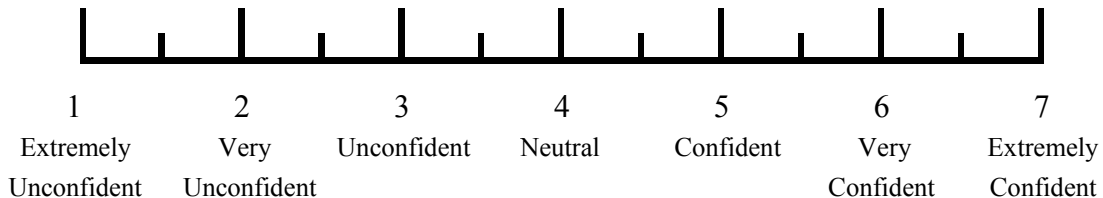
12. During the day and when there is inclement weather, how difficult is it to merge into traffic?

Response: _____



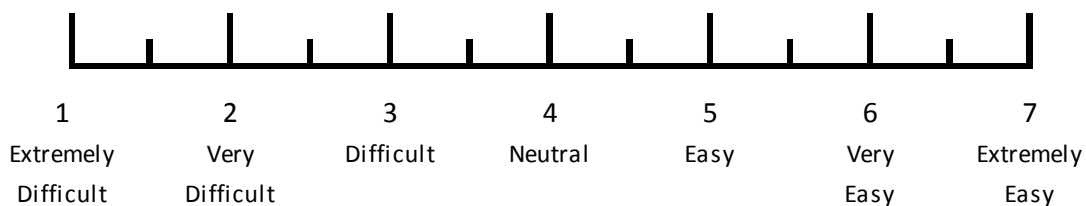
13. During the day and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic?

Response: _____



14. During the day and when there is inclement weather, how difficult is it to back up to an object?

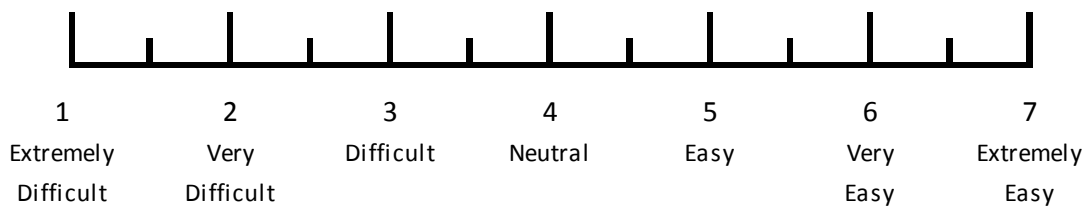
Response: _____



Night Time Driving

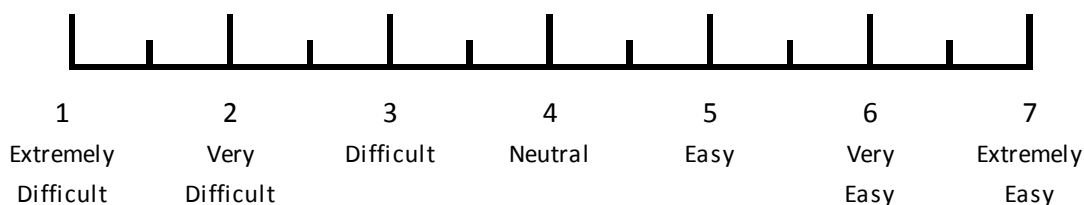
15. At night, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind spots (no-zone) area.

Response: _____



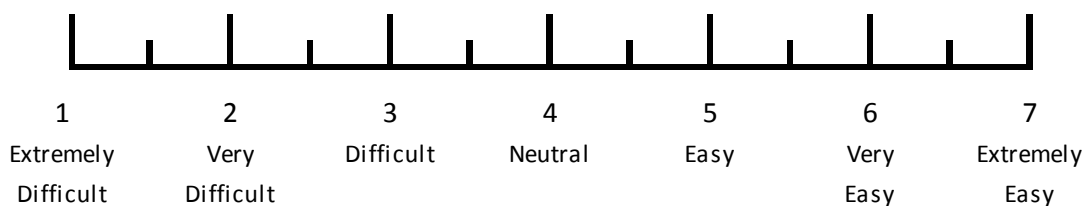
16. At night, how difficult is it to determine whether there is clearance between the back edge of the trailer and the front of a vehicle traveling beside the truck?

Response: _____



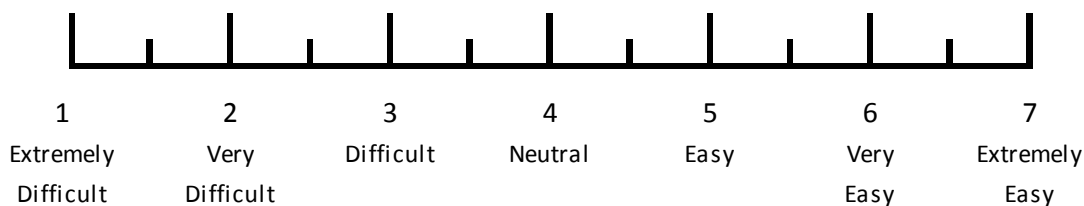
17. At night, how difficult is it to tell what kind of vehicle is traveling in the lane beside me?

Response: _____



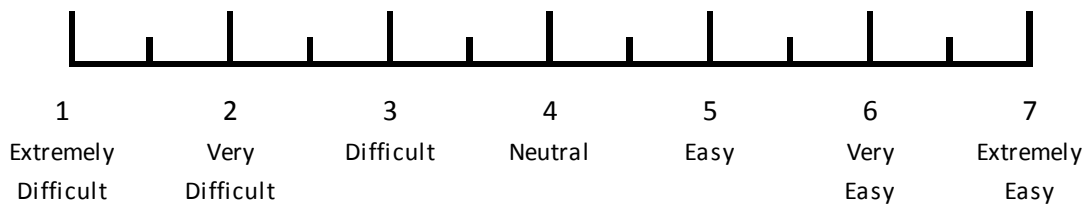
18. At night, how difficult is it to tell how fast a vehicle in the lane beside me is approaching me?

Response: _____



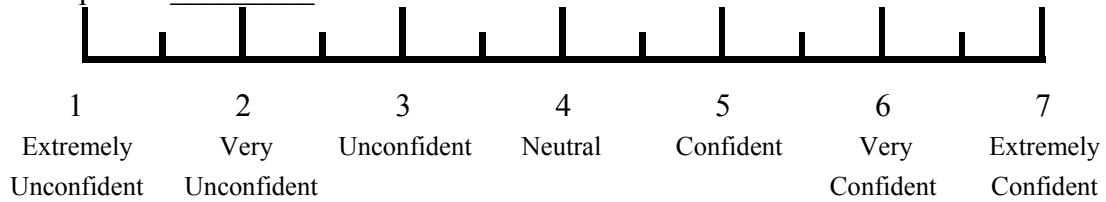
19. At night, how difficult is it to merge into traffic?

Response: _____



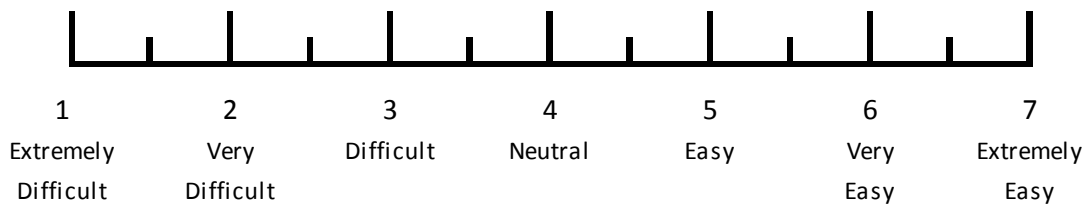
20. At night, how confident are you that you will not hit an adjacent vehicle when merging into traffic?

Response: _____



21. At night, how difficult is it to back up to an object?

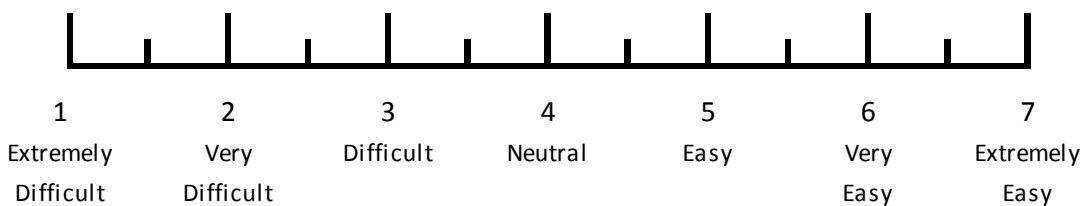
Response: _____



Night Time Inclement Weather Driving

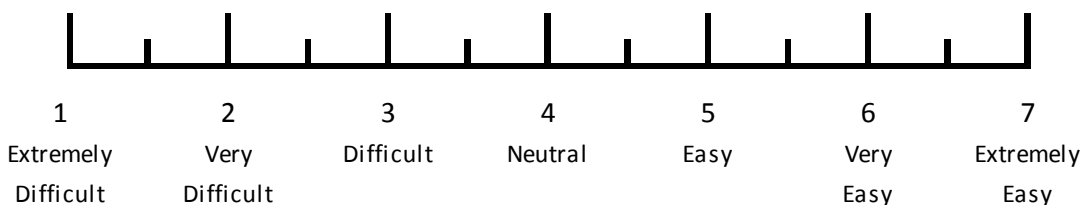
- 22. During the night and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind spots (no-zone) area.**

Response: _____



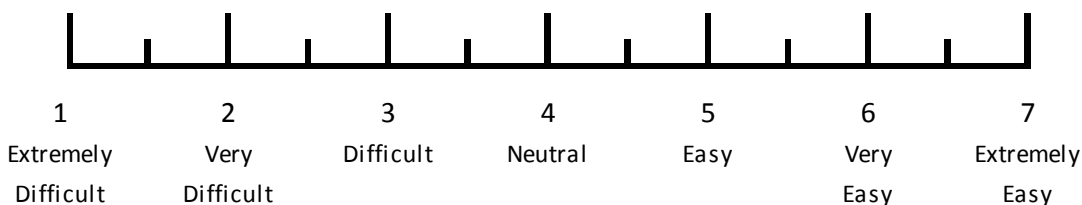
- 23. During the night and when there is inclement weather, how difficult is it to determine whether there is clearance between the back edge of the trailer and the front of a vehicle traveling beside the truck?**

Response: _____



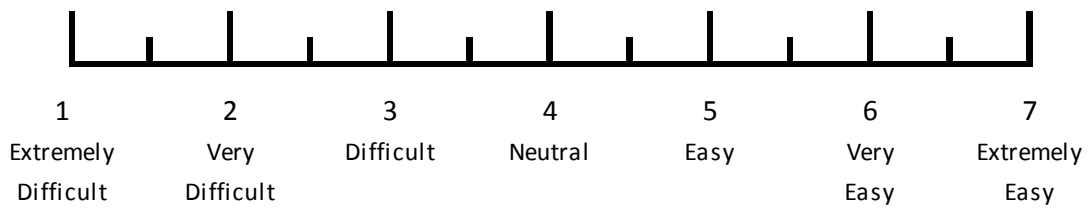
- 24. During the night and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside me?**

Response: _____



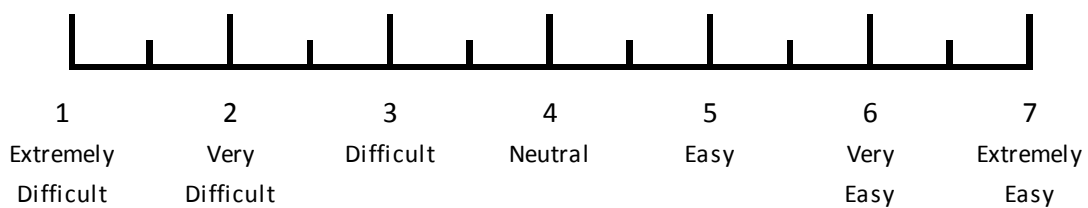
25. During the night and when there is inclement weather, how difficult is it to tell how fast a vehicle in the lane beside me is approaching me?

Response: _____



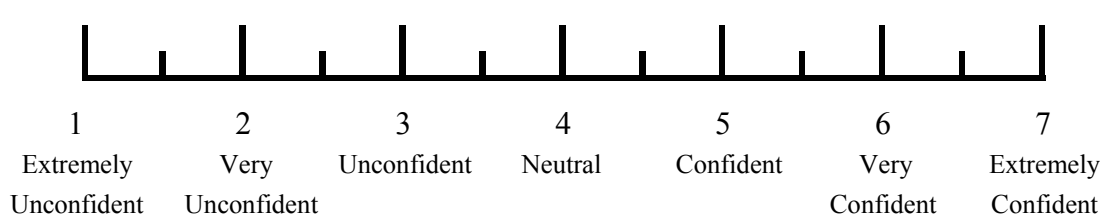
26. At night and when there is inclement weather, how difficult is it to merge into traffic?

Response: _____



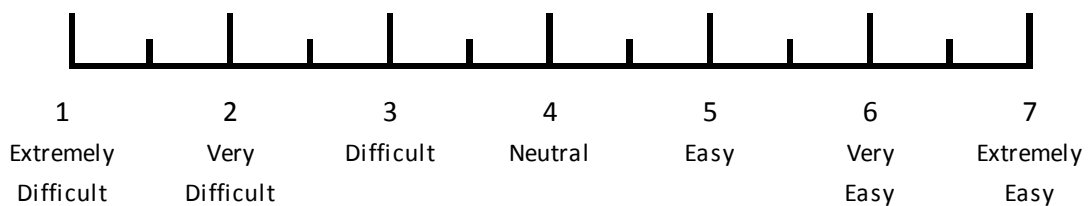
27. At night and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic?

Response: _____

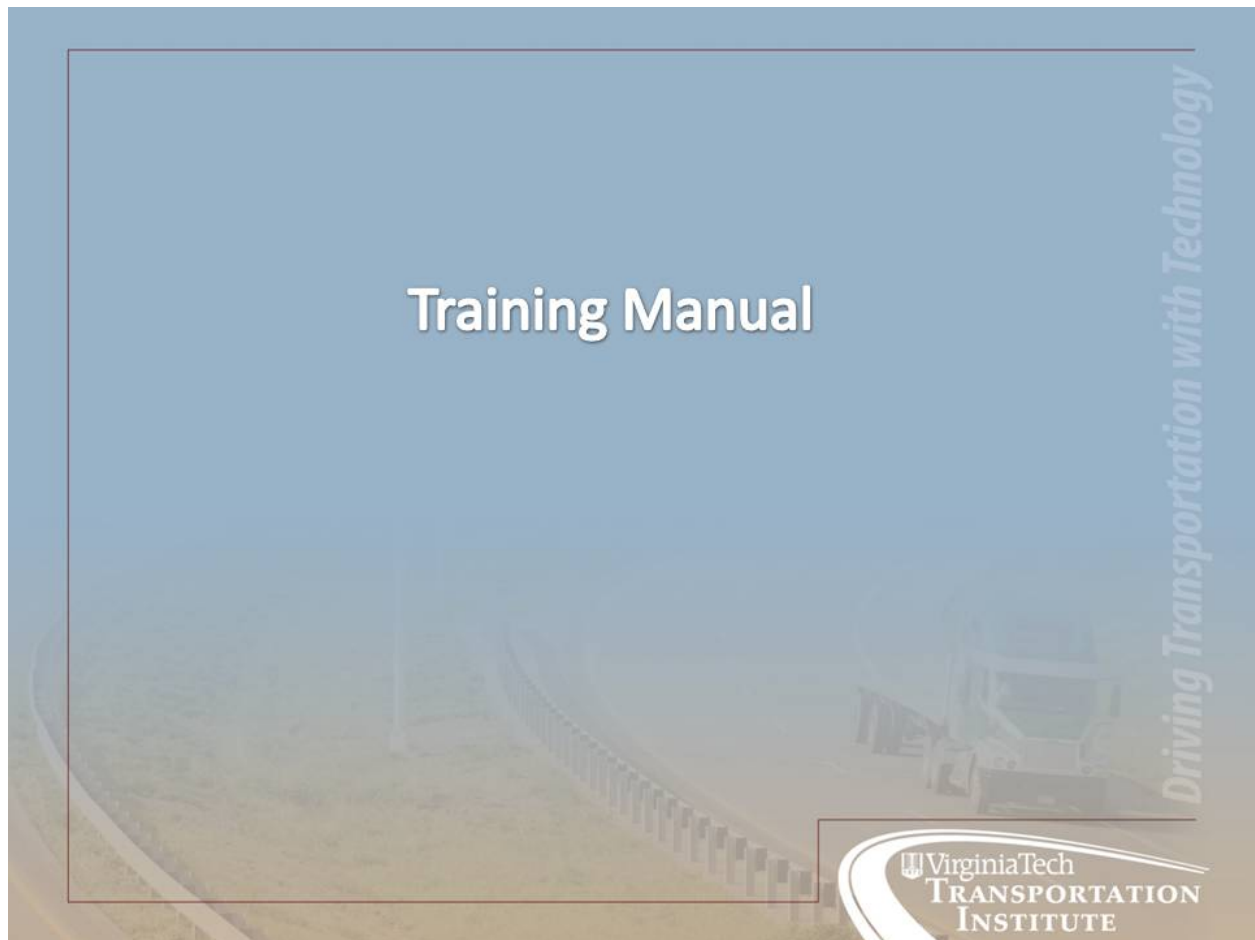


28. At night and when there is inclement weather, how difficult is it to back up to an object?

Response: _____



APPENDIX K. A-C/VIS TRAINING MANUAL



Introduction

- This Camera/Video Imaging System (C/VIS) helps you see vehicles in the “No-Zone” around your truck
- It is to be used in addition to your existing mirrors

3 Cameras Mounted on Truck

- 3 cameras show “No-Zones” behind trailer
- Camera mounted on:
 - Left fender pointing back at adjacent lane
 - Right fender pointing back at adjacent lane
 - Top rear of trailer pointing down
- Cameras are weatherproof



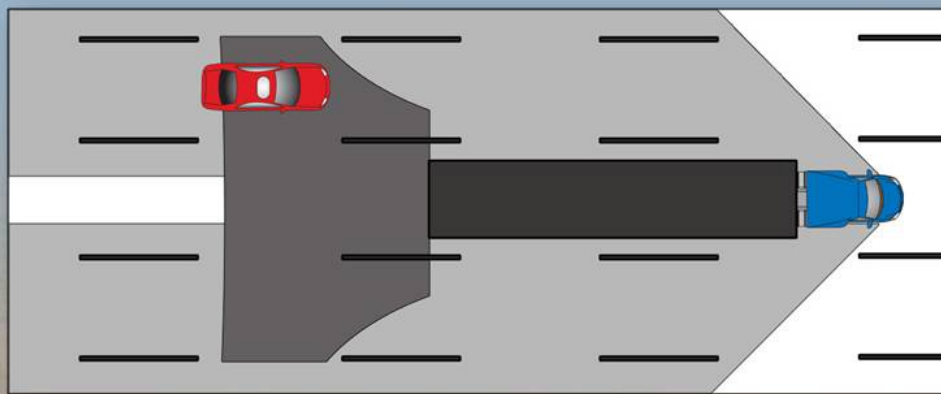
3 Monitors Mounted In Cab

- One at top of left A-Pillar
- One at top center of windshield
- One at top of right A-Pillar



C/VIS Coverage

- Light grey shading shows area recorded by left and right fender cameras (shown in left and right monitors)
- Dark grey shading shows area recorded by center camera (shown in center monitor)



Night Vision

- Infrared light illuminators mounted on trailer give you night vision of objects around trailer
 - 4 illuminators on left side
 - 4 illuminators on right side
 - Turns on automatically when dark
 - Each one has approximately an 8-ft range



Driver Vehicle Interface

- Driver Vehicle Interface (DVI) integrated with left monitor



Day/Night Modes



- Day/Night Mode
 - Press to toggle between day and night mode
- Day Mode:
 - Color Video
 - Bright Screen
- Night Mode:
 - Black & White Video
 - Dim Screen
 - Helps keep eyes adapted to darkness

Monitor Brightness



- Monitor Brightness
- Press “-” button to decrease brightness
 - Keep dim at night
- Press “+” button to increase brightness
- To save your settings, you must wait for the on-screen display to disappear.

Object Detection



- Object Detection Feature
- Traces white lines around objects
- Use to make objects easier to see

Object Detection Example



11

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Driving Transportation with Technology

Object Detection Level



- Object Detection Level
- Press “-” button to decrease lines traced around objects
- Press “+” button to increase lines traced around objects
- To save your settings, you must wait for the on-screen display to disappear.

How to Use Center Monitor

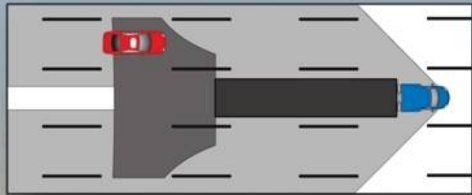


- Orange line shows 30 ft back
 - Change lanes with caution if vehicle at top of monitor
- Red line shows 20 ft back
 - Do not change lanes if vehicle in middle of monitor
- Red line shows 0 ft back
 - Edge of trailer
 - Do not change lanes if vehicle overlaps trailer

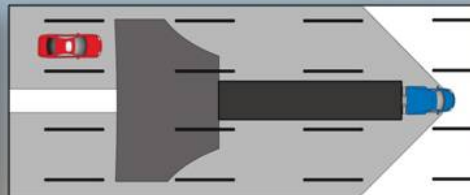
How to Use Center Monitor

- Vehicles seen in center monitor are closer than they appear
- Advised to only change lanes when vehicles can just be seen at the top of the monitor, or are out of the picture altogether

Vehicle Close By



Vehicle Not Close By



Maintenance

- Keep C/VIS camera lens clean of debris
- Spray Rainex once every week (provided by VTTI)
- Use towel to wipe down if covered by rain/mud to improve visibility

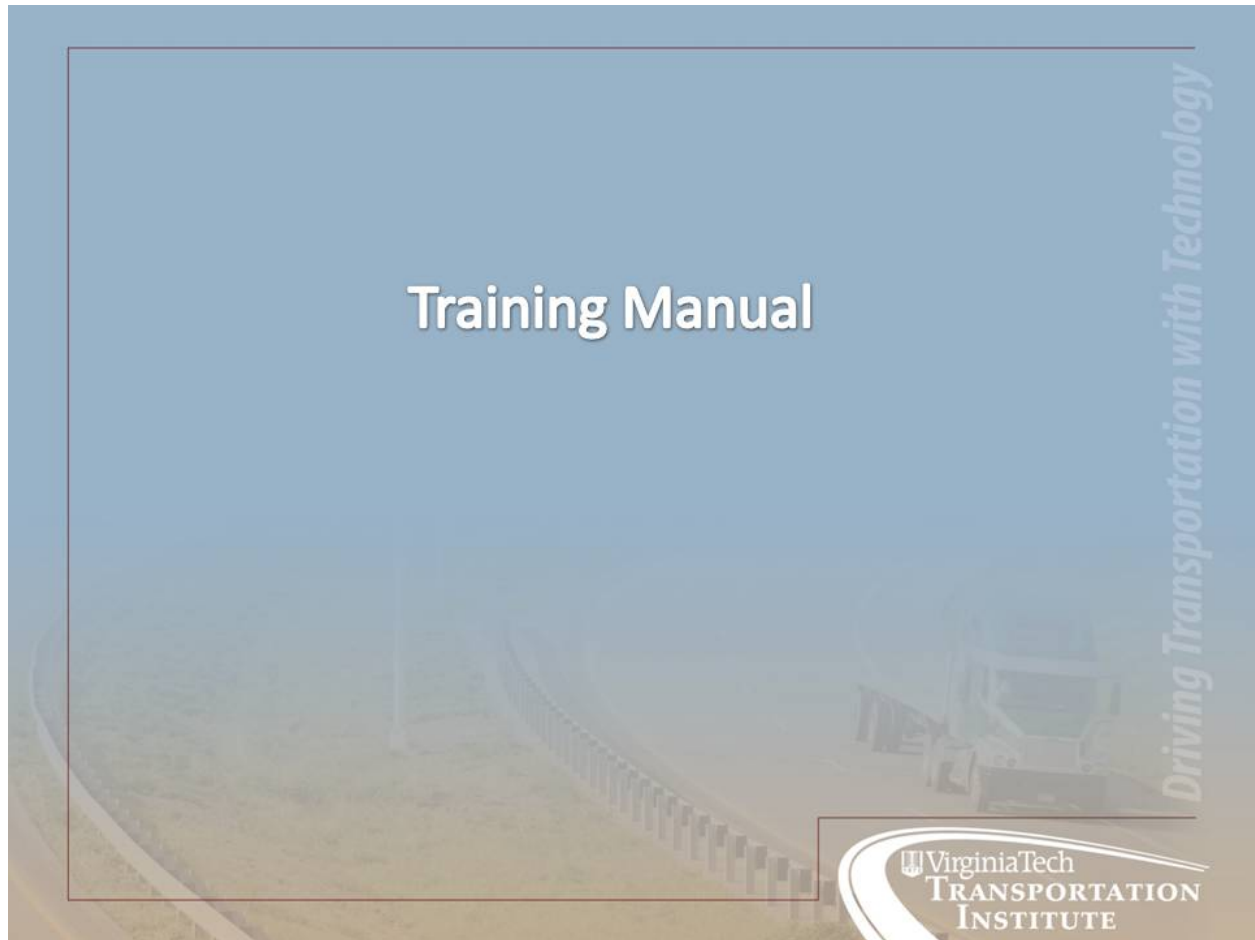


Questions



Driving Transportation with Technology

APPENDIX L. COMMERCIAL C/VIS TRAINING MANUAL



Introduction

- This Camera/Video Imaging System (C/VIS) helps you see vehicles in the “No-Zone” around your truck
- It is to be used in addition to your existing mirrors

2 Cameras Mounted on Truck

- 2 cameras show “No-Zones” beside trailer
- Camera mounted on:
 - Left fender pointing back at adjacent lane
 - Right fender pointing back at adjacent lane
- Cameras are weatherproof



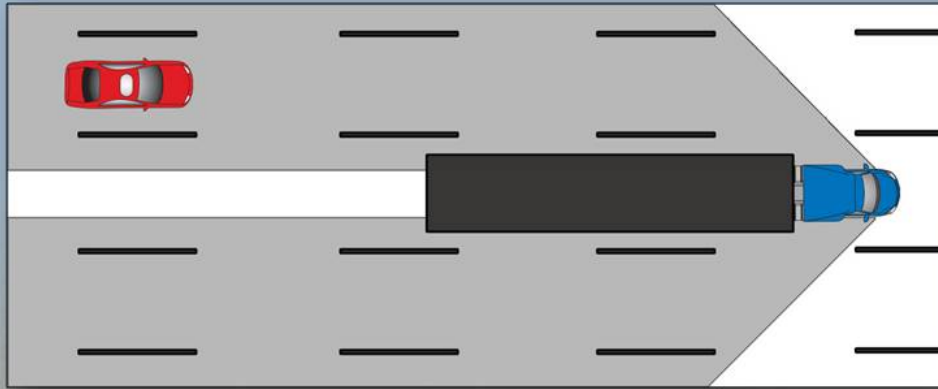
2 Monitors Mounted In Cab

- One on right side of dash
- One on left side of dash

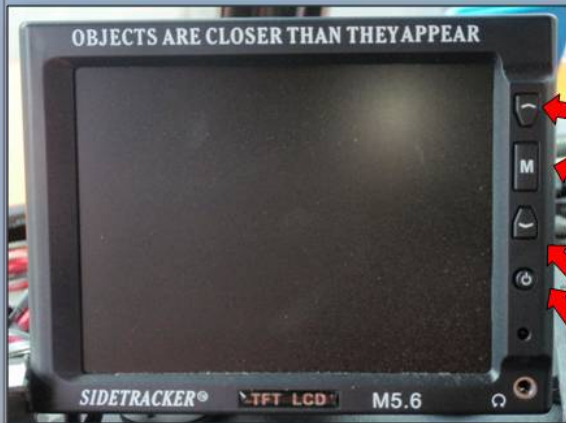


C/VIS Coverage

- Light grey shading shows area recorded by left and right fender cameras (shown in left and right monitors)



Adjusting Monitor



- Up
- Mode
 - Brightness
 - Color
 - Contrast
 - Tint
- Down
- Power

Adjusting Brightness



- Press "M" until "BRT" appears on display
 - Use "Up" and "Down" keys to adjust Brightness
- To help dim monitor, also use Contrast (CON)
 - Press "M" again until CON appears
 - Use "Up" and "Down" keys to adjust Contrast
- Please make sure display is dim at night to prevent distraction

Adjusting Color



- Press "M" until "COL" appears on display
 - Use "Up" and "Down" keys to adjust Color
- "Up" all the way produces a full color image
- "Down" all the way produces a black and white image

Maintenance

- Keep C/VIS camera lens clean of debris
- Spray Rainex once every week (provided by VTTI)
- Use towel to wipe down if covered by rain/mud to improve visibility



Questions



Driving Transportation with Technology

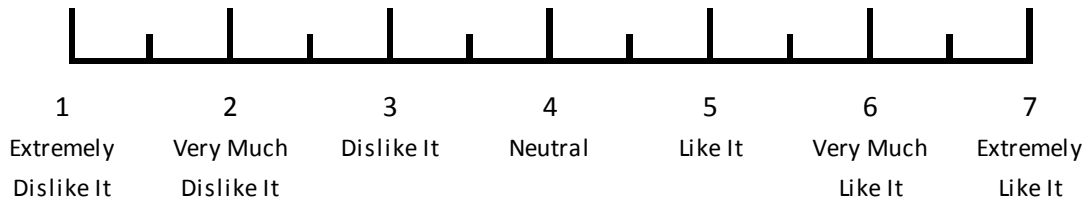
10

Virginia Tech Transportation Institute

APPENDIX M. A-C/VIS QUESTIONNAIRE

- 1) How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?**

Response: _____



- 2) I think the C/VIS is... (Please place an X on each line below that best matches your response)**

useful | | | | | | | useless

pleasant | | | | | | | unpleasant

bad | | | | | | | good

nice | | | | | | | annoying

effective | | | | | | | superfluous

irritating | | | | | | | likeable

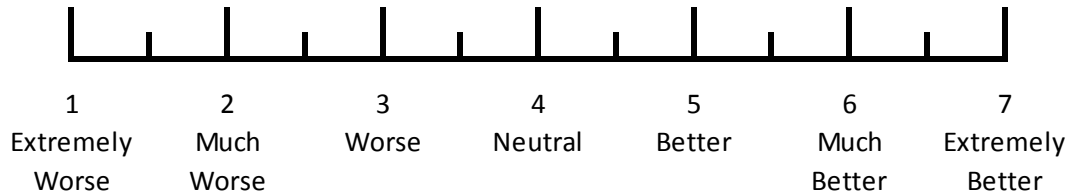
assisting | | | | | | | worthless

undesirable | | | | | | | desirable

raising alertness | | | | | | | sleep-inducing

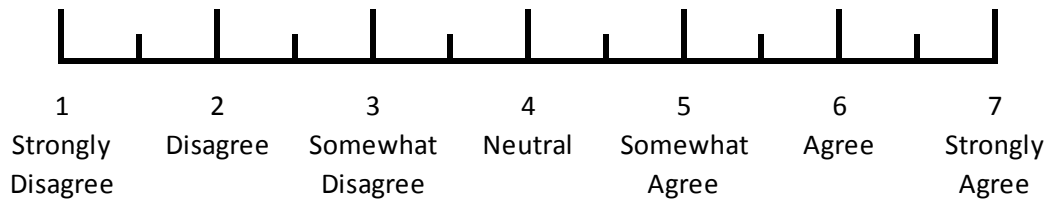
- 3) **How does your driving performance with a C/VIS compare to your driving performance without a CVIS?**

Response: _____



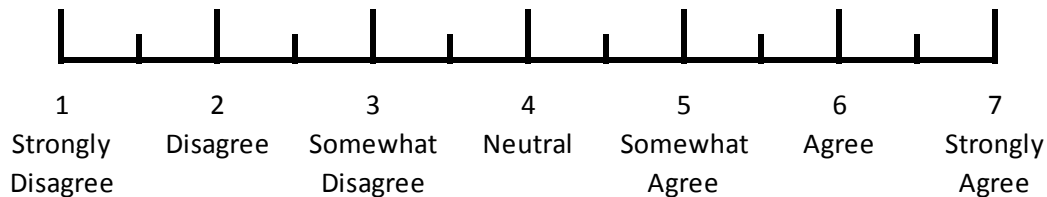
- 4) **How much do you agree with the statement: “I would like to have this C/VIS in my truck”**

Response: _____



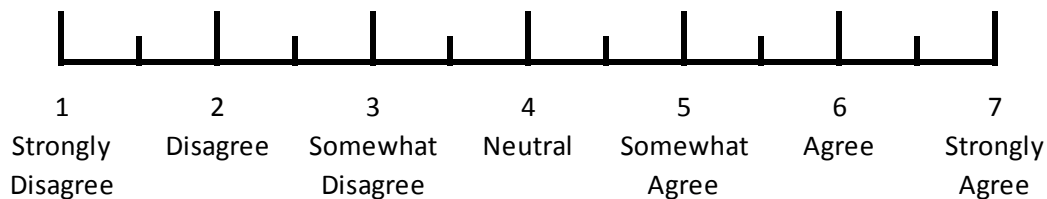
- 5) **How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”**

Response: _____



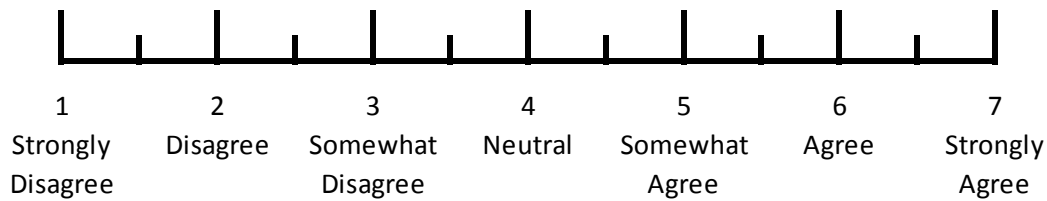
- 6) **How much do you agree with the statement: “This C/VIS is easy to use.”**

Response: _____



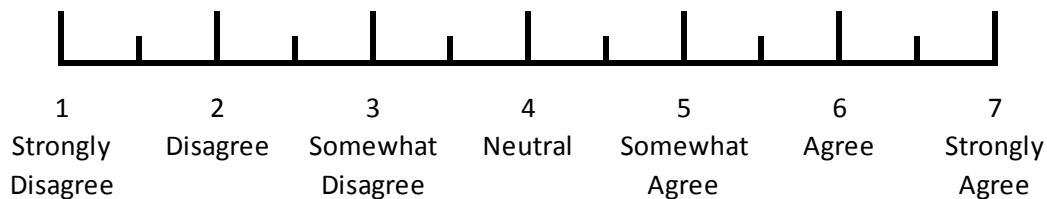
7) How much do you agree with the statement: “The object detection feature is useful.”

Response: _____



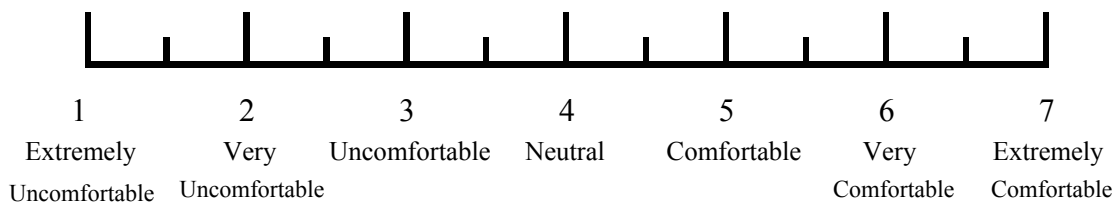
8) How much do you agree with the statement: “I know how to use all the features the system offers”?

Response: _____



9) How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?

Response: _____



10) By how much does the lighting from the monitors reduce your ability to discern details in the road ahead of you (for example, ability to read the license plate characters)?

Response: _____



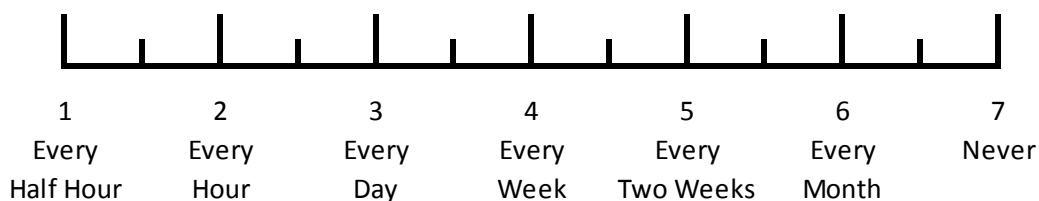
11) How much does the monitor block your view of the road?

Response: _____



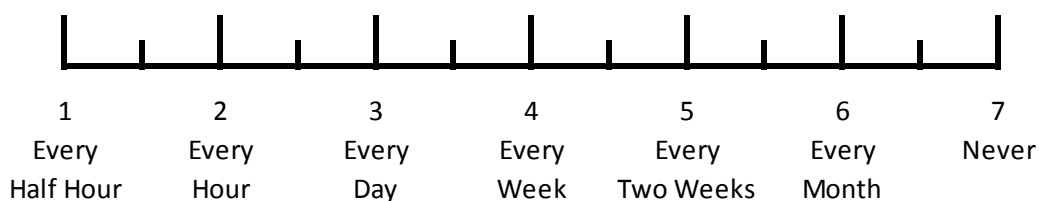
12) When it's clear outside, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



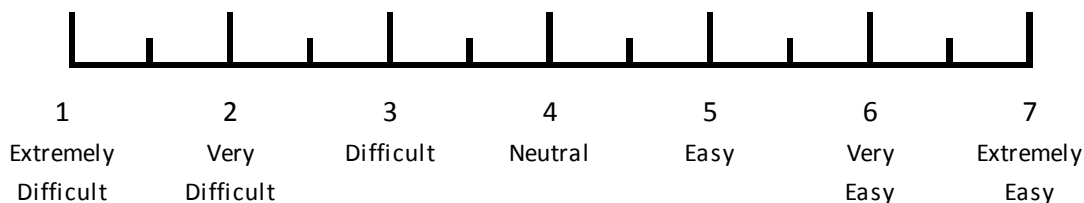
13) When it's raining, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



14) How easy is it to clean the camera lens?

Response: _____



15) What are your top two ***most favorite*** features of the system, and why?

1. _____

2. _____

16) What are your top two ***least favorite*** features of the system?

1. _____

2. _____

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

1. _____

2. _____

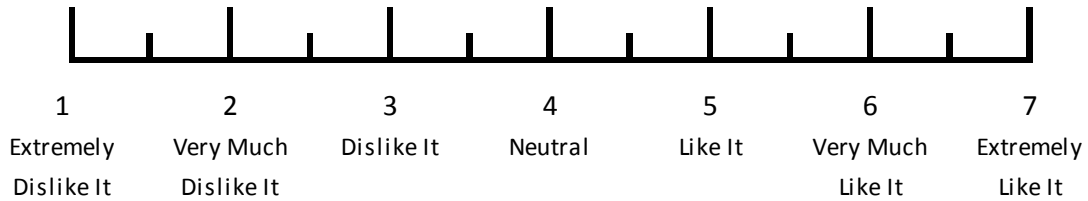
3. _____

Thank you for your participation this evening!

APPENDIX N. SIDETRACKER QUESTIONNAIRE

1) How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?

Response: _____



2) I think the C/VIS is... (Please place a circle on each line below that best matches your response)

useful | | | | | | | useless

pleasant | | | | | | | unpleasant

bad | | | | | | | good

nice | | | | | | | annoying

effective | | | | | | | superfluous

irritating | | | | | | | likeable

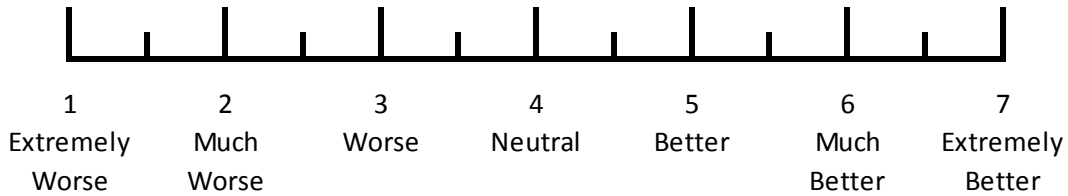
assisting | | | | | | | worthless

undesirable | | | | | | | desirable

raising alertness | | | | | | | sleep-inducing

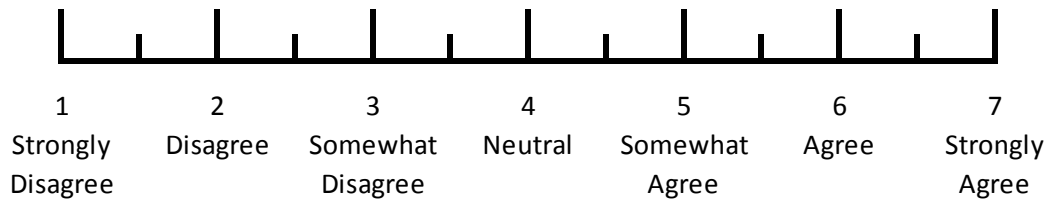
- 3) **How does your driving performance with a C/VIS compare to your driving performance without a CVIS?**

Response: _____



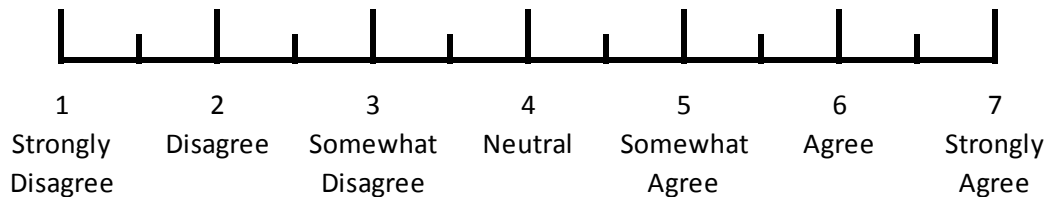
- 4) **How much do you agree with the statement: “I would like to have this C/VIS in my truck”**

Response: _____



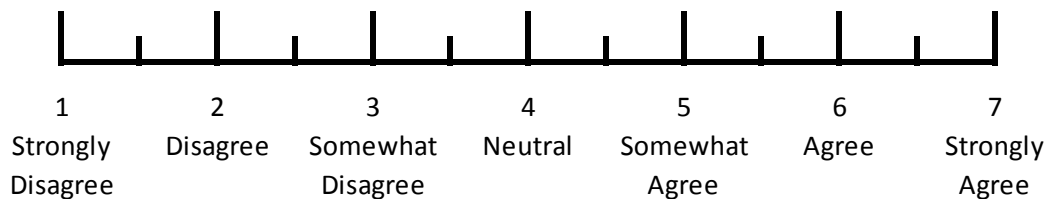
- 5) **How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”**

Response: _____



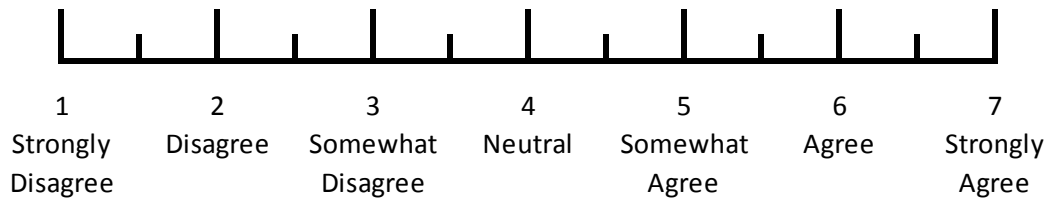
- 6) **How much do you agree with the statement: “This C/VIS is easy to use.”**

Response: _____



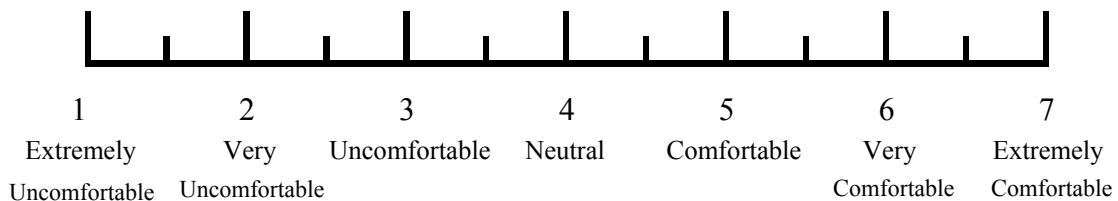
- 7) **How much do you agree with the statement: “I know how to use all the features the system offers”?**

Response: _____



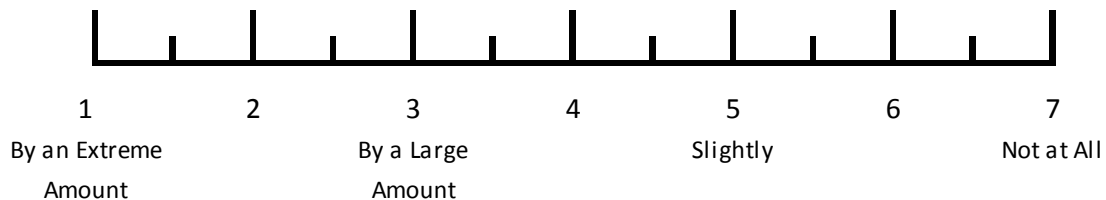
- 8) **How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?**

Response: _____



- 9) **By how much does the lighting from the monitors reduce your ability to discern details in the road ahead of you (for example, ability to read the license plate characters)?**

Response: _____



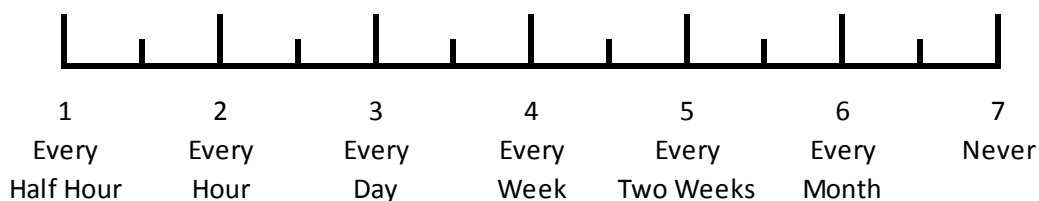
10) How much does the monitor block your view of the road?

Response: _____



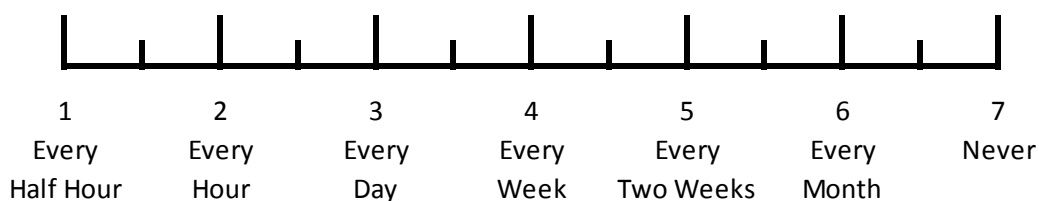
11) When it's clear outside, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



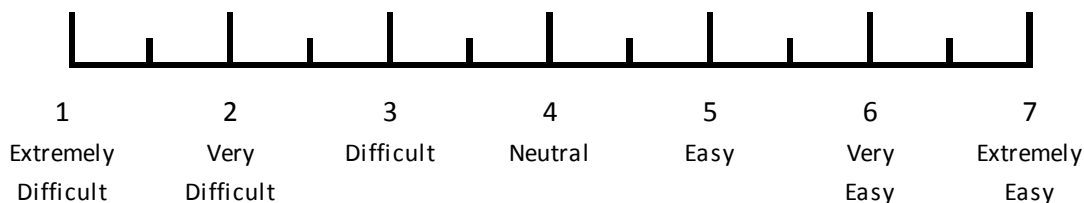
12) When it's raining, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



13) How easy is it to clean the camera lens?

Response: _____



14) What are your top two **most favorite** features of the system, and why?

1. _____

2. _____

15) What are your top two *least favorite* features of the system?

1. _____

2. _____

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

1. _____

2. _____

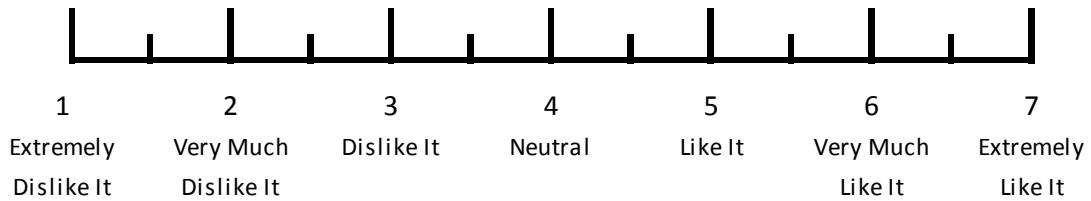
3. _____

Thank you for your participation this evening!

APPENDIX O. A-C/VIS FINAL MEETING QUESTIONNAIRE

1) How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?

Response: _____



2) I think the C/VIS is... (Please place an X on each line below that best matches your response)

useful | | | | | useless

pleasant | | | | | unpleasant

bad | | | | | good

nice | | | | | annoying

effective | | | | | superfluous

irritating | | | | | likeable

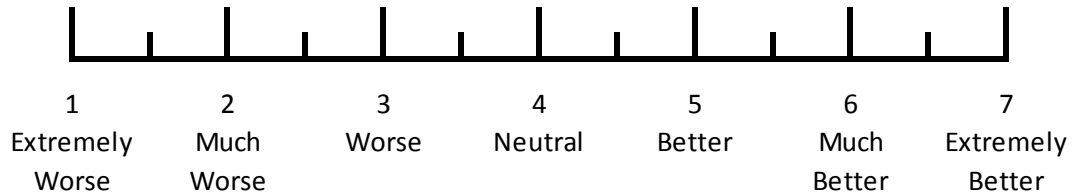
assisting | | | | | worthless

undesirable | | | | | desirable

raising alertness | | | | | sleep-inducing

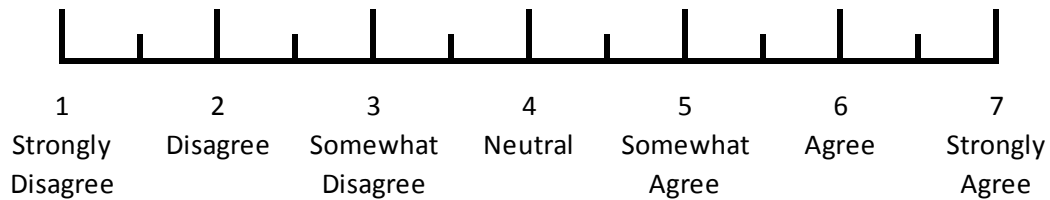
- 3) **How does your driving performance with a C/VIS compare to your driving performance without a CVIS?**

Response: _____



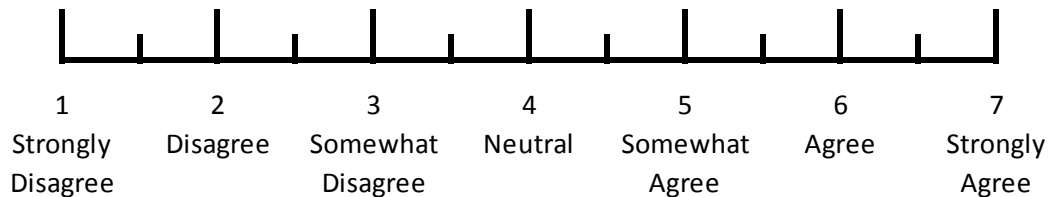
- 4) **How much do you agree with the statement: “I would like to have this C/VIS in my truck”**

Response: _____



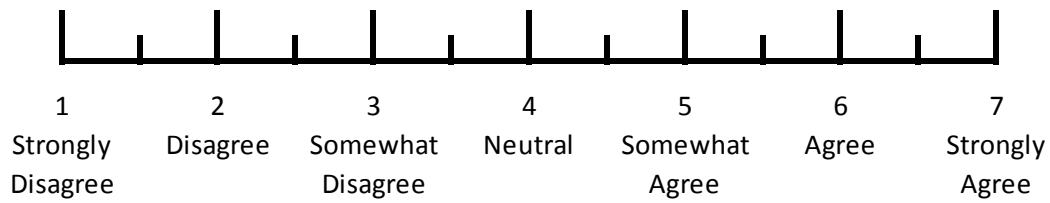
- 5) **How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”**

Response: _____



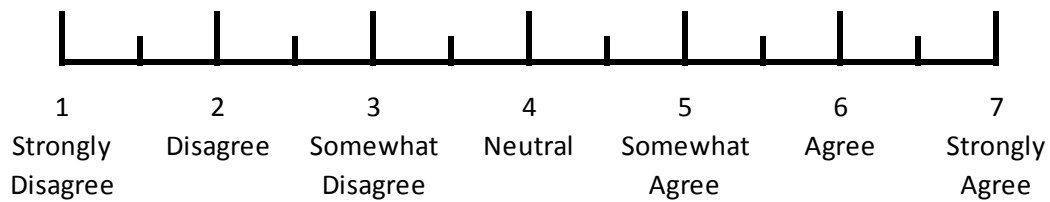
6) How much do you agree with the statement: “This C/VIS is easy to use.”

Response: _____



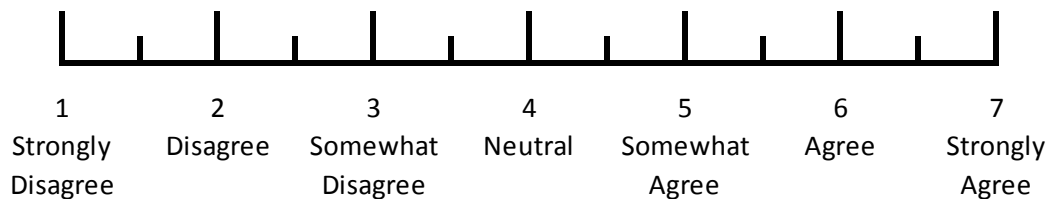
7) How much do you agree with the statement: “The object detection feature is useful.”

Response: _____



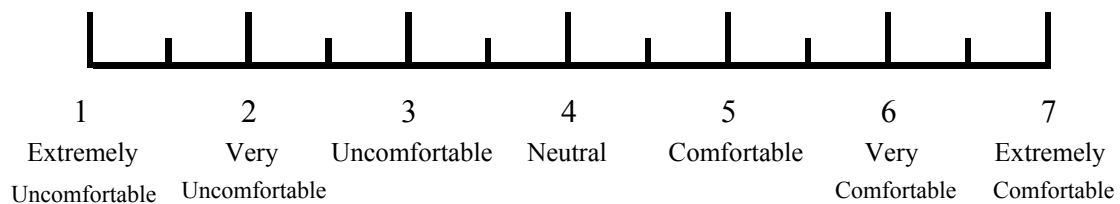
8) How much do you agree with the statement: “I know how to use all the features the system offers”?

Response: _____



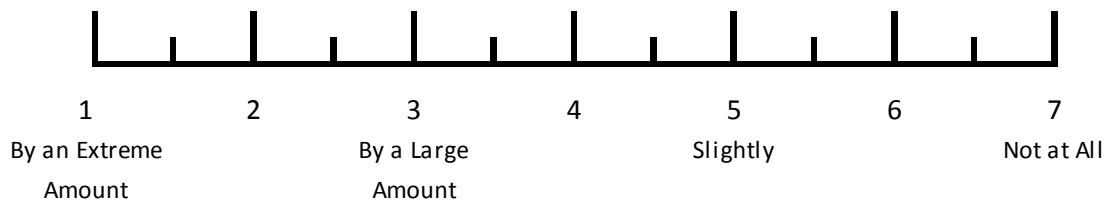
9) How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?

Response: _____



10) By how much does the lighting from the monitors reduce your ability to see details in the road ahead of you (for example, ability to read the license plate characters)?

Response: _____



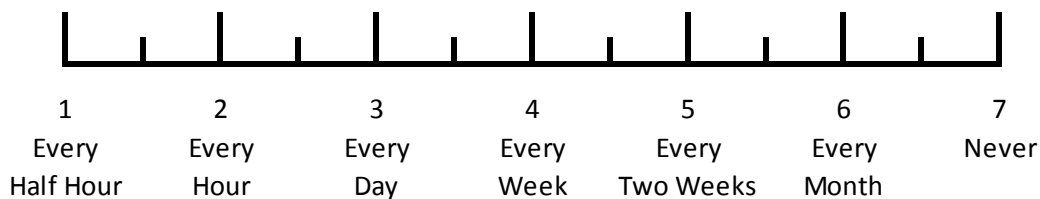
11) How much does the monitor block your view of the road?

Response: _____



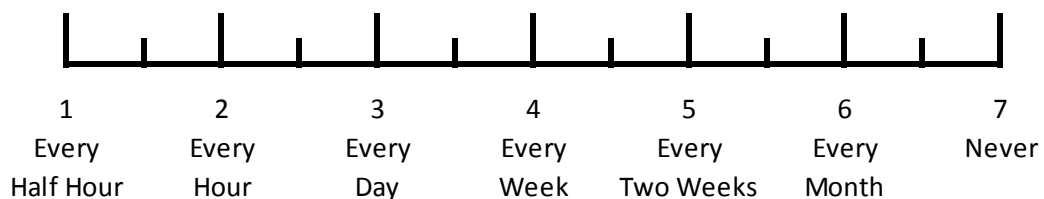
12) When it's clear outside, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



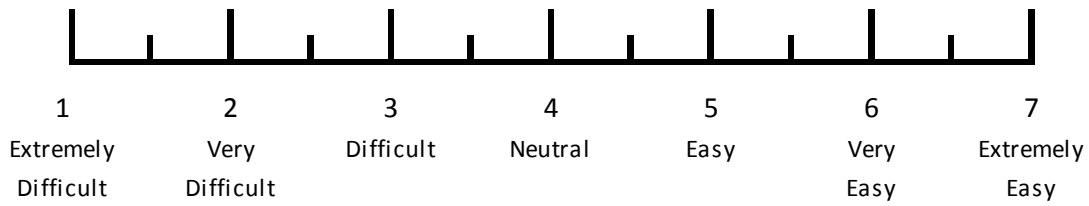
13) When it's raining, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



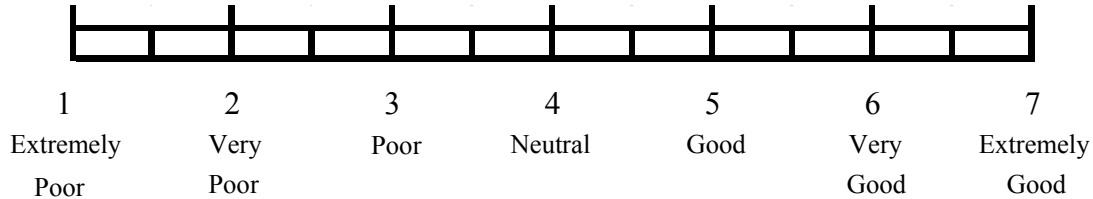
14) How easy is it to clean the camera lens?

Response: _____



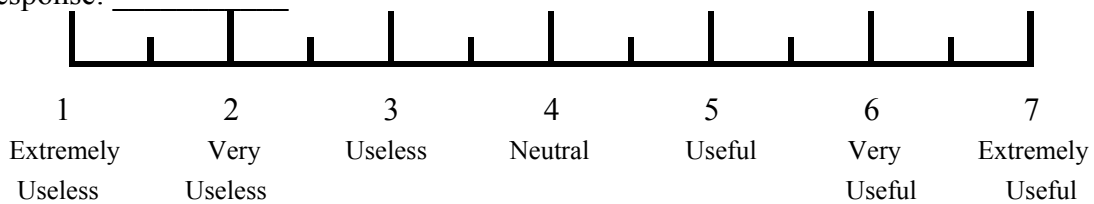
- 15) The camera's Field-of-View determines how much area around the truck can be seen in the monitor at once. However, as the Field-of-View increases, the size and clarity of objects in the monitor decrease. Given this tradeoff, how would you rate the Field-of-View of the side cameras and resulting size of objects in the monitors?

Response: _____



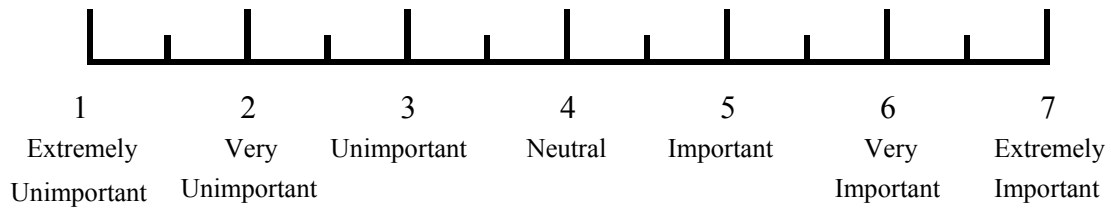
- 16) How useful are the *left* monitor and camera (driver side)?

Response: _____



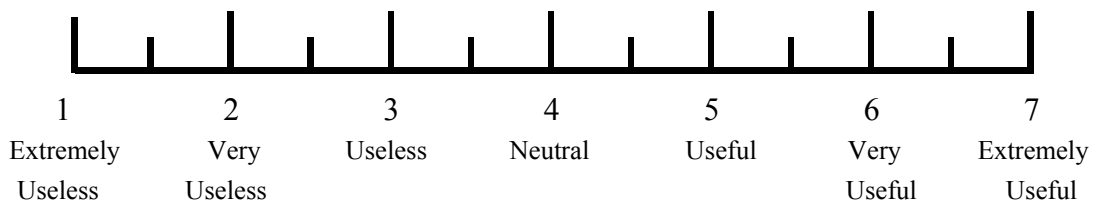
17) How important are the *left* monitor and camera (driver side)?

Response: _____



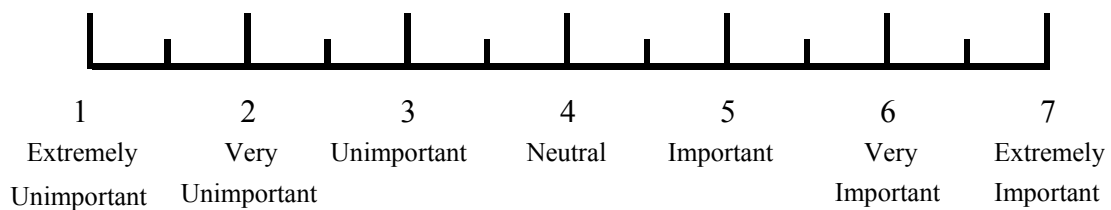
18) How useful are the *right* monitor and camera (passenger side)?

Response: _____



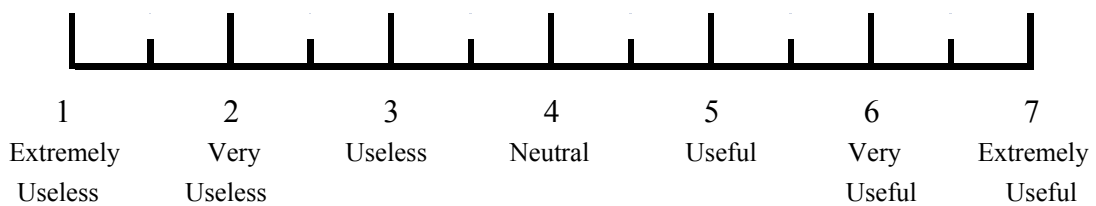
19) How important are the *right* monitor and camera (passenger side)?

Response: _____



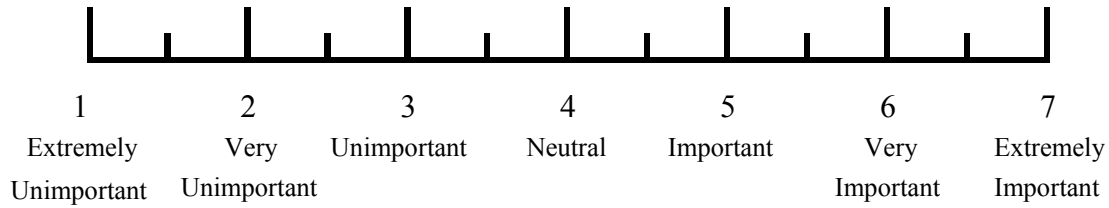
20) How useful are the *rearview* monitor and camera (center)?

Response: _____



21) How important are the *rearview* monitor and camera (center)?

Response: _____



22) Please rank each camera from 1-3 according to their usefulness (1 = most useful, 3 = least useful).

Driver side (left) camera: _____
Passenger side (right) camera: _____
Rearview (center) camera: _____

23) Do you ever look at a monitor from the corner of your eye while looking in another direction? For example, do you ever look at the left monitor while looking at the forward roadway? If so, please explain.

24) If you use the monitors, when and where do you use them? For instance, if you use them when changing lanes, at what point while making the lane change do you look at them?

25) If you look at a monitor before changing lanes, please select at what point in time you're most likely to look at them:

- ☐ 16 seconds or more before starting the lane change
- ☐ Less than 16 seconds before starting the lane change
- ☐ Less than 8 seconds before starting the lane change
- ☐ Less than 3 seconds before starting the lane change
- ☐ When starting the lane change
- ☐ After starting the lane change

26) What are your top two ***most favorite*** features of the system, and why?

- 3. _____
- 4. _____

27) What are your top two ***least favorite*** features of the system, and why?

- 3. _____
- 4. _____

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

- 4. _____

- 5. _____

- 6. _____

Thank you for your participation this evening!

APPENDIX P. SIDETRACKER FINAL MEETING QUESTIONNAIRE

16) How much do you like the idea of having a Camera/Video Imaging System (C/VIS) on your truck?

Response: _____

1	2	3	4	5	6	7
Extremely Dislike It	Very Much Dislike It	Dislike It	Neutral	Like It	Very Much Like It	Extremely Like It

17) I think the C/VIS is... (Please place a circle on each line below that best matches your response)

useful | | | | | | | useless

pleasant | | | | | | | unpleasant

bad | | | | | | | good

nice | | | | | | | annoying

effective | | | | | | | superfluous

irritating | | | | | | | likeable

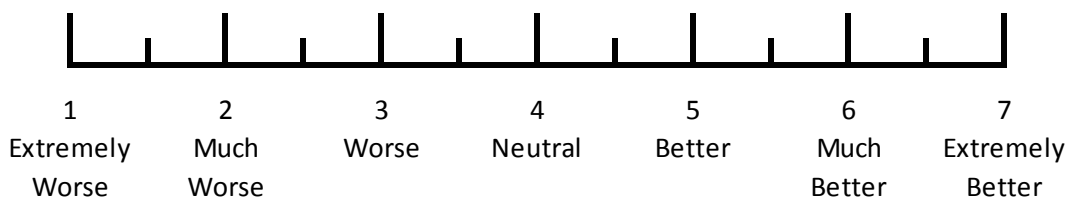
assisting | | | | | | | worthless

undesirable | | | | | | | desirable

raising alertness | | | | | | | sleep-inducing

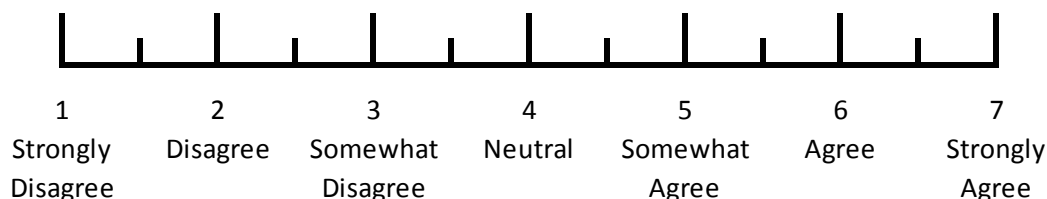
18) How does your driving performance with a C/VIS compare to your driving performance without a CVIS?

Response: _____



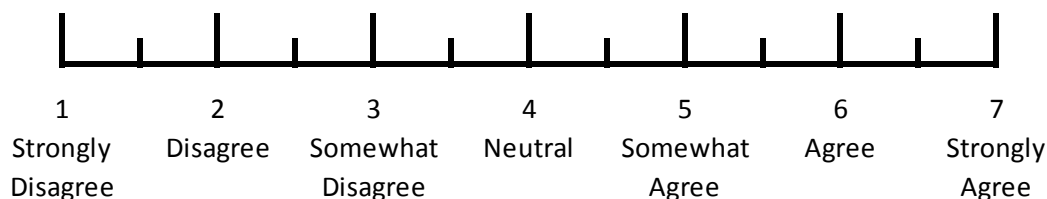
19) How much do you agree with the statement: “I would like to have this C/VIS in my truck”

Response: _____



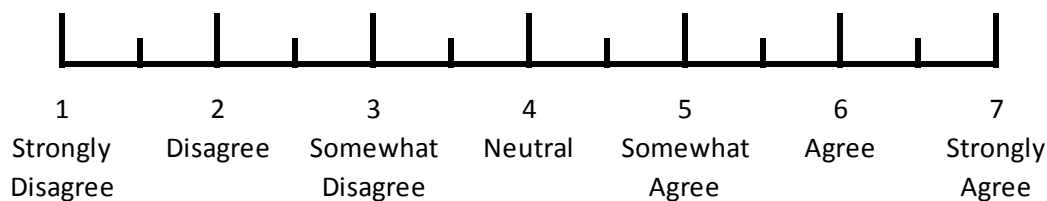
20) How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”

Response: _____



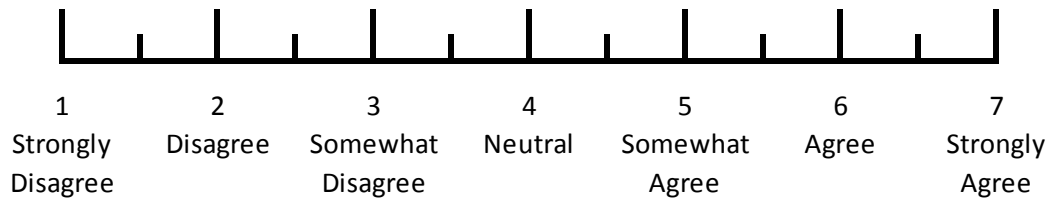
21) How much do you agree with the statement: “This C/VIS is easy to use.”

Response: _____



22) How much do you agree with the statement: “I know how to use all the features the system offers”?

Response: _____



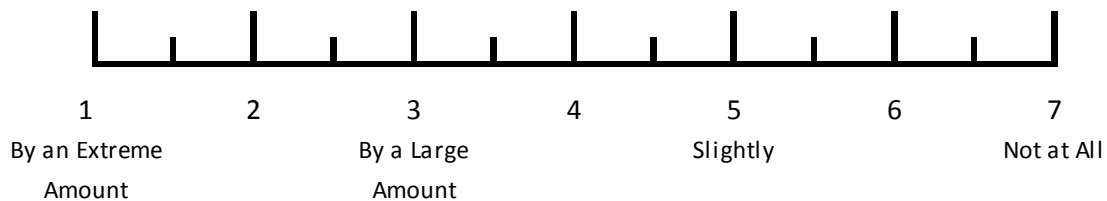
23) How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?

Response: _____



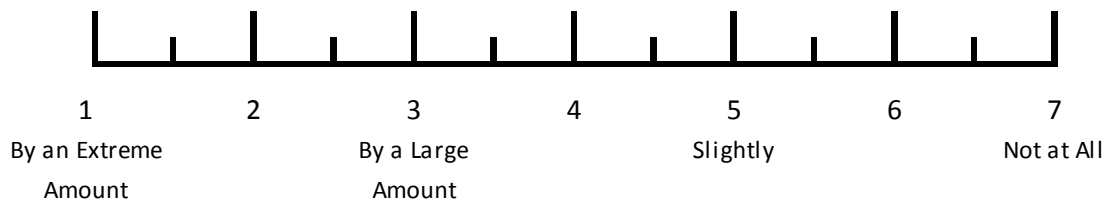
24) By how much does the lighting from the monitors reduce your ability to see details in the road ahead of you (for example, ability to read the license plate characters)?

Response: _____



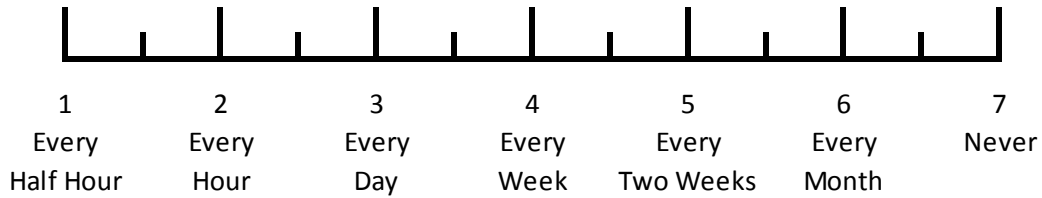
25) How much does the monitor block your view of the road?

Response: _____



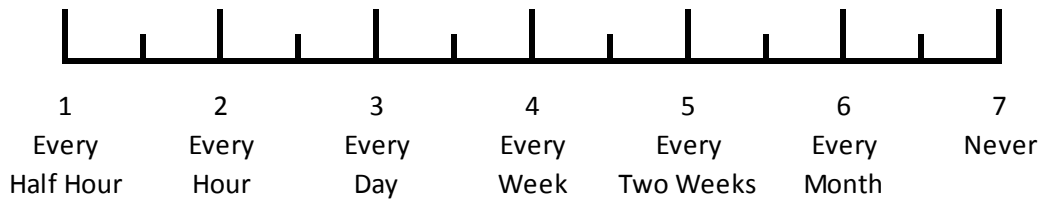
26) When it's clear outside, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



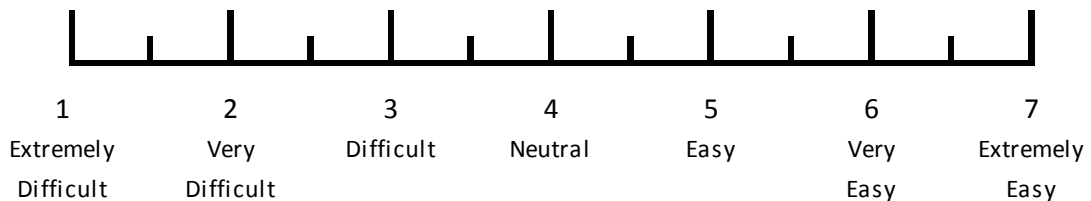
27) When it's raining, how often does the camera lens get dirty to the point where it affects the view of the road?

Response: _____



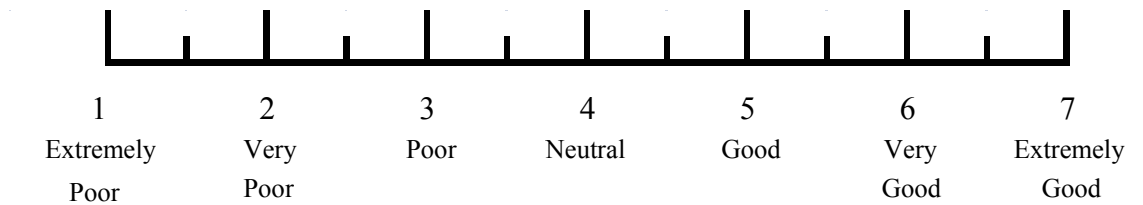
28) How easy is it to clean the camera lens?

Response: _____



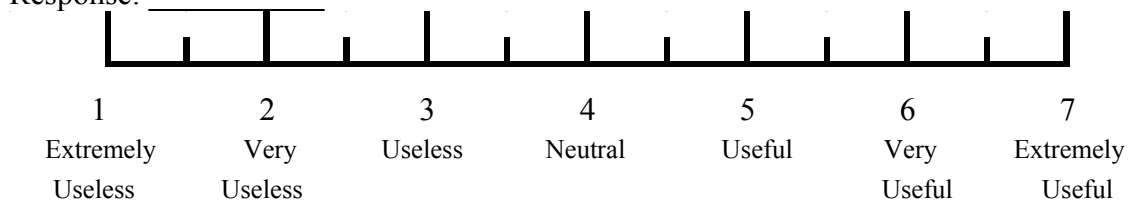
29) The camera's Field-of-View determines how much area around the truck can be seen in the monitor at once. However, as the Field-of-View increases, the size and clarity of objects in the monitor decrease. Given this tradeoff, how would you rate the Field-of-View of the side cameras and resulting size of objects in the monitors?

Response: _____



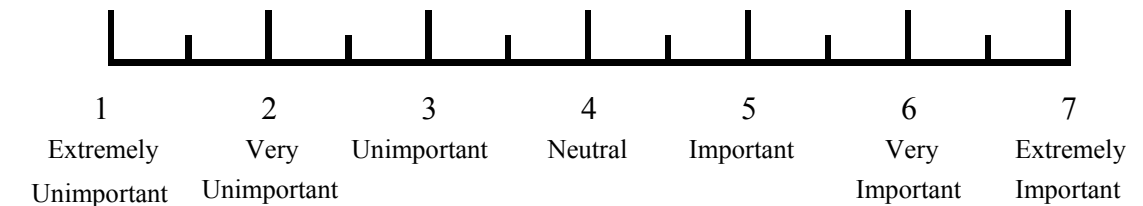
30) How useful are the *left* monitor and camera (driver side)?

Response: _____



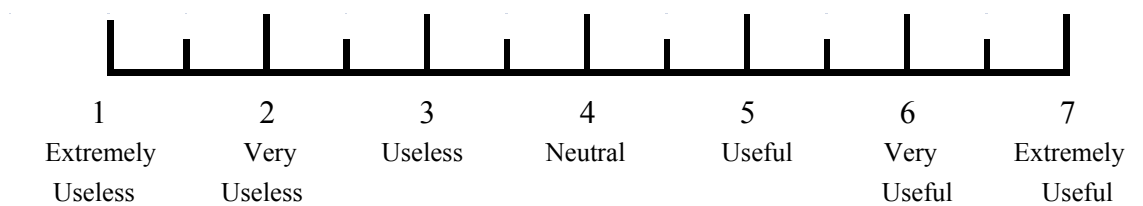
31) How important are the *left* monitor and camera (driver side)?

Response: _____



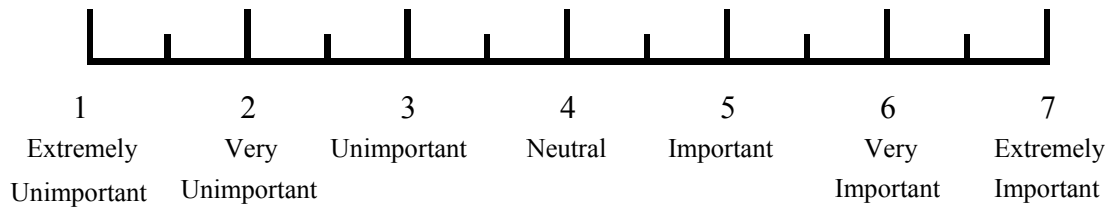
32) How useful are the *right* monitor and camera (passenger side)?

Response: _____



33) How important are the *right* monitor and camera (passenger side)?

Response: _____



34) Please rank each camera according to their usefulness (1 = most useful, 2 = least useful).

Driver side (left) camera: _____

Passenger side (right) camera: _____

35) Do you ever look at a monitor from the corner of your eye while looking in another direction? For example, do you ever look at the left monitor while looking at the forward roadway? If so, please explain.

36) If you use the monitors, when and where do you use them? For instance, if you use them when changing lanes, at what point while making the lane change do you look at them?

37) If you look at a monitor before changing lanes, please circle at what point in time you're most likely to look at them:

☐ 16 seconds or more before starting the lane change

- ☐ Less than 16 seconds before starting the lane change
- ☐ Less than 8 seconds before starting the lane change
- ☐ Less than 3 seconds before starting the lane change
- ☐ When starting the lane change
- ☐ After starting the lane change

38) What are your top two ***most favorite*** features of the system, and why?

1. _____
2. _____

39) What are your top two ***least favorite*** features of the system, and why?

1. _____
2. _____

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

1. _____

2. _____

3. _____

Thank you for your participation this evening!

APPENDIX Q. PARTICIPANT CONTACT FORM

We would like to thank you for your time and effort you have put into this study. We would like to speak with you again in 1 month (by phone, or in-person at Schneider) to ask you a few more questions regarding your thoughts and opinions of the system. In the meantime, we are going to begin analyzing your data, which will take us quite a bit of time. In the event we find one or more of your video files to be extremely relevant to transportation safety, we would like to contact you to show you the video and discuss how it may be used to further transportation safety research. Without your permission, we may not be able to use the data as intended. Providing you are willing, could you please provide us with your contact information for future communication:

Name: _____

Address: _____

Cell: _____

Home: _____

Email: _____

In case you move, could you please provide contact information of two people (they can be family members or friends) who you believe will always have contact with you.

1st Contact

Name: _____ **Relationship:** _____

Telephone Number: _____

Email: _____

2nd Contact

Name: _____ **Relationship:** _____

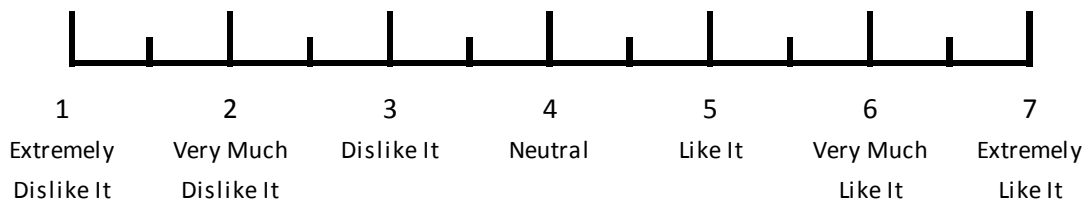
Telephone Number: _____

Email: _____

APPENDIX R. SIDETRACKER QUESTIONNAIRE FOR A-C/VIS DRIVERS AT THE END OF THE STUDY

40) How much do you like the idea of having this Camera/Video Imaging System (C/VIS) on your truck?

Response: _____



41) I think this C/VIS is... (Please place a circle on each line below that best matches your response)

useful | | | | | | | useless

pleasant | | | | | | | unpleasant

bad | | | | | | | good

nice | | | | | | | annoying

effective | | | | | | | superfluous

irritating | | | | | | | likeable

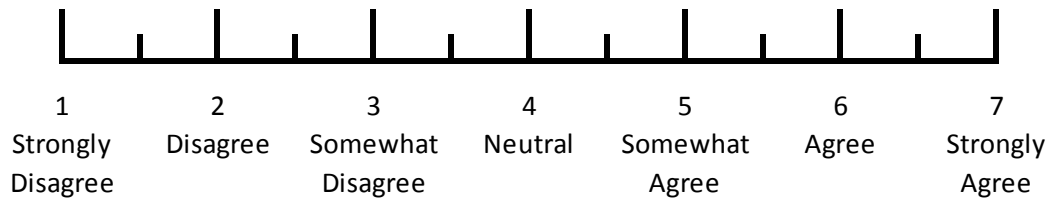
assisting | | | | | | | worthless

undesirable | | | | | | | desirable

raising alertness | | | | | | | sleep-inducing

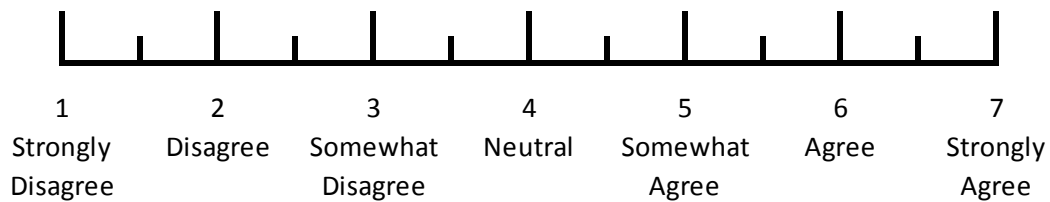
42) How much do you agree with the statement: “I would like to have this C/VIS in my truck”

Response: _____



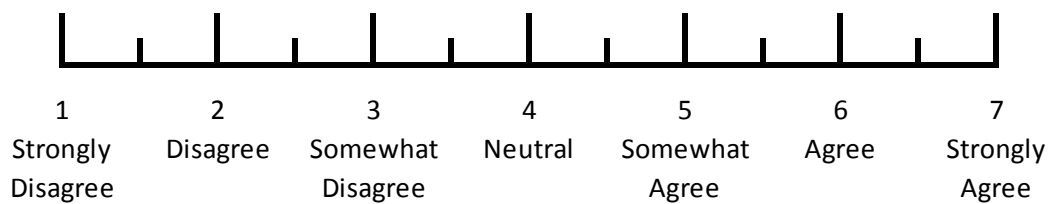
43) How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”

Response: _____



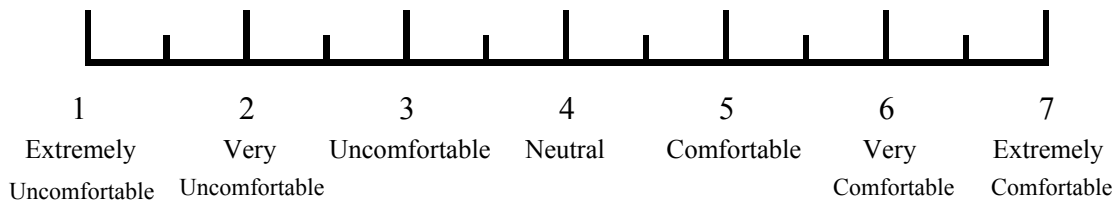
44) How much do you agree with the statement: “This C/VIS is easy to use.”

Response: _____



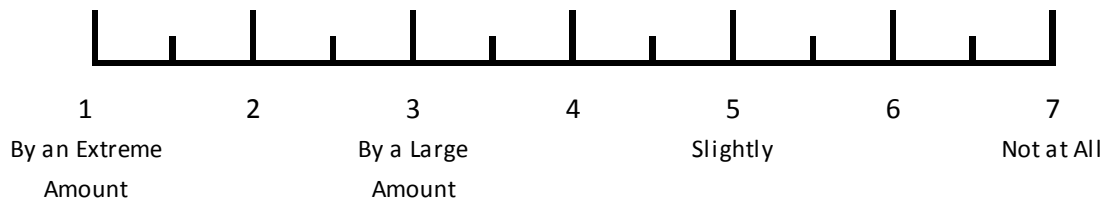
45) How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?

Response: _____



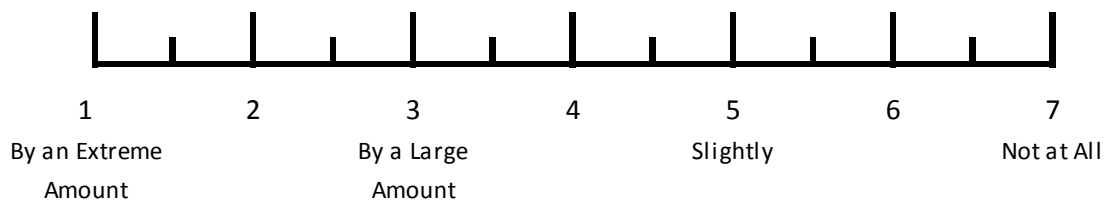
46) By how much does the lighting from the monitors reduce your ability to see details in the road ahead of you (for example, ability to read the license plate characters)?

Response: _____



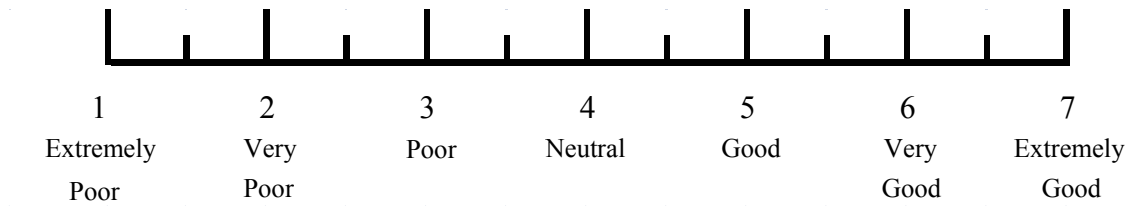
47) How much does the monitor block your view of the road?

Response: _____



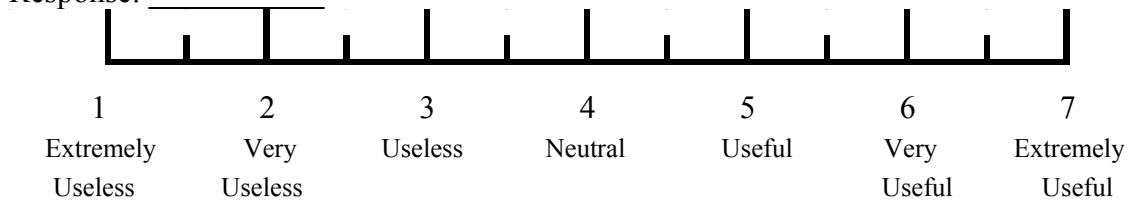
48) The camera's Field-of-View determines how much area around the truck can be seen in the monitor at once. However, as the Field-of-View increases, the size and clarity of objects in the monitor decrease. Given this tradeoff, how would you rate the Field-of-View of the side cameras and resulting size of objects in the monitors?

Response: _____



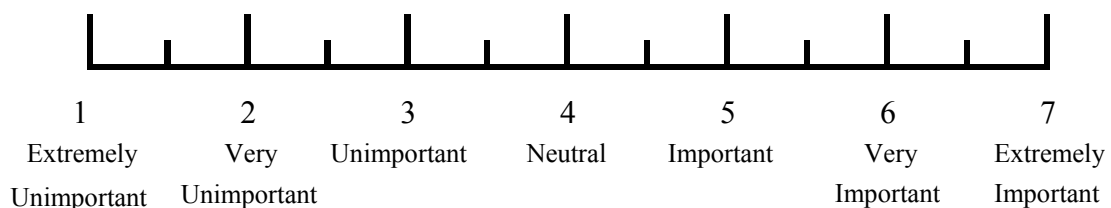
49) How useful is the *left* view provided by the C/VIS (driver side)?

Response: _____



50) How important is the *left* view provided by the C/VIS (driver side)?

Response: _____



Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

1.

2.

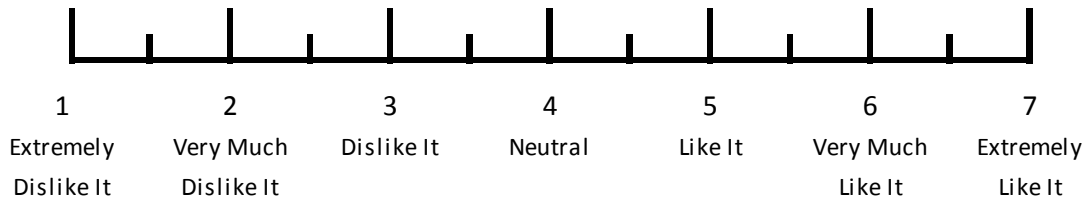
3.

Thank you for your participation this evening!

APPENDIX S. A-C/VIS QUESTIONNAIRE FOR SIDETRACKER DRIVERS AT THE END OF THE STUDY

1) How much do you like the idea of having this Camera/Video Imaging System (C/VIS) on your truck?

Response: _____

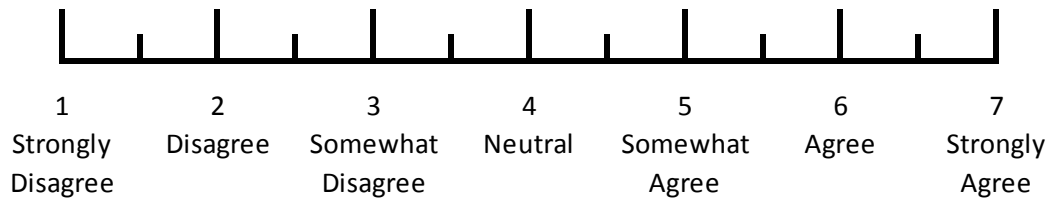


2) I think this C/VIS is... (Please place an X on each line below that best matches your response)

useful							useless
pleasant							unpleasant
bad							good
nice							annoying
effective							superfluous
irritating							likeable
assisting							worthless
undesirable							desirable
raising alertness							sleep-inducing

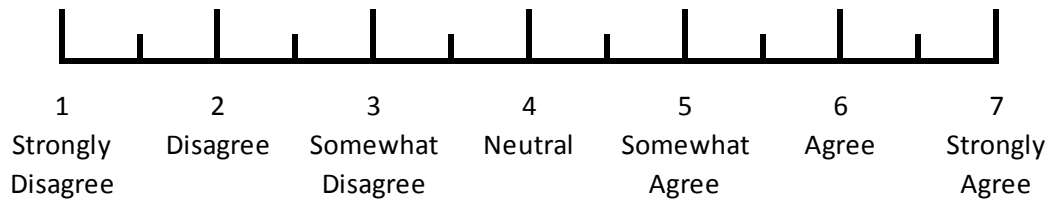
- 3) How much do you agree with the statement: “I would like to have this C/VIS in my truck”

Response: _____



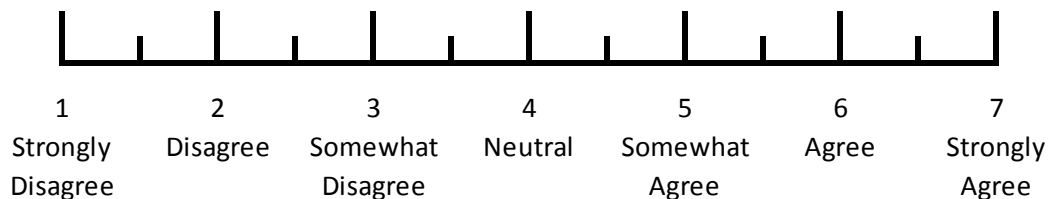
- 4) How much do you agree with the statement: “This C/VIS eliminates the blind spots around my truck.”

Response: _____



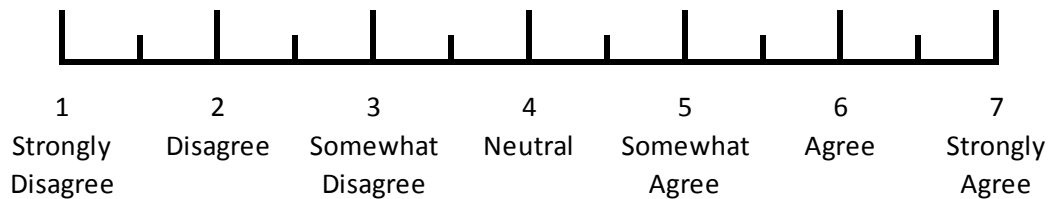
- 5) How much do you agree with the statement: “This C/VIS is easy to use.”

Response: _____



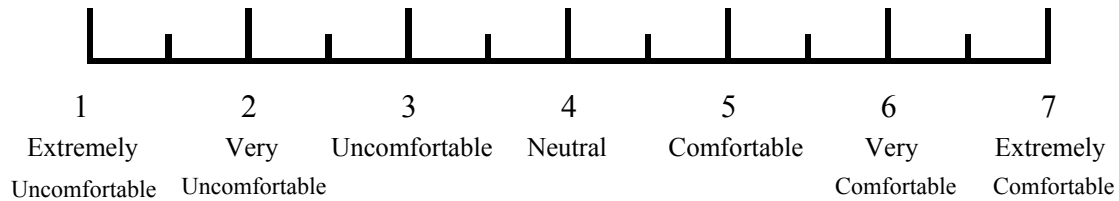
- 6) How much do you agree with the statement: “The object detection feature is useful.”

Response: _____



- 7) **How uncomfortable is the glare from the monitors when you are driving at night and looking forward down the road?**

Response: _____



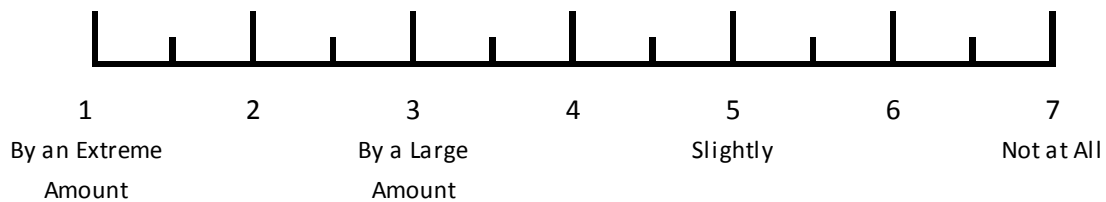
- 8) **By how much does the lighting from the monitors reduce your ability to see details in the road ahead of you (for example, ability to read the license plate characters)?**

Response: _____



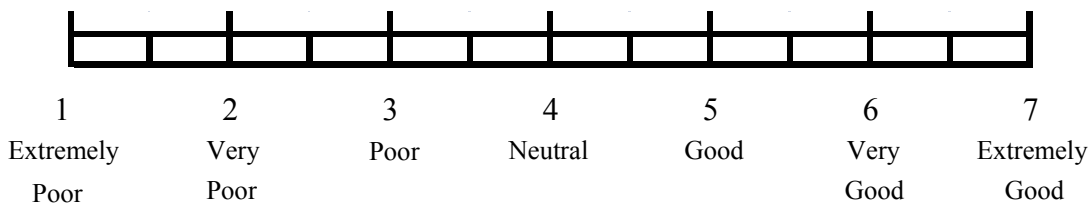
- 9) **How much does the monitor block your view of the road?**

Response: _____



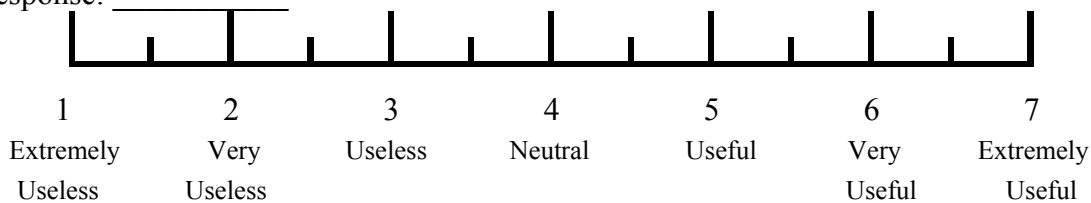
10) The camera's Field-of-View determines how much area around the truck can be seen in the monitor at once. However, as the Field-of-View increases, the size and clarity of objects in the monitor decrease. Given this tradeoff, how would you rate the Field-of-View of the side cameras and resulting size of objects in the monitors?

Response: _____



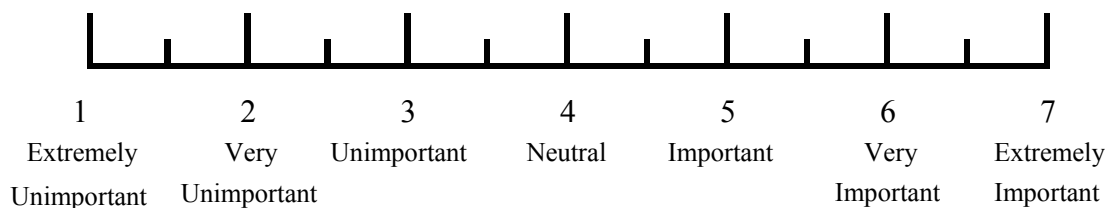
11) How useful are the *left* monitor and camera (driver side)?

Response: _____



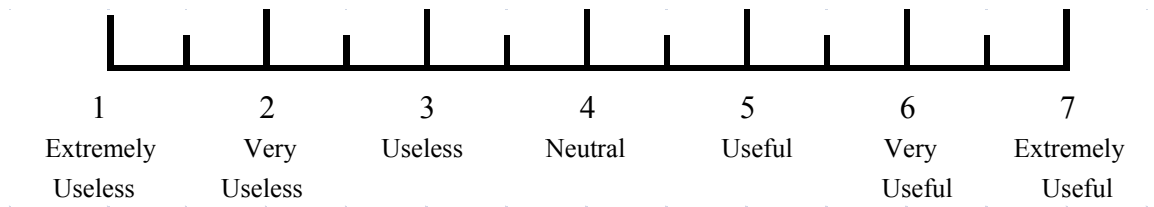
12) How important are the *left* monitor and camera (driver side)?

Response: _____



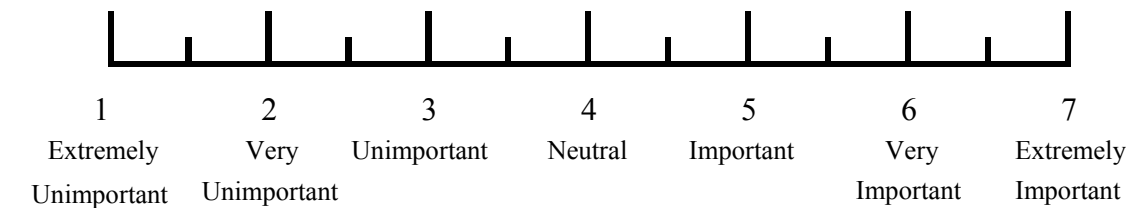
13) How useful are the *right* monitor and camera (passenger side)?

Response: _____



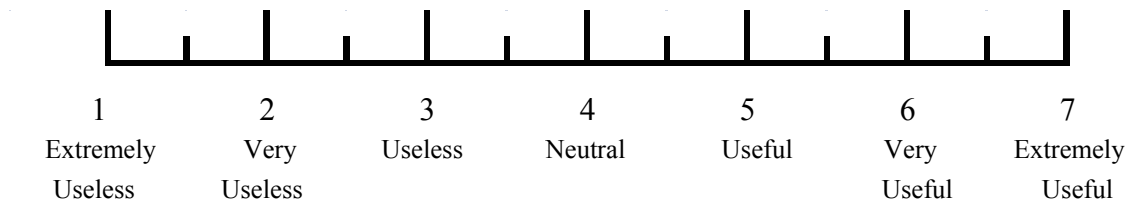
14) How important are the *right* monitor and camera (passenger side)?

Response: _____



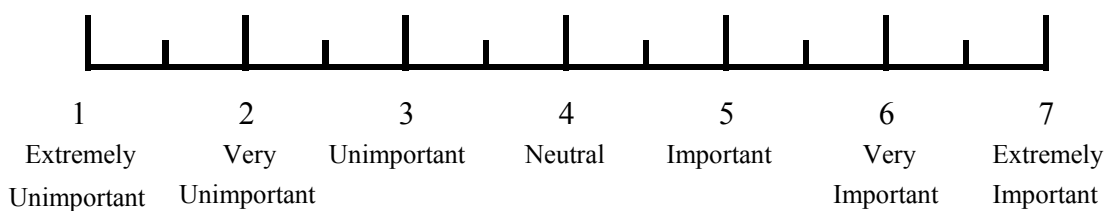
15) How useful are the *rearview* monitor and camera (center)?

Response: _____



16) How important are the *rearview* monitor and camera (center)?

Response: _____



17) Please rank each camera from 1-3 according to their usefulness (1 = most useful, 3 = least useful).

Driver side (left) camera: _____

Passenger side (right) camera: _____

Rearview (center) camera: _____

18) What are your top two ***most favorite*** features of the system, and why?

5. _____

6. _____

19) What are your top two ***least favorite*** features of the system, and why?

5. _____

6. _____

Additional Comments

Are there any additional comments you would like to make regarding the video system(s)?

7. _____

8. _____

9. _____

Thank you for your participation this evening!

APPENDIX T. 1-MONTH FOLLOW-UP QUESTIONNAIRE

Depending on participant preference and current location, this questionnaire will be administered to participants by experimenters either:

- a. Over the phone, or
- b. In-person at Schneider

Telephone Script (if administered over the phone): *Hello. My name is _____ and I am a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA. You recently participated in a study of camera/video imaging systems. You provided your contact information so that we could reach you one month after completing the study to ask you some additional questions regarding your thoughts and opinions of the system. This should take approximately 10 minutes. Do you have time to answer these questions now?*

If No: *Okay, is there a better time to call back?*

If No: *Okay, thank you for your time.*

If Yes: Arrange alternate time to contact participant and administer questionnaire.

If Yes, Proceed:

1. Has your employment changed since completing the study? (If yes, please elaborate. If no longer a commercial motor vehicle driver, then end the questionnaire).
2. Has your driving experience changed as a result of no longer driving a truck equipped with a camera/video imaging system (C/VIS)? Do you miss the C/VIS? Why or why not?
3. Would you prefer to drive a truck with or without a C/VIS? Why?
4. If you could only have one of the cameras (left side, right side, or rearview), which one would you want to have on your truck? Why?
5. How aware of your surroundings are you? How does this compare to when you were driving with the C/VIS?
6. How confident are you in making lane changes? How does this compare to when you were driving with the C/VIS?

APPENDIX U. DRIVER ROUTE, TIME IN TRUCK, AND MILES PER WEEK

DRIVERS OF A-C/VIS-EQUIPPED TRUCKS

Driver 1

Driver 1's nightly route involved driving south from the Winchester, VA terminal to the Richmond, VA area and back (Figure 223). Driver 1 drove 1,980 miles per week, and was typically in the truck from 8 p.m. to 6 a.m.

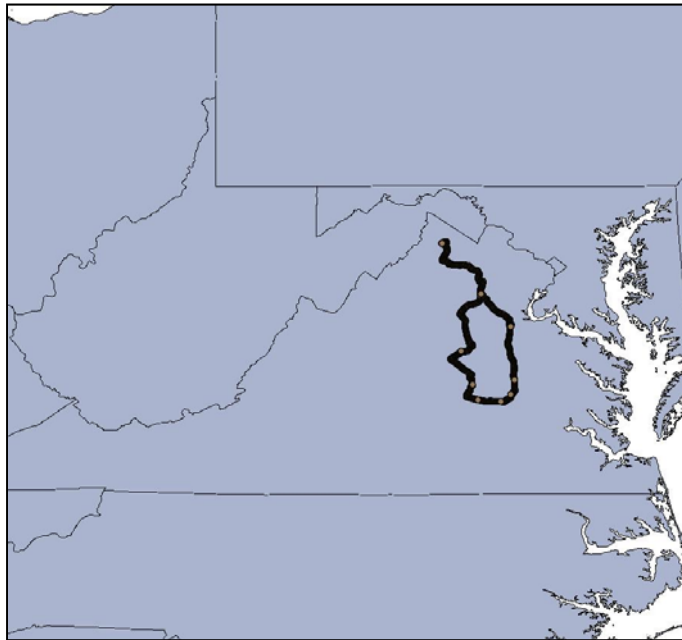


Figure 223. Map of Driver 1's Nightly Route

Driver 3

Driver 3's nightly route involved driving northeast from the Winchester, VA terminal to the Baltimore, MD area and back (Figure 224). Driver 3 drove 1,685 miles per week, and was typically in the truck from 10 p.m. to 7 a.m.

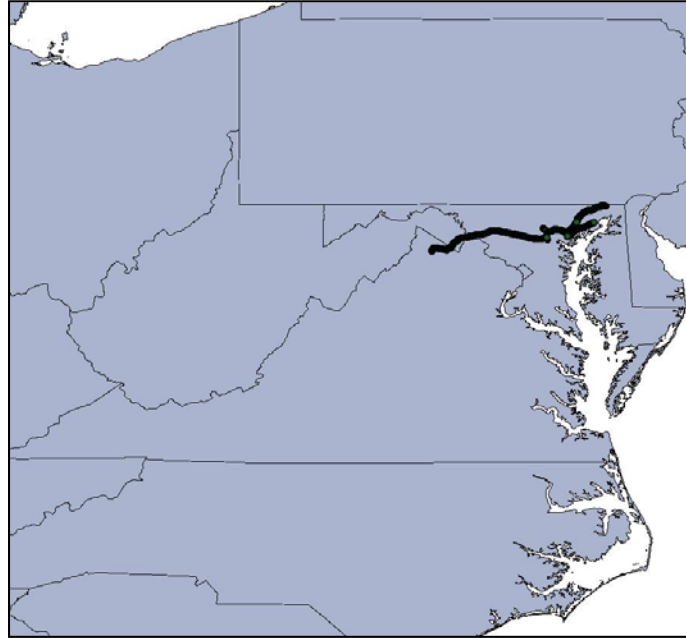


Figure 224. Map of Driver 3's Nightly Route

Driver 4

Driver 4's nightly route involved driving northwest from the Winchester, VA terminal to the Charleston, WV area and back (Figure 225). Driver 4 drove an average of 2,713 kilometers and was typically in the truck from 4 p.m. to 3 a.m.

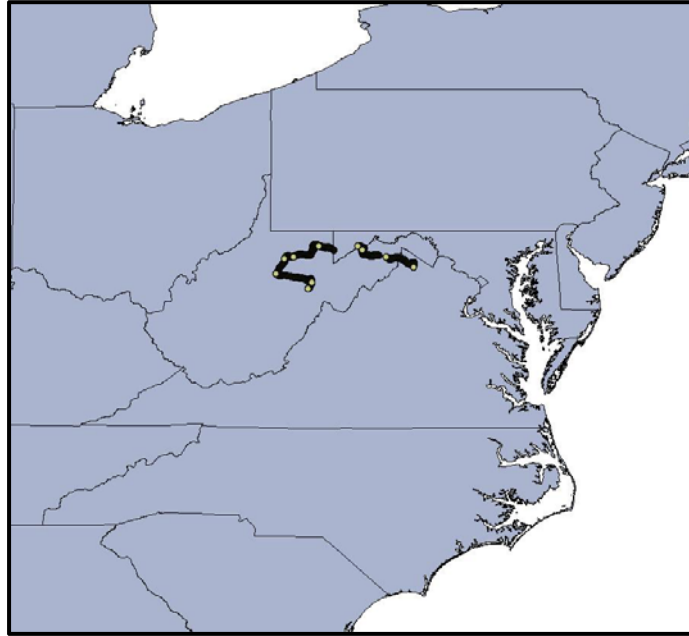


Figure 225. Map of Driver 4's Nightly Route

Driver 5

Driver 5's nightly route involved driving south from the Winchester, VA terminal to the Richmond, VA area and back (Figure 226). Driver 5 drove an average of 2,570 kilometers per week, and was typically in the truck from 10 p.m. to 7 a.m.

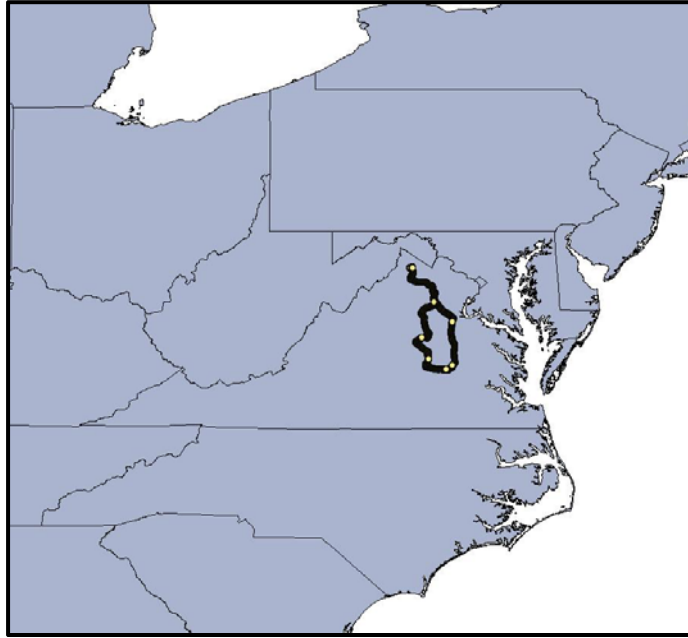


Figure 226. Map of Driver 5's Nightly Route

Driver 13

Driver 13's nightly route involved driving south from the Winchester, VA terminal to the Richmond, VA area and back (Figure 227). Driver 13 drove 1,695 miles per week, and was typically in the truck from 10:30 p.m. to 7:30 a.m.

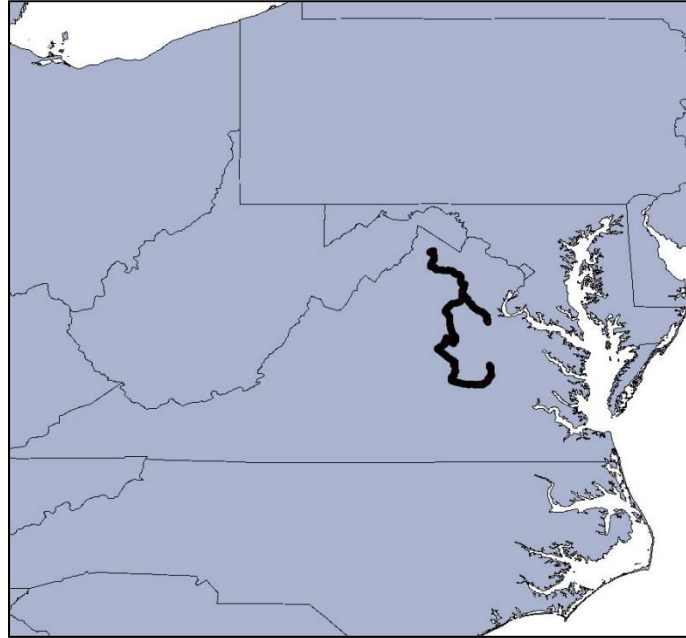


Figure 227. Map of Driver 13's Nightly Route

Driver 15

Driver 15's nightly route involved driving northeast from the Winchester, VA terminal to the northern Baltimore, MD area and back (Figure 228). Driver 15 drove an average of 2,499 kilometers per week, and was typically in the truck from 11 p.m. to 7 a.m.

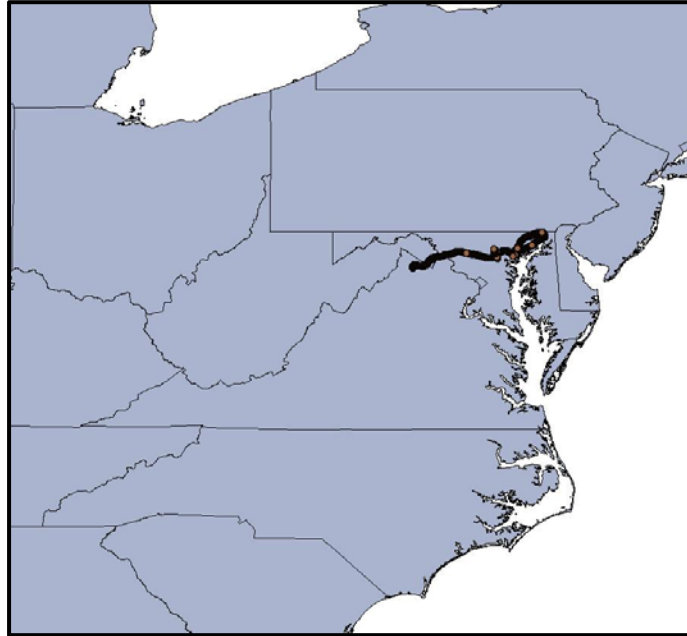


Figure 228. Map of Driver 15's Nightly Route

DRIVERS OF COMMERCIAL C/VIS-EQUIPPED TRUCKS

Driver 7

Driver 7's nightly route involved driving northeast from the Winchester, VA terminal to the Baltimore, MD area and back (Figure 229). Driver 7 drove 1,225 miles per week, and was typically in the truck from 8:30 p.m. to 5 a.m.

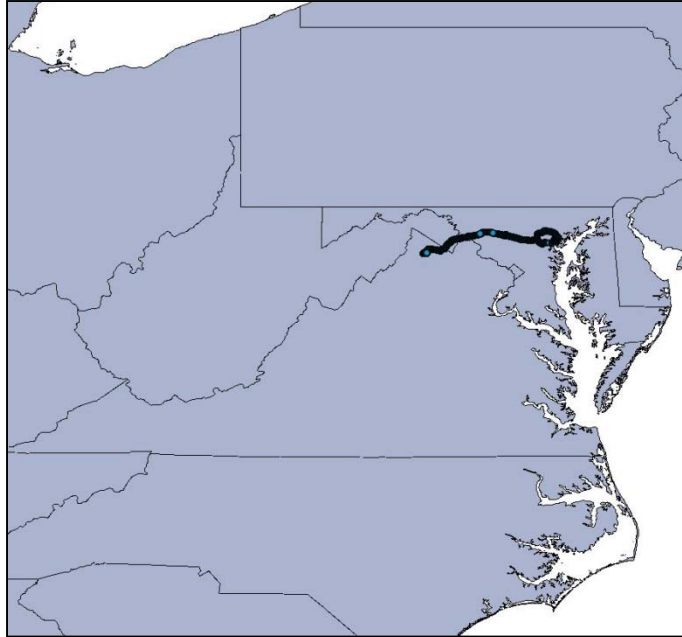


Figure 229. Map of Driver 7's Nightly Route

Driver 8

Driver 8's nightly route involved driving east from the Winchester, VA terminal to the Annapolis, MD area and back (Figure 230). Driver 8 drove 1,205 miles per week, and was typically in the truck from 11 p.m. to 8 a.m.

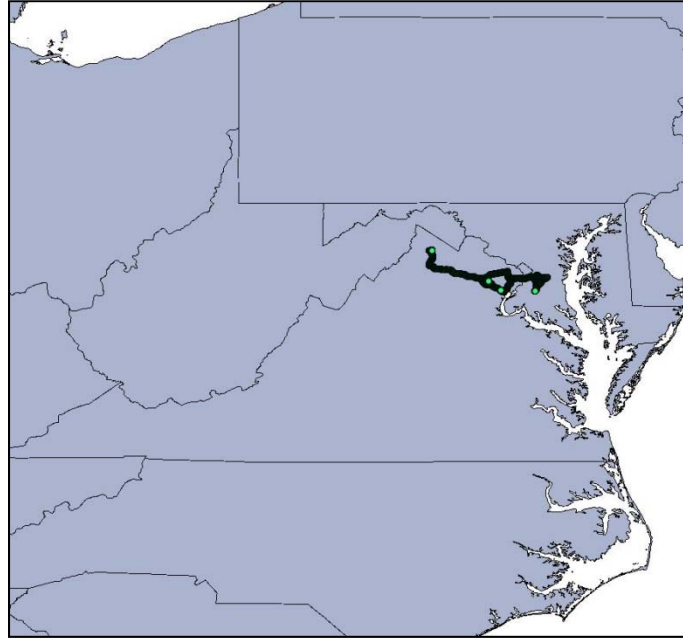


Figure 230. Map of Driver 8's Nightly Route

Driver 9

Driver 9's nightly route involved driving northeast from the Winchester, VA terminal to the Baltimore, MD area and back (Figure 231). Driver 9 drove 1,390 miles per week, and was typically in the truck from 11 p.m. to 8 a.m.

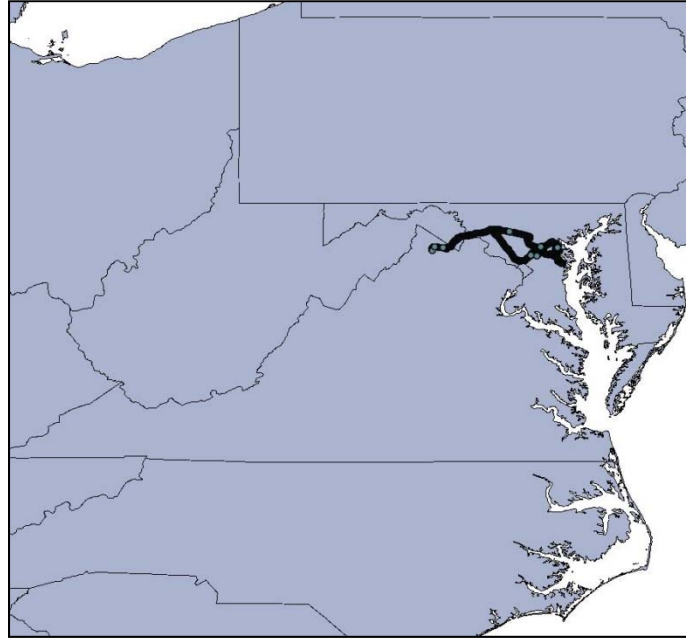


Figure 231. Map of Driver 9's Nightly Route

Driver 10

Driver 10's nightly route involved driving northeast from the Winchester, VA terminal to the Baltimore, MD area and back (Figure 232). Driver 10 drove 1,805 kilometers per week, and was typically in the truck from 9 p.m. to 9 a.m.

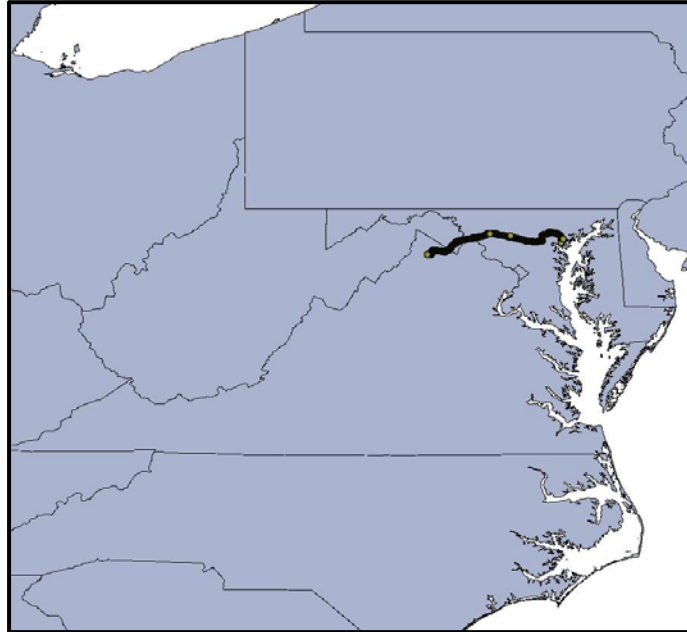


Figure 232. Map of Driver 10's Nightly Route

Driver 12

Driver 12's nightly route involved driving northeast from the Winchester, VA terminal to the Baltimore, MD area and back (Figure 233). Driver 12 drove an average of 2,197 kilometers per week, and was typically in the truck from 1 am to 11 am.



Figure 233. Map of Driver 12's Nightly Route

Driver 14

Driver 14's nightly route involved driving east from the Winchester, VA terminal to the Annapolis, MD area and back (Figure 234). Driver 12 drove an average 1,852 kilometers per week, and was typically in the truck from 11 p.m. to 8 a.m.

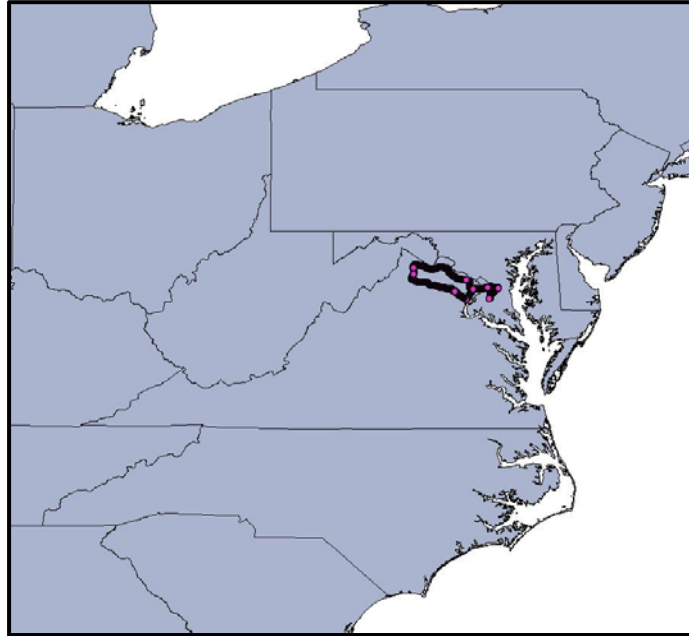
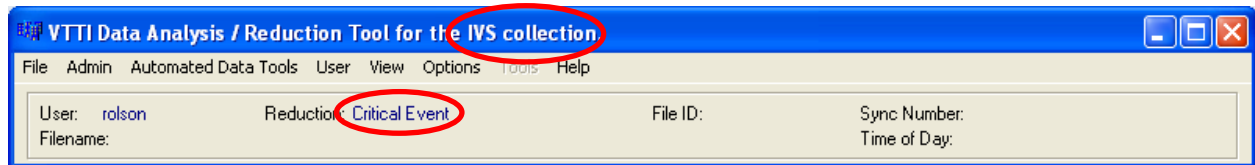


Figure 234. Map of Driver 14's Nightly Route

APPENDIX V. SAFETY-CRITICAL EVENT TRIGGER VALIDATION TRAINING MANUAL

Loading DART I:

1. Load DART I on your computer.
2. Open the **IVS** collection (File → Open Collection → IVS).
3. Logon using your PID and password (VTTI) (User → Login).
4. Switch to the **Critical Event** reduction (User → Change reduction → Critical Event).



Open SCE Triggers for Analysis:

1. In DART, load Query Tool (File → Query Tool).
2. Load the collection specific query (File → Saved Query List).
3. Click Go.
4. Open one of the triggers listed in the results.

Set up Views:

You will need the following views to validate events and/or to perform the reduction (Figure 235):

1. View → Video and Play Controller
2. View → Triggers
3. View → J1708 → Composite Speed MPH
4. View → Accel → X_Accel
5. View → IVS Front Radar → TTC
6. View → Birds Eye View

You can place the views however you like. Once you've arranged your windows the way you want them, save your View Setup for use during the next time you login (User → View Setups → Add). A sample view setup is provided below. Other views can be used as needed.

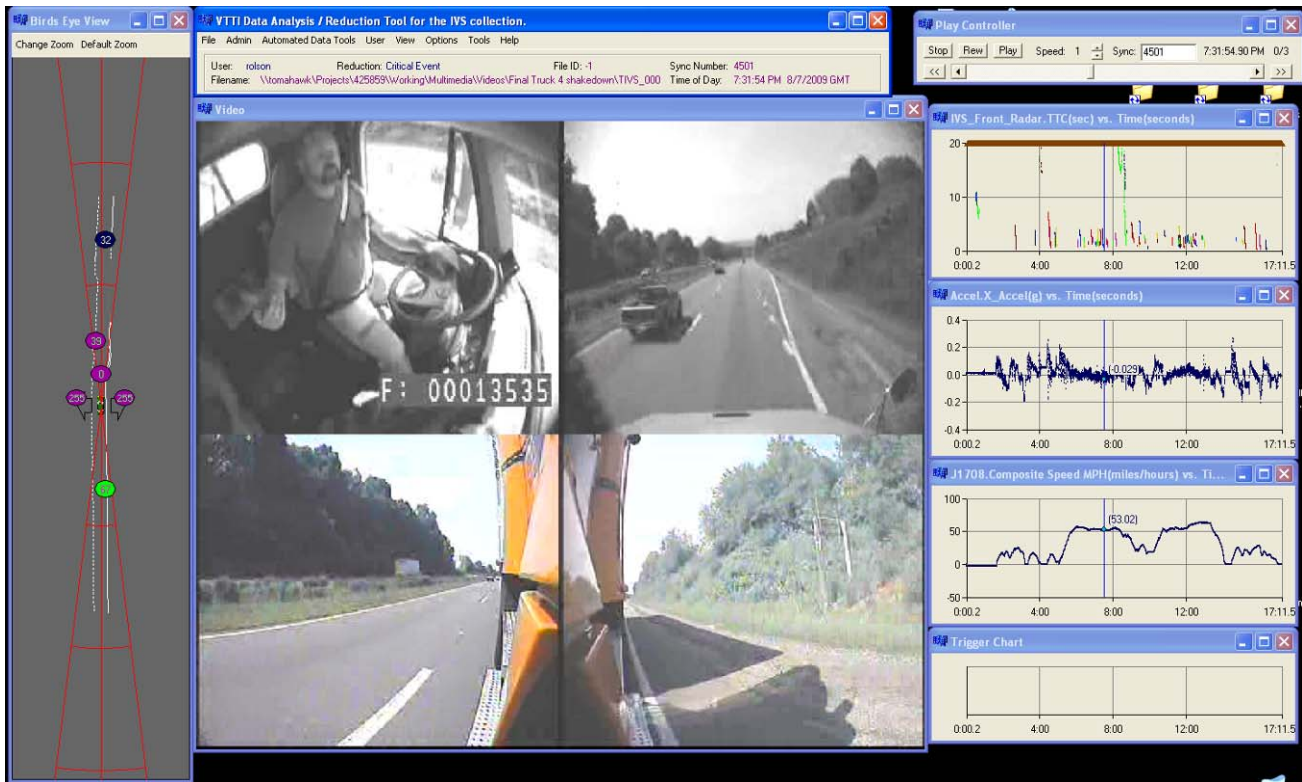


Figure 235. Example of a view setup in DART

Trigger Validation

To identify an SCE, pre-determined thresholds are set and the data is scanned to create triggers in the data set.

- Trigger** – A trigger is used to identify a point of interest (e.g., hard braking) in the data. There are thousands of triggers that will be identified throughout the data set. Each trigger will be viewed to determine if it is valid or not. It is not necessary that you understand the details of how the trigger is formed, simply that you understand what the different triggers mean.

Potential triggers include: hard braking (LA), sharp steering maneuver (Swerve), close time-to-collision (TTC), and analyst identified (AI); see Table 53 below:

Table 53. Trigger Types

Trigger Type	Definition	Description
Longitudinal Acceleration	Hard braking	(1) Deceleration greater than or equal to -0.20 G. Speed greater than or equal to 1 mph (1.6 km/h). Brake applied.
Time-to-Collision	The amount of time (in seconds) that it would take for two vehicles to collide if one vehicle did not perform an evasive maneuver	(2) A forward time-to-collision value of less than or equal to 2 s, coupled with a range of less than or equal to 250 ft (76.2m), a target velocity of greater than or equal to 5 mph (2.2 m/s), a gyro rate of less than or equal to $ 6^\circ/\text{s} $, an azimuth of less than or equal to $ 0.12 \text{ rad/s} $, a Y range of less than or equal to $ 2.0 \text{ m/s} $, a X range of greater than or equal to 5 m/s and a network speed of greater than or equal to 5 mph (2.2 m/s).
Swerve	A sudden “jerk” of the steering wheel to return the truck to its original position in the lane.	(3) Swerve value of greater than or equal to 2 rad/s^2 . Speed greater than or equal to 5 mph (8.05 km/h).
Analyst Identified (AI)	An event that is identified by the analyst but has not been identified by a trigger	Event that was identified by a data analyst viewing video footage; no other trigger is listed above identified the event (i.e. Longitudinal Acceleration, TTC, etc.).

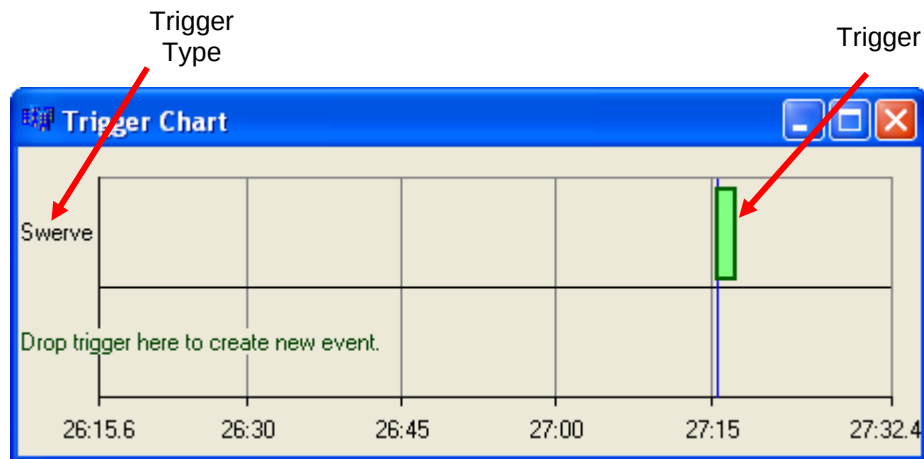


Figure 236. Trigger Chart showing an Unvalidated Trigger

- Epoch** – An epoch is the period of time that surrounds and includes a trigger. An epoch can be any length of time that is pre-set in the software. For the purposes of this study, there will be 60 seconds before the trigger and 15 seconds after the trigger, making a total epoch time of 75 seconds. An epoch is created so that you can quickly view the data surrounding the point of interest (the trigger) without having to open the entire 60-minute file. Figure 237 shows an example of an epoch.

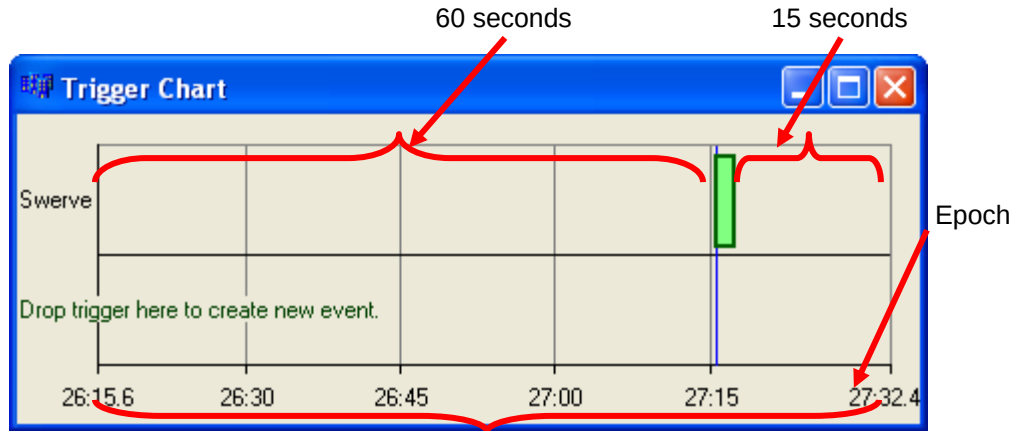


Figure 237. Trigger Chart showing an Unvalidated Trigger and an Epoch

Once you have opened an unvalidated trigger, you will need to determine if the trigger is valid or invalid:

- **Valid trigger** – A trigger in which something of interest is happening. For example, if the trigger is a swerve trigger, such as that in Figure 240, and after reviewing the video you determine that the driver was about to drive off the side of the road and had to swerve to get back on the road, you would mark this as a valid trigger since the truck sensors picked up something that was happening. Previously, less than 1% of the total triggers will be valid triggers.
- **Invalid trigger** – A trigger that was created correctly base on the threshold criteria, but is not valid based on the definition of a safety-critical event. There are several different types of invalid triggers:
 - **Non-conflict trigger** – A trigger in which something of interest is not happening, or the severity is not enough to be of interest, according to the criteria for the present study data analysis.
 - **Sensor error** – A TTC trigger in which the radar is detecting something other than another vehicle in the subject's intended path of travel (e.g., a bridge overpass or a tree).
 - **No video** – A trigger where either the face camera is out, or where one or more of the video quads are out and you are unable to determine the situation.

Examples of each of these different trigger types are shown below.

Longitudinal Acceleration Trigger (LA) – hard braking

Valid: In this example (Figure 238), the lead vehicle brakes unexpectedly, causing the truck driver to brake hard (-0.50 G).

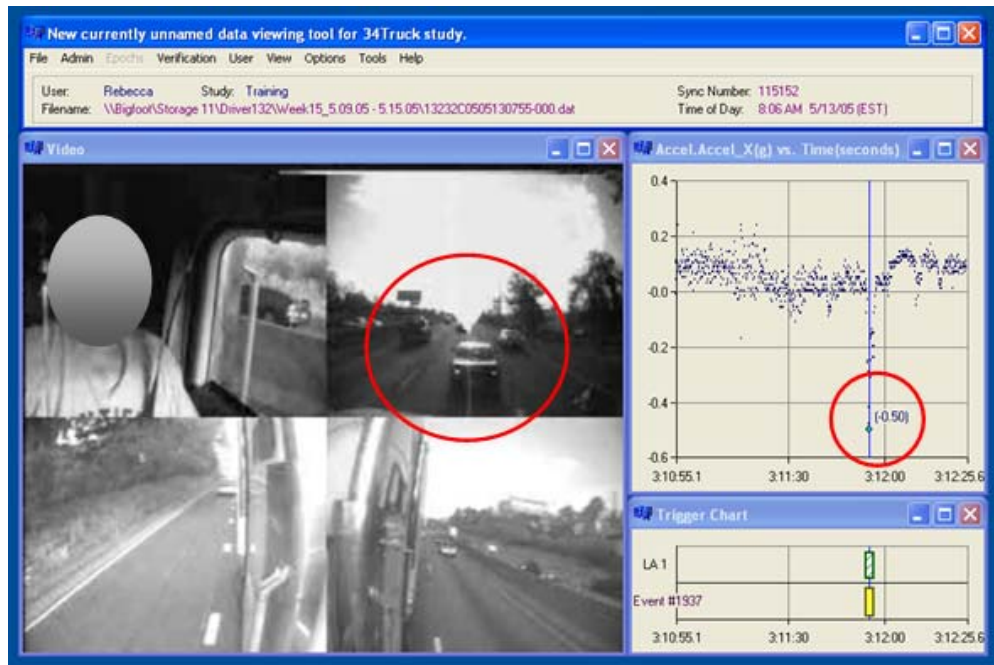


Figure 238. Valid Longitudinal Acceleration Trigger (LA)

Invalid: In this example (Figure 239), the Accel_X value has dropped below the trigger threshold of -0.35 G to -0.37 G. Looking at the video, it is clear that there is not a traffic safety threat to the driver and that he is braking to take an exit ramp.

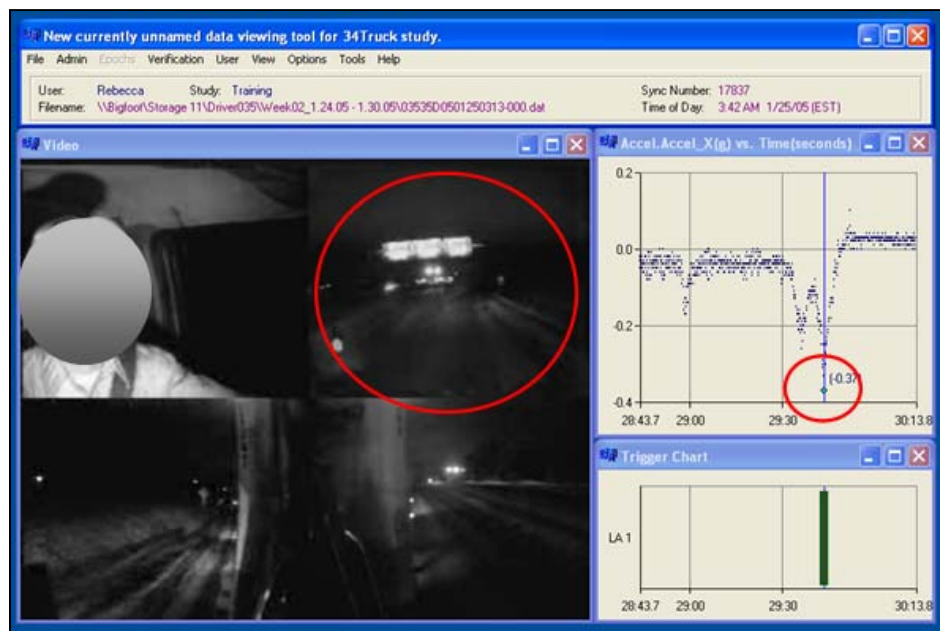


Figure 239. Invalid Longitudinal Acceleration Trigger (LA)

Swerve Trigger (Swerve) – sharp steering

Valid: In this example (Figure 240), the swerve value (**Gyro Rate**) reaches -3.95 rad/sec^2 (trigger threshold is set at -3 rad/sec^2) as the driver swerves the truck back onto the road after nearly driving off the right edge of the road while distracted.

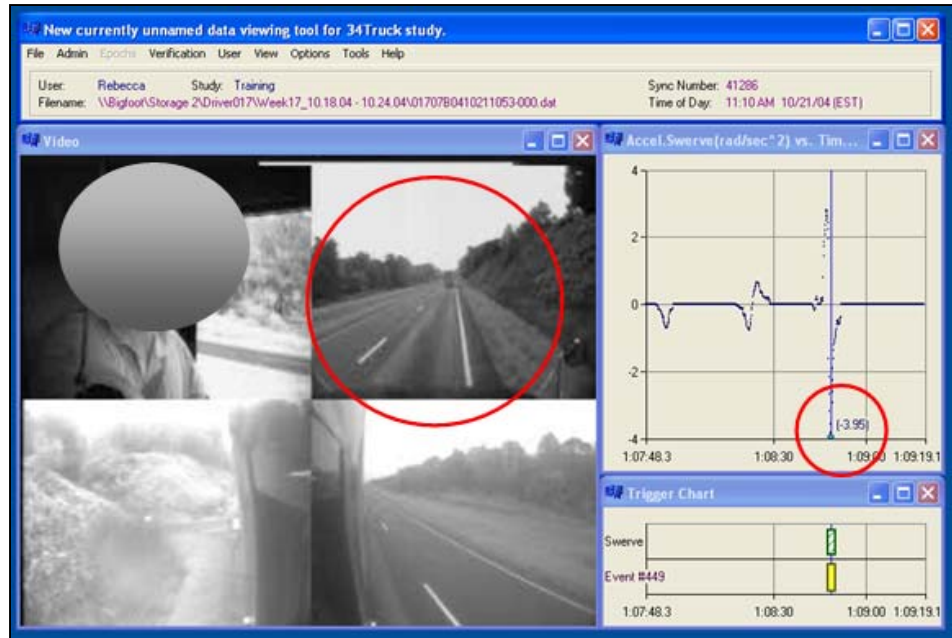


Figure 240. Valid Swerve Trigger (Swerve)

Invalid: In this example (Figure 241), the swerve value (**Gyro Rate**) has gone above the trigger threshold value of 3 rad/sec^2 to 3.68 rad/sec^2 . Looking at the video, it can be seen that the driver is only changing lanes into a turn lane and it not swerving to avoid a conflict.

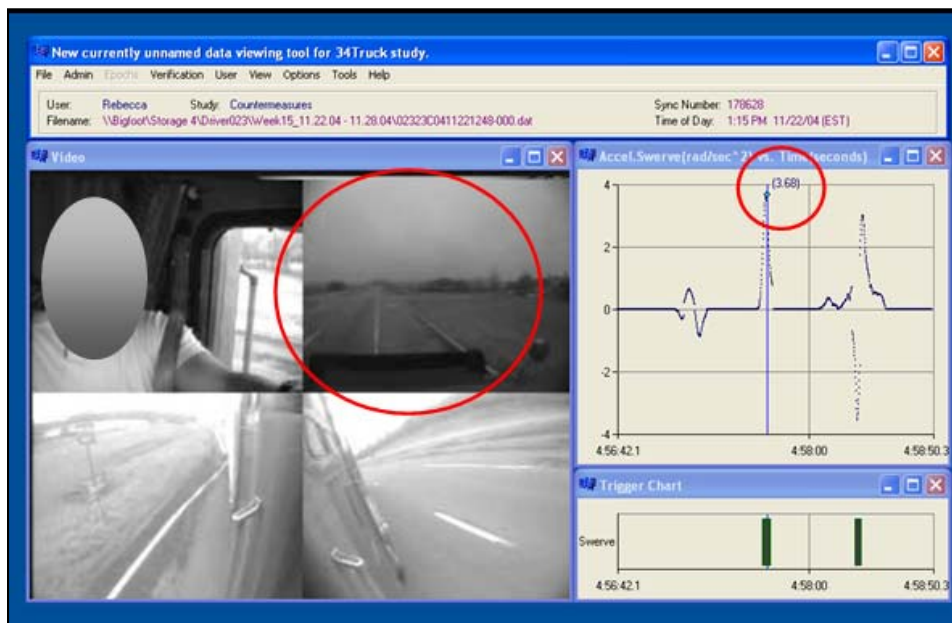


Figure 241. Invalid Swerve Trigger (Swerve)

Time-to-Collision (TTC) – rapid approach of the SV to a lead vehicle or other object in the subject’s path of travel.

Valid: In this example (Figure 242), the time-to-collision (TTC) value has dropped to 0.48 sec (trigger threshold set at 1.85 sec). This means that the truck driver has gotten too close to the lead vehicle which is making a right turn onto a side road.

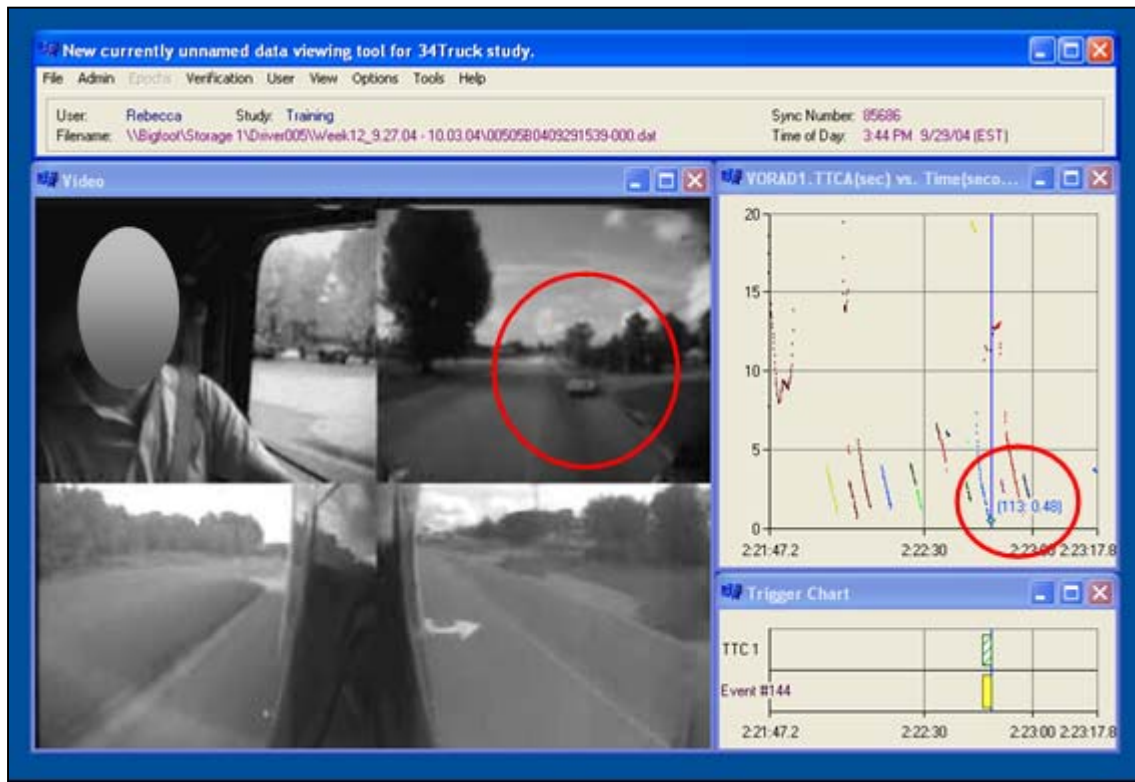


Figure 242. Valid Time-to-Collision (TTC) Trigger

Invalid: In this example, the TTC value drops below the threshold of 1.85 seconds to 1.13 seconds. Looking at the video, it can be seen that the forward radar is detecting the vehicle in the left turn lane as the target vehicle. Since the two vehicles are not in a path for a possible conflict, this is considered an invalid trigger.

Sensor Error: In this example (Figure 243) the TTC value drops below the threshold of 1.85 seconds to 1.62 seconds. Looking at the video, it can be seen that there are not any vehicles in front of the truck and that the radar is detecting the bridge as a target vehicle. There is no threat of collision.

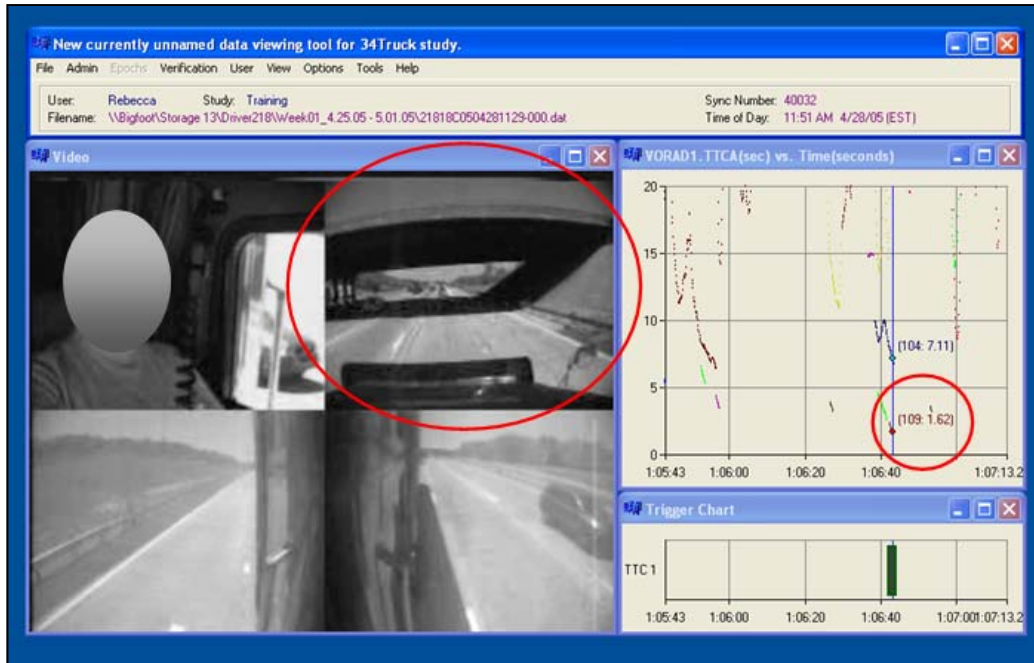


Figure 243. Invalid Time-to-Collision (TTC) Trigger

No video: In this example (Figure 244), the trigger is an LA, meaning the driver likely had to brake due to something in front of his truck, but since the front camera is out, it is not possible to see what is happening.

- There are several conditions for which a trigger would be marked as no video:
 - The face camera is out or not working correctly and the screen is completely black or fuzzy.
 - The camera that you need to use to see what is going on is out or not working correctly. For example, if the conflict is happening with a car in front of the truck, and the front camera is out.
 - There is an error and the video won't load in DART.
 - The video is frozen.

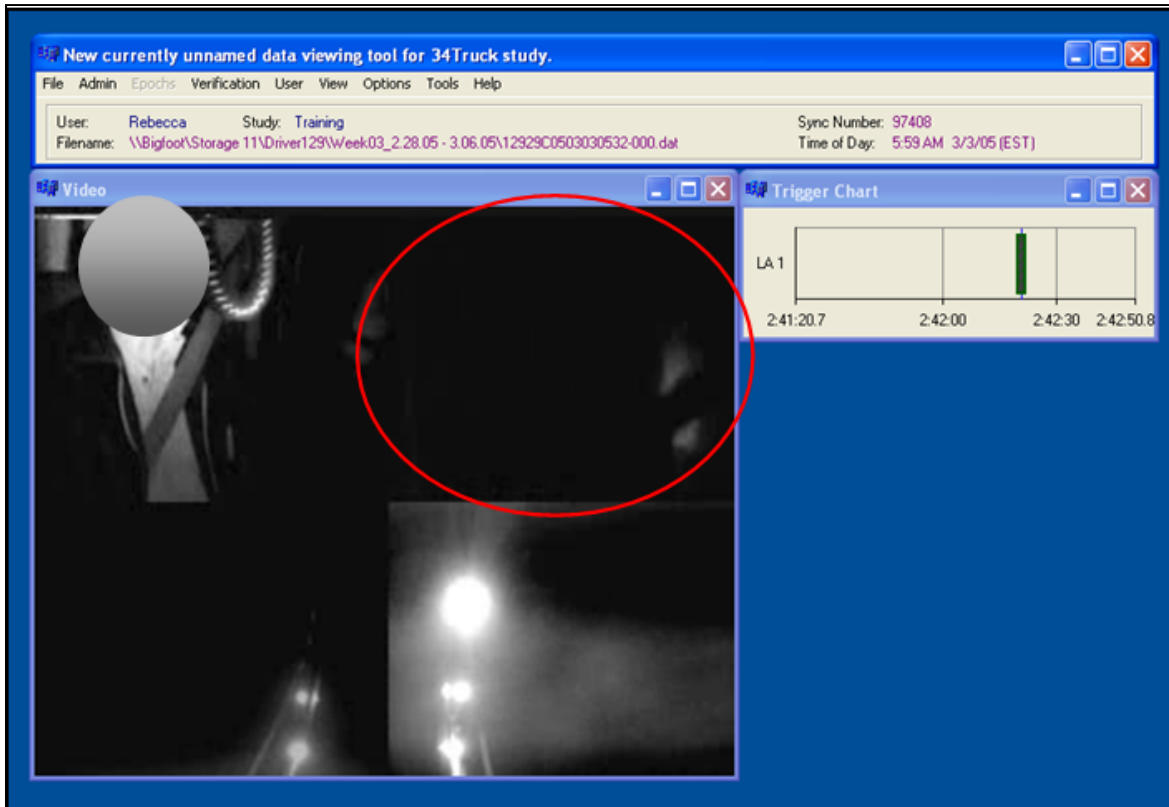


Figure 244. “No Video” Example

Once you have determined what type of trigger you are looking at, you will mark it appropriately. To mark a trigger as *valid*, you will left click on the colored trigger (Figure 245) and drag it straight down to the bottom of the trigger chart (Figure 246). A yellow event box and an event ID will appear.



Figure 245. Drag Trigger Straight Down to Validate

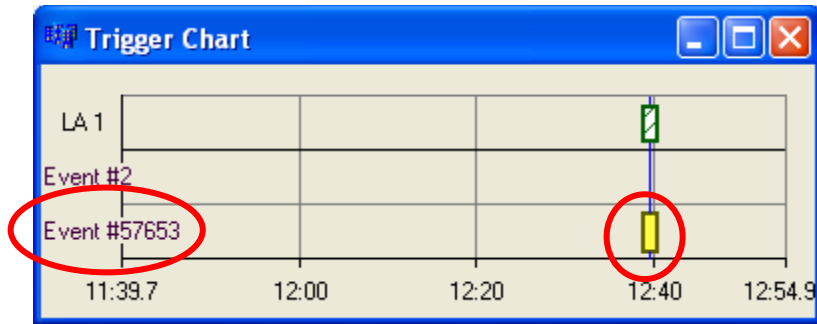


Figure 246. Yellow Event Marker and Event ID

To mark a trigger as *invalid*, right-click on the trigger and choose the appropriate invalid option (Figure 247).

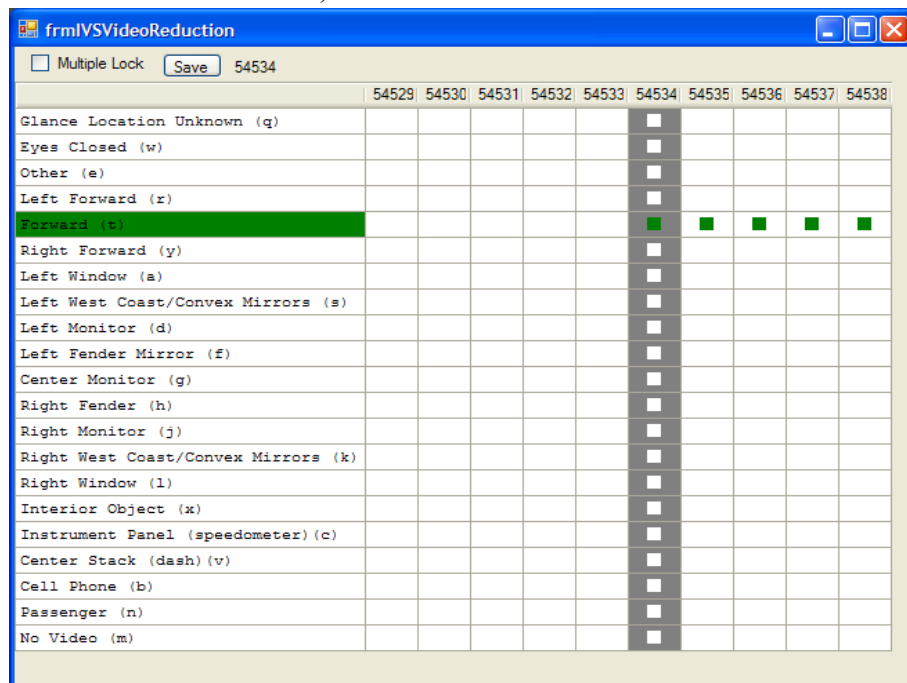


Figure 247. Invalidate Trigger

APPENDIX W. SCE EYE GLANCE REDUCTION PROTOCOL

DART II will be required to perform the eyeglance analysis.

1. Open DART II
2. Open the **IVS** collection (File → Open Collection → IVS).
3. Open the Excel Log:
 - On the **Driver Sign Out tab**, sign out a driver for Safety-Critical Events
 - On the **Safety-Critical Event tab**, sign out an event for that driver to begin working on
4. Load the Open File ID Query Window (File → Open File ID). Paste in the File ID you signed out. Click Open.
5. Load the following views:
 - View → Video/Play Controller
 - Tools → Video Reduction
 - Variables → HEL_CAN_Port → Video Frame
6. From the Excel log, note the start and stop sync numbers for your Event ID. Using the Play Controller, locate the start sync.
7. Verify that the video is aligned to the data by checking the frame number printed on the video against the value listed in the Video_Frame chart.
8. Load the Video Reduction Chart so that you can see at a glance all the data that you've entered. (Tools → Video Reduction)

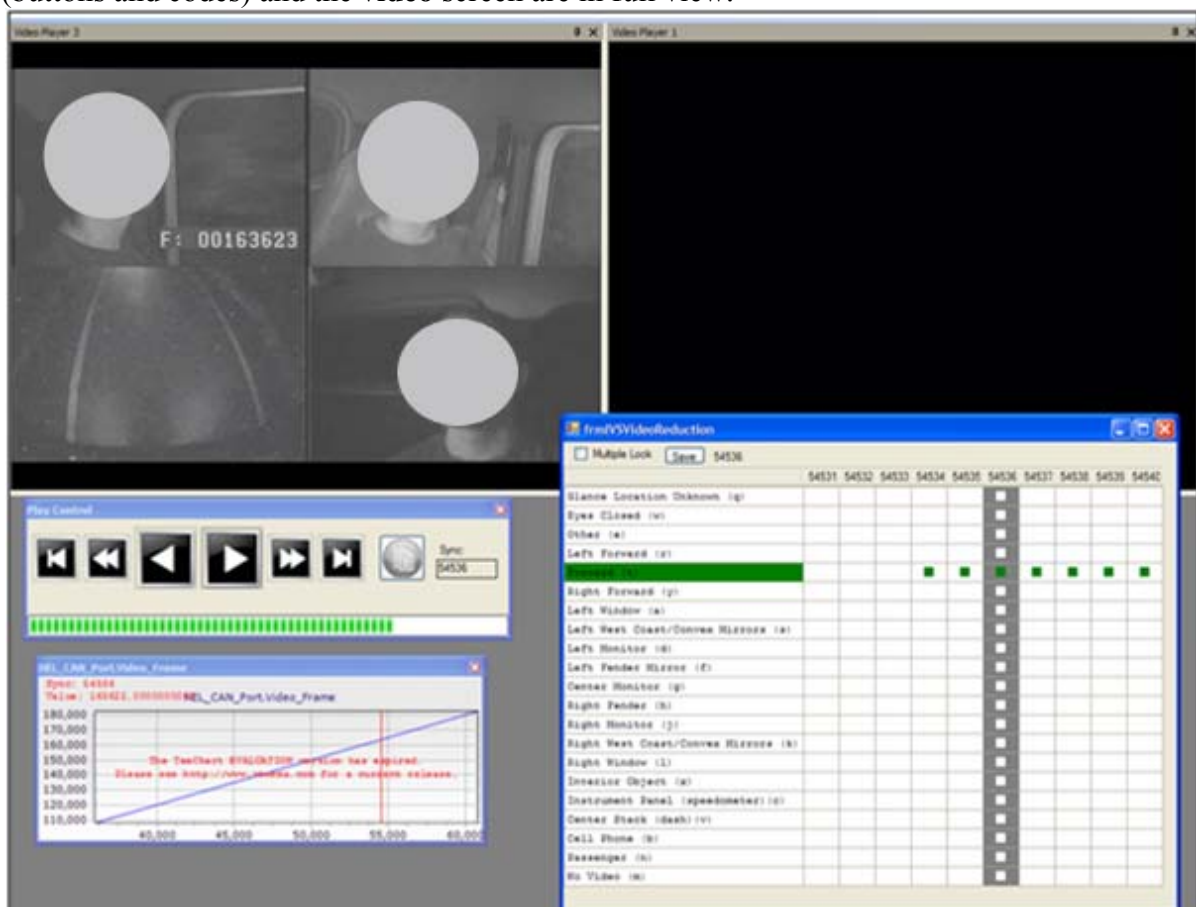


	54529	54530	54531	54532	54533	54534	54535	54536	54537	54538
Glance Location Unknown (q)										
Eyes Closed (w)										
Other (e)										
Left Forward (r)										
Forward (t)										
Right Forward (y)										
Left Window (a)										
Left West Coast/Convex Mirrors (s)										
Left Monitor (d)										
Left Fender Mirror (f)										
Center Monitor (g)										
Right Fender (h)										
Right Monitor (j)										
Right West Coast/Convex Mirrors (k)										
Right Window (l)										
Interior Object (x)										
Instrument Panel (speedometer) (c)										
Center Stack (dash) (v)										
Cell Phone (b)										
Passenger (n)										
No Video (m)										

9. Review the event first from the start sync to the stop sync to verify that you are able to complete eye glance. Some reasons for being unable to complete eyeglance are:
 - Driver is wearing dark sunglasses and it is not possible to see eyes for the majority of the necessary time frame.
 - Video is bad/dark/out of alignment and it is not possible to see eyes for the majority of the necessary time frame.

If either of the above is true, mark down on the log that the event could not be reduced and the reason why.

10. You should watch the three face view quadrants of the video to get an idea of the type of glances made during the event. However, it is also important to pay attention to the other quadrants as well. For example, seeing that the driver is trying to change lanes, by watching the video of the roadway will tell you to expect mirror/window and monitor glances.
11. When you are ready to begin entering in eyeglance data, make sure you are at the “Eyeglance Start Sync” indicated in the Excel Log.
12. Arrange the DART modules on your desktop to ensure that both the **video reduction** screen (buttons and codes) and the **video** screen are in full view.



13. Select the **video reduction** screen, and using your keyboard, enter in the first glance location. Please refer to Table 54 for glance location definitions and codes. Figure 248 includes diagrams that illustrate different locations in vehicles.
14. Each time you press the glance location key, the video will advance one sync. You will need to press the key for each sync. DO NOT hold down a key when performing eyegance in DART 2, because the video will not advance smoothly.
15. Notice that when you press a specific key, the corresponding sync will be highlighted in gray on the video reduction screen. Any unsaved data that you've entered will show up as red squares. Data that has already been saved will show up as green squares.

The screenshot shows a software window titled "frmIVSVideoReduction". It has a "Multiple Lock" checkbox and a "Save" button next to the number "794". Below this is a grid with 11 columns representing syncs (789 to 798) and 20 rows representing different glance locations. The grid contains green squares (saved data) and red squares (unsaved data). The 794 column is highlighted in gray.

	789	790	791	792	793	794	795	796	797	798
Left Window (a)						■				
Cell Phone (b)						■				
Instrument Panel (speedometer) (c)	■					■				
Left Monitor (d)						■				
Left Forward (e)				■	■	■				
Center Monitor (f)						■				
Right Monitor (g)	■	■	■			■				
Right West Coast/Convex Mirrors (h)						■				
Right Window (j)						■				
No Video (m)						■				
Passenger (n)						■				
Glance Location Unknown (q)						■				
Forward (r)						■				
Left West Coast/Convex Mirrors (s)						■				
Right Forward (t)						■				
Center Stack (dash) (v)						■				
Eyes Closed (w)						■				
Interior Object (x)						■				
Other (y)						■				

16. If you want to go back and review your data entry and the video, you can use the left and right arrows on your keyboard to shuttle the video and the corresponding eyegance entries (as noted on the **video reduction** screen). If upon your review, you wish to change a glance location, shuttle the video reduction tool to the sync of the erroneous entry, and re-key in the correct glance location. This will overwrite your previous data.
17. A glance begins with a fixation on one of the glance locations defined in the table and ends when the next glance starts (with the next fixation). Any transition time from one fixation to another is kept with the first glance. For example, if the participant is looking forward and shifts their gaze to the instrument panel, you would mark **Forward** until their eyes are fixated on the center stack (at which point you would start marking **Instrument panel**).

18. Blinking is not recorded
19. Continue reducing continuously until you have reached the “Eyeglance End Sync” indicated in the Excel log.
20. Save the eyeglance.

	789	790	791	792	793	794	795	796	797	798
Left Window (a)						■				
Cell Phone (b)						■				
Instrument Panel (speedometer) (c)	■					■				
Left Monitor (d)						■				
Left Forward (e)				■	■	■				
Center Monitor (f)						■				
Right Monitor (g)	■	■	■			■				
Right West Coast/Convex Mirrors (h)						■				
Right Window (j)						■				
No Video (m)						■				
Passenger (n)						■				
Glance Location Unknown (q)						■				
Forward (r)						■				
Left West Coast/Convex Mirrors (s)						■				
Right Forward (t)						■				
Center Stack (dash) (v)						■				
Eyes Closed (w)						■				
Interior Object (x)						■				
Other (y)						■				

21. In the Excel log, describe any special conditions that characterized the event (e.g. eyes obstructed by visor or glare for part of event).
22. Document in the log's comments sections any situations that are unique and might affect interpretation of the glances. For example, note anything unusual in any camera view, or reasons for any unusually long glances to glance locations off of the roadway (e.g. the participant looks at the radio continuously for 5 seconds because he/she is stopped at a red light).
23. Move on to the next event indicated in the Excel log.

Table 54. Eye Glance Location Definitions and Codes

Key	Position	Description
T	Forward	Any glance out the forward windshield. Note that when the vehicle is turning, these glances may not be directed directly forward but towards the vehicle's heading. Count these as forward glances. Note also that 'forward' glances may be directed to vehicles ahead in the adjacent lane or other external distractions slightly ahead of the subject. Also count as forward side glances that are taken in the process of turning into or crossing a road (e.g. the vehicle is stopped at an intersection and waiting for a gap in traffic to enter or cross the intersecting road, the driver looks left and right to check traffic conditions).
C	Instrument Panel	Any glance to the instrument cluster underneath the dashboard. This includes glances to the speedometer, control stalks, and steering wheel.
V	Center Stack	Any glance to the truck's center stack, located to the right of the Instrument Panel. This is where radio, climate, etc. controls are located. Glances below the Center Stack (e.g., to the cup holder area or the gear shift) would be coded as Interior Object.
S	Left West Coast/ Convex Mirror	Any glance to the left-side west coast/convex mirror.
K	Right West Coast/ Convex Mirror	Any glance to the right-side west coast/convex mirror.
B	Cell Phone (electronic communications device)	Any glance at a cell phone no matter where it is located. THIS DOES NOT INCLUDE THE ELECTRONIC TRACKING DEVICES THAT DRIVERS USE; PLEASE MARK THAT AS INTERIOR OBJECT.
A	Left Window	Any glance out the left-side window.
D	Left Monitor	Any glance at the left-side monitor.
F	Left Fender Mirror	Any glance to the left fender mirror, located on the front part of the truck's front fender.
R	Left Forward	Any glance to the left out the front window.
G	Center Monitor	Any glance at the center monitor.
Y	Right Forward	Any glance to the right out the front window.
J	Right Monitor	Any glance at the right-side monitor.

Key	Position	Description
H	Right Fender Mirror	Any glance to the right fender mirror, located on the front part of the truck's front fender.
L	Right Window	Any glance out the right-side window.
n	Passenger	Any glance at a passenger.
X	Interior Object	Any glance to an identifiable object in the vehicle other than a cell phone. These objects include personal items brought in by the participant (e.g., purse, food, papers), any part of their body that may look at (e.g., hand, ends of hair), electronic devices other than cell phones (e.g., iPod, laptop, CB radio), and also OEM installed devices that don't fall into other categories (e.g., door lock, window and seat controls). Glances to the center console (cupholder area between passenger seat and driver seat) and gear shifter (if located in that area) will also be included in this category. The object does not need to be in the camera view for a specific frame to be coded with this category. If it is clear from surrounding video that the participant is looking at the object, this category may be used. This category can be used regardless of whether the participant's hands are/aren't visible. Note: in truck studies such as this, Interior Object also includes glances to the instruments at the top of the windshield/overhead.
M	No Video	Unable to complete glance analysis because the face video view is unavailable.
Q	Glance Location Unknown	Unable to complete glance analysis due to an inability to see the driver's eyes/face. Video data is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand,), or due to glare.
W	Eyes Closed	Any time that the participant's eyes are closed outside of normal blinking (e.g., the subject is falling asleep). As a rule of thumb, if the eyes are closed for five or more syncs (1/2 a second) during a slow blink, code it as Eyes Closed.
E	Other	Any glance that cannot be categorized using the above codes (e.g., specific built-in vehicle features). If you come across anything that could fall under this category, please inform the Lab Manager and leave an explanation in the Excel log for appropriate follow-up.

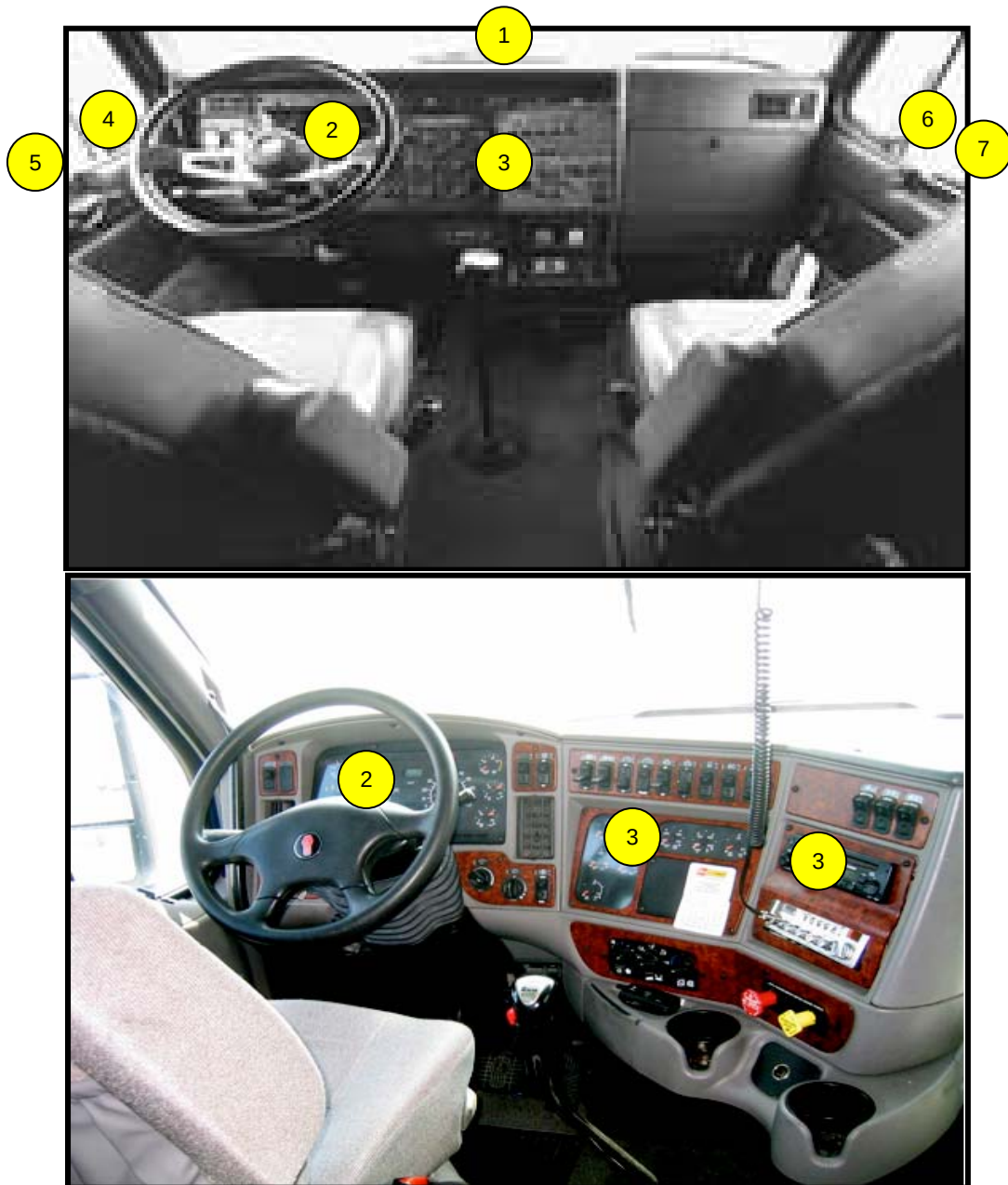


Figure 248. Illustration of Truck Interior

- 1- Forward
- 2- Instrument Panel
- 3- Center Stack
- 4- Left Mirror
- 5- Left Window
- 6- Right Mirror
- 7- Right Window

APPENDIX X. SAFETY-CRITICAL EVENT VARIABLES

The following variables will be recorded for all safety-critical events.

Event Variables

1. Event Classification

- 01 = Crash. Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals.
- 02 = Curb Strike: Avoidable. Any contact with a curb or median where it is apparent that the driver could have performed a maneuver to avoid the contact.
- 03 = Curb Strike: Unavoidable. Any contact with a curb or median where it is apparent that the driver could not have performed a maneuver to avoid the contact. The most likely cause for these events are poor roadway design.
- 04 = Near-Crash. Any circumstance requiring a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash, OR any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A rapid, evasive maneuver is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.
- 05 = Crash-Relevant Conflict. Any circumstance that requires a crash avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a “normal maneuver” to avoid a crash OR any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A “normal maneuver” for the subject vehicle is defined as a control input that falls within the 99% confidence limit for control inputs for the initial study data sample. Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat, or proximity to other vehicles.
- 06 = Illegal Maneuver. Any circumstance where either the subject vehicle or the other vehicle performs an illegal maneuver such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.

Note: Categories adapted from Dingus et al., 2005 and Hickman et al., 2005. Crash: Tire Strike category only used in Hickman et al., 2005. This variable is extremely subjective and is determined using the best judgment of an analyst. Illegal Maneuver is new to the 8Truck study.

2. Vehicles/Non-Motorists Involved

- 01 = 1 vehicle (Subject vehicle only or subject vehicle + object)
- 02 = 2 vehicles
- 03 = 3 vehicles
- 04 = 4 or more vehicles
- 05 = Subject vehicle + pedestrian
- 06 = Subject vehicle + pedalcyclist
- 07 = Subject vehicle + animal
- 08 = Other

Note: For some events (e.g., those involving transient encroachment into an oncoming lane), it will be difficult to decide whether the event should be considered a one or two vehicle event. Consider the event a two-vehicle event if the crash resulting from the incident would likely have involved two vehicles, and/or if either driver's maneuvers were influenced by the presence of the other vehicle (e.g., if DV1 maneuvered to avoid V2). Consider the event a one-vehicle event if the presence of other vehicles presented no immediate threat and had no effect on DV1's maneuvers or behaviors.

3. Vehicle/Non-Motorist 2 Type

- 00b = Not applicable (single vehicle event – no object)
- 01 = Automobile
- 02 = Van (minivan or standard van)
- 03 = Pickup truck
- 04 = SUV (includes Jeep)
- 05 = School bus
- 06 = Transit bus
- 07 = Greyhound bus
- 08 = Conversion bus
- 09 = Single-unit straight truck: Multi-stop/Step Van
- 10 = Single-unit straight truck: Box
- 11 = Single-unit straight truck: Dump
- 12 = Single-unit straight truck: Garbage/Recycling
- 13 = Single-unit straight truck: Concrete mixer
- 14 = Single-unit straight truck: Beverage
- 15 = Single-unit straight truck: Flatbed
- 16 = Single-unit straight truck: Tow truck
- 17 = Single-unit straight truck: Other
- 18 = Single-unit straight truck: Unknown
- 19 = Straight Truck + trailer
- 20 = Tractor-trailer: Cab only
- 21 = Tractor-trailer: Cab + trailer
- 22 = Tractor-trailer: Flatbed

- 23 = Tractor-trailer: Tank
- 24 = Tractor-trailer: Car carrier
- 25 = Tractor-trailer: Livestock
- 26 = Tractor-trailer: Lowboy trailer
- 27 = Tractor-trailer: Dump trailer
- 28 = Tractor-trailer: Multiple trailers
- 29 = Tractor-trailer: Multiple trailers/grain
- 30 = Tractor-trailer: Other
- 31 = Other large construction equipment
- 32 = Ambulance
- 33 = Fire truck
- 34 = Motorcycle or moped
- 35 = Police car
- 36 = Vehicle pulling trailer (other than tractor-trailer)
- 37 = Other vehicle type
- 38 = Pedestrian
- 39 = Pedacyclist
- 40 = Deer
- 41 = Other animal
- 42 = Object (single vehicle event with relevant object)
- 43 = Unknown

Note: Highly abridged version of GES V5, Body Type; above codes do not match GES codes. Examples of heavy vehicles are shown in the tables below.

Table 55. Buses

 School Bus	 Transit Bus
 Greyhound Bus	 Conversion Bus

Table 56. Straight Trucks

 Multistop/Step Van	 Box
 Dump	 Garbage/Recycling
 Concrete Mixer	 Beverage
 Other Large Construction Equipment	 Other: Flatbed
 Other: Tow Truck	 Straight Truck (dump truck) + Trailer

Table 57. Tractor-Trailer Trucks

 Tractor-trailer (Cab only)	 Tractor-trailer (Cab plus trailer)
 Tractor-trailer: Flatbed	 Tractor-trailer: Tank
 Tractor-trailer: Car carrier	 Tractor-trailer: Livestock
 Tractor-trailer: Lowboy trailer	 Tractor-trailer: Dump trailer
 Tractor-trailer: Multiple trailers	 Tractor-trailer: Multiple trailers/grain

Table 58. Emergency Vehicles

 Ambulance	 Fire Truck

4. Relevant Object

- 00b = Not applicable (single vehicle event – no relevant object; e.g., shoulder only)
- 00c = Not applicable (multi-vehicle event, pedestrian, animal, etc.)
- 01 = Parked motor vehicle

Fixed objects:

- 02 = Building
- 03 = Impact attenuator/crash cushion
- 04 = Bridge structure (e.g., abutment)
- 05 = Guardrail
- 06 = Concrete traffic barrier or other longitudinal barrier (e.g., “Jersey Barrier”)
- 07 = Post, pole, or support (e.g., sign, light)
- 07a = Mailbox
- 08 = Culvert/ditch/edge of road
- 09 = Curb
- 10 = Embankment
- 11 = Fence
- 12 = Wall
- 13 = Fire hydrant
- 14 = Shrubbery or bush
- 15 = Tree *[not overhang – see below]*
- 16 = Boulder
- 17 = Loading dock
- 18 = Loading equipment (e.g., fork lift, pallets)
- 19 = Cargo

Overhanging objects (only if struck or potentially struck by top of truck/trailer)

- 20 = Tree branch
- 21 = Overhanging part of sign or post
- 22 = Bridge/overpass
- 23 = Building
- 24 = Telephone wires

Non-fixed objects:

- 25 = *Vehicle parts, including tire parts*
- 26 = *Spilled cargo*
- 27 = *Dead animal in roadway*
- 28 = *Broken tree limbs or other tree/shrub parts*
- 29 = *Trash/debris*
- 30 = *Construction barrel*
- 31 = *Construction cone*

Other:

- 98 = *Other*
- 99 = *Unknown object hit*

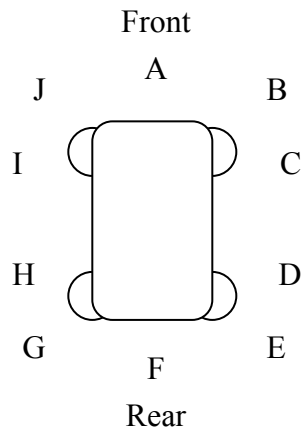
Note: GES A06, First Harmful Event. Options in italics are not A06 codes.

5. Vehicle/Non-Motorist 2 Position (in Relation to V1)

The vehicle in the diagram represents the subject vehicle (V1, the truck). The relative position of Vehicle 2 (in relation to Vehicle 1) is coded for the time in which the Critical Event occurs (i.e., the event creating the crash risk). Vehicles in adjacent left lane are coded J, I, H, or G depending on position. Vehicles in adjacent right lane are coded B, C, D or E depending on position. Please also code the position of animals, pedestrians, pedacyclists and objects.

00b = Not applicable (single vehicle event – no object)

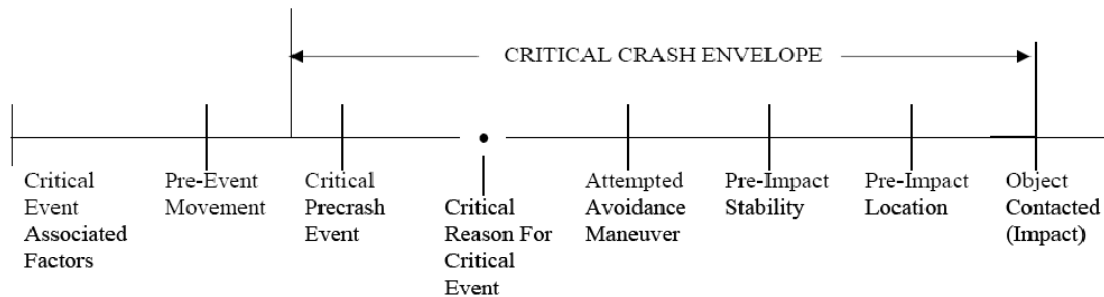
K = Top of vehicle

**6. Vehicle 1 Pre-Event Movement**

- 01 = Going straight (and not known to be engaged in movements listed below)
- 02 = Decelerating in traffic lane
- 03 = Accelerating in traffic lane
- 04 = Starting in traffic lane
- 05 = Stopped in traffic lane

- 06 = Passing or overtaking another vehicle
- 07 = Disabled or parked in travel lane
- 08a = Leaving a parking position, moving forward
- 08b = Leaving a parking position, backing
- 09a = Entering a parking position, moving forward
- 09b = Entering a parking position, backing
- 10 = Turning right
- 11 = Turning left
- 12 = Making a u-turn
- 13 = Backing up (other than parking)
- 14 = Negotiating a curve
- 15 = Changing lanes
- 16 = Merging
- 17 = Successful avoidance maneuver to a previous critical event
- 98 = Other
- 99 = Unknown

Note: LTCCS Variable 4 with expanded choices for 8 and 9. The Pre-Event Movement is considered to be outside of the Critical Crash Envelope, shown below.

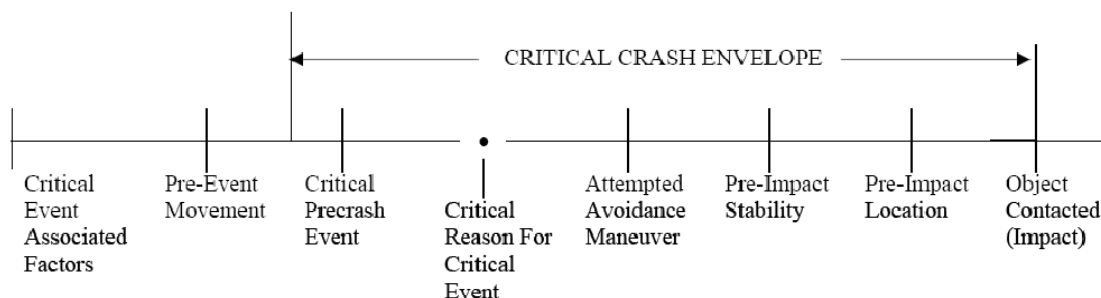


7. Vehicle 2 Pre-Event Movement

- 00b = Not applicable (single vehicle event)
- 01 = Going straight (and not known to be engaged in movements listed below)
- 02 = Decelerating in traffic lane
- 03 = Accelerating in traffic lane
- 04 = Starting in traffic lane
- 05 = Stopped in traffic lane
- 06 = Passing or overtaking another vehicle
- 07 = Disabled or parked in travel lane
- 08a = Leaving a parking position, moving forward
- 08b = Leaving a parking position, backing
- 09a = Entering a parking position, moving forward
- 09b = Entering a parking position, backing

- 10 = Turning right
- 11 = Turning left
- 12 = Making a u-turn
- 13 = Backing up (other than parking)
- 14 = Negotiating a curve
- 15 = Changing lanes
- 16 = Merging
- 17 = Successful avoidance maneuver to a previous critical event
- 98 = Other
- 99 = Unknown

Note: LTCCS Variable 4 with expanded choices for 8 and 9. The Pre-Event Movement is considered to be outside of the Critical Crash Envelope, shown below.



8. Vehicle 1 Critical Pre-Crash Event

This variable is coded for both vehicles in a two-vehicle incident. However, the Critical Reason (see below), is coded for only one vehicle. For consistency with the Accident Type variable (20), lane edges between travel lanes and non-travel lanes (e.g., shoulders) are considered road edges. Unlike the Accident Type variable, however, you should code the actual precipitating event and should not project or extrapolate the event.

THIS VEHICLE (V1) LOSS OF CONTROL DUE TO:

- 01 = Blow out or flat tire
- 02 = Stalled engine
- 03 = Disabling vehicle failure (e.g., wheel fell off)
- 04 = Non-disabling vehicle problem (e.g., hood flew up)
- 05 = Poor road conditions (*wet road*, puddle, pot hole, ice, etc.)
- 06 = Traveling too fast for conditions
- 07 = Jackknife event
- 08 = Cargo shift
- 09 = *Braking*
- 10 = *Steering*
- 18 = Other cause of control loss
- 19 = Unknown cause of control loss

THIS VEHICLE (V1) TRAVELING

- 20 = *Toward or over the lane line on left side of travel lane*
- 21 = *Toward or over the lane line on right side of travel lane*
- 22 = *Toward or off the edge of the road on the left side*
- 23 = *Toward or off the edge of the road on the right side*
- 24 = End departure
- 25 = Turning left at intersection
- 26 = Turning right at intersection
- 27 = Crossing over (passing through) intersection
- 28 = This vehicle decelerating
- 28a = This vehicle accelerating
- 29 = Unknown travel direction

OTHER MOTOR VEHICLE (V2) IN LANE

- 50 = Other vehicle stopped
- 51 = Traveling in same direction with lower steady speed
- 52 = Traveling in same direction while decelerating
- 53 = Traveling in same direction with higher speed
- 54 = Traveling in opposite direction
- 55 = In crossover
- 56 = Backing
- 59 = Unknown travel direction of other motor vehicle in lane

OTHER MOTOR VEHICLE (V2) ENCROACHING INTO LANE

- 60 = From adjacent lane (same direction) – *toward or over left lane line*
- 61 = From adjacent lane (same direction) – *toward or over right lane line*
- 62 = From opposite direction – *toward or over left lane line*
- 63 = From opposite direction – *toward or over right lane line*
- 64 = From parking lane
- 65 = From crossing street, turning into same direction
- 66 = From crossing street, across path
- 67 = From crossing street, turning into opposite direction
- 68 = From crossing street, intended path not known
- 70 = From driveway, turning into same direction
- 71 = From driveway, across path
- 72 = From driveway, turning into opposite direction
- 73 = From driveway, intended path not known
- 74 = From entrance to limited access highway
- 78 = Encroachment by other vehicle – details unknown

PEDESTRIAN, PEDALCYCLIST, OR OTHER NONMOTORIST

- 80 = Pedestrian in roadway
- 81 = Pedestrian approaching roadway
- 82 = Pedestrian - unknown location
- 83 = Pedalcyclist or other nonmotorist in roadway
- 84 = Pedalcyclist or other nonmotorist approaching roadway
- 85 = Pedalcyclist or other nonmotorist - unknown location

OBJECT OR ANIMAL

- 87 = Animal in roadway
- 88 = Animal approaching roadway
- 89 = Animal – unknown location
- 90 = Object in roadway
- 91 = Object approaching roadway
- 92 = Object – unknown location

OTHER

- 98 = Other critical pre-crash event
- 99 = Unknown

Note: LTCCS Variable 5.

9. Vehicle 2 Critical Pre-Crash Event

This variable is coded for both vehicles in a two-vehicle incident. However, the Critical Reason (see below), is coded for only one vehicle.

- 00b = Not applicable (single vehicle event)

THIS VEHICLE (V2) LOSS OF CONTROL DUE TO:

- 01 = Blow out or flat tire
- 02 = Stalled engine
- 03 = Disabling vehicle failure (e.g., wheel fell off)
- 04 = Non-disabling vehicle problem (e.g., hood flew up)
- 05 = Poor road conditions (*wet road*, puddle, pot hole, ice, etc.)
- 06 = Traveling too fast for conditions
- 07 = Jackknife event
- 08 = Cargo shift
- 09 = *Braking*
- 10 = *Steering*
- 18 = Other cause of control loss
- 19 = Unknown cause of control loss

THIS VEHICLE (V2) TRAVELING

- 20 = *Toward or over the lane line on left side of travel lane*
- 21 = *Toward or over the lane line on right side of travel lane*

- 22 = *Toward* or off the edge of the road on the left side
- 23 = *Toward* or off the edge of the road on the right side
- 24 = End departure
- 25 = Turning left at intersection
- 26 = Turning right at intersection
- 27 = Crossing over (passing through) intersection
- 28 = This vehicle decelerating
- 28a = This vehicle accelerating
- 29 = Unknown travel direction

OTHER MOTOR VEHICLE (V1) IN LANE

- 50 = Other vehicle stopped
- 51 = Traveling in same direction with lower steady speed
- 52 = Traveling in same direction while decelerating
- 53 = Traveling in same direction with higher speed
- 54 = Traveling in opposite direction
- 55 = In crossover
- 56 = Backing
- 59 = Unknown travel direction of other motor vehicle in lane

OTHER MOTOR VEHICLE (V1) ENCROACHING INTO LANE

- 60 = From adjacent lane (same direction) – *toward* or over left lane line
- 61 = From adjacent lane (same direction) – *toward* or over right lane line
- 62 = From opposite direction – *toward* or over left lane line
- 63 = From opposite direction – *toward* or over right lane line
- 64 = From parking lane
- 65 = From crossing street, turning into same direction
- 66 = From crossing street, across path
- 67 = From crossing street, turning into opposite direction
- 68 = From crossing street, intended path not known
- 70 = From driveway, turning into same direction
- 71 = From driveway, across path
- 72 = From driveway, turning into opposite direction
- 73 = From driveway, intended path not known
- 74 = From entrance to limited access highway
- 78 = Encroachment by other vehicle – details unknown

PEDESTRIAN, PEDALCYCLIST, OR OTHER NONMOTORIST

- 80 = Pedestrian in roadway
- 81 = Pedestrian approaching roadway
- 82 = Pedestrian - unknown location

- 83 = Pedalcyclist or other nonmotorist in roadway
- 84 = Pedalcyclist or other nonmotorist approaching roadway
- 85 = Pedalcyclist or other nonmotorist - unknown location

OBJECT OR ANIMAL

- 87 = Animal in roadway
- 88 = Animal approaching roadway
- 89 = Animal – unknown location
- 90 = Object in roadway
- 91 = Object approaching roadway
- 92 = Object – unknown location

OTHER

- 98 = Other critical pre-crash event
- 99 = Unknown

Note: LTCCS Variable 5.

10. Vehicle 1 Critical Reason for the Critical Event

“This vehicle” will always be used for the vehicle being coded. Note that vehicle-related factors will rarely be apparent to analysts. Analysts will choose one critical reason that appears to be the main critical reason – the critical reason is coded for either V1 or V2, not both.

- 000b = Critical reason not coded to this vehicle

DRIVER RELATED FACTOR: Critical Non-Performance Errors

- 100 = Sleep, that is, actually asleep
- 101 = Heart attack or other physical impairment of the ability to act
- 107 = *Drowsiness, fatigue, or other reduced alertness (not asleep)*
- 108 = Other critical non-performance
- 109 = Unknown critical non-performance

DRIVER RELATED FACTOR: Recognition Errors

- 110 = Inattention (i.e., daydreaming)
- 111a = Internal distraction
- 111b = Looking at C/VIS
- 112 = External distraction
- 113 = Inadequate surveillance (e.g., failed to look, looked but did not see)
- 118 = Other recognition error
- 119 = Unknown recognition error

DRIVER RELATED FACTOR: Decision Errors

- 120 = Too fast for conditions (*e.g., for safe vehicle control or to be able to respond to unexpected actions of other road users*)

- 121 = Too slow for traffic stream
- 122 = Misjudgment of gap or other's speed
- 123 = Following too closely to respond to unexpected actions (close proximity for 2 or more seconds)
- 124 = False assumption of other road user's actions
- 125a = *Apparently intentional sign/signal violation*
- 125b = *Illegal U-turn*
- 125c = *Other illegal maneuver*
- 126 = Failure to turn on head lamps
- 127 = Inadequate evasive action (e.g., braking only not braking and steering; *release accelerator only instead of braking*)
- 128a = *Aggressive driving behavior: Intimidation: any behavior emitted by a driver while driving that is intended to cause physical or psychological harm to another person.*
- 128b = *Aggressive driving behavior: Wanton, neglectful or reckless behavior: excessive risky driving behaviors performed without intent to harm others, such as weaving through traffic, maneuvering without signaling, running red lights, frequent lane changing, and tailgating*
- 138 = Other decision error
- 139 = Unknown decision error
- 140 = *Apparent recognition or decision error (unknown which)*

DRIVER RELATED FACTOR: Performance Errors

- 141 = Panic/Freezing
- 142 = Overcompensation
- 143 = Poor directional control (e.g., failing to control vehicle with skill ordinarily expected)
- 148 = Other performance error
- 149 = Unknown performance error
- 199 = Type of driver error unknown

VEHICLE RELATED FACTOR

- 200 = Tires/wheels failed
- 201 = Brakes failed
- 202 = Steering failed
- 203 = Cargo shifted
- 204 = Trailer attachment failed
- 205 = Suspension failed
- 206 = Lights failed
- 207 = Vehicle related vision obstructions
- 208 = Body, doors, hood failed
- 209 = Jackknifed
- 298 = Other vehicle failure

299 = Unknown vehicle failure

ENVIRONMENT RELATED FACTOR: Highway Related

- 500 = Signs/signals missing
- 501 = Signs/signals erroneous/defective
- 503 = View obstructions by roadway design
- 504 = View obstructed by other vehicles crash circumstance
- 505 = Road design – roadway geometry (e.g., ramp curvature)
- 506 = Road design – sight distance
- 507 = Road design – other
- 508 = Maintenance problems (potholes, deteriorated road edges, etc.)
- 509 = Slick roads (low friction road surface due to ice, loose debris, any other cause)
- 518 = Other highway-related condition

ENVIRONMENT RELATED FACTOR: Weather Related

- 521 = Rain, snow [Note: code loss-of-control as 509]
- 522 = Fog
- 523 = Wind gust
- 528 = Other weather-related condition

ENVIRONMENT RELATED FACTOR: Other

- 530 = Glare
- 531 = Blowing debris
- 532 = *Animal in roadway (no driver error)*
- 533 = *Pedestrian or pedalcyclist in roadway (no driver error)*
- 534 = *Object in roadway (no driver error)*
- 538 = Other sudden change in ambience
- 999 = Unknown reason for critical event

Note: LTCCS Variable 6 with revisions in.

11. Vehicle 2 Critical Reason for the Critical Event

The elements for DV2 are either maneuvers or conditions visible from outside the vehicle (e.g., most of the decision error choices) or reasonable general inferences. Analysts will choose one critical reason that appears to be the main critical reason – the critical reason is coded for either V1 or V2, not both.

- 000b = Not applicable (single vehicle event)
- 000c = Critical reason not coded to this vehicle

DRIVER RELATED FACTOR

- 109 = Apparent critical non-performance [includes any apparent driver impairment]

DRIVER RELATED FACTOR: Recognition Errors

119 = Apparent recognition error

DRIVER RELATED FACTOR: Decision Errors

120 = Too fast for conditions (*e.g., for safe vehicle control or to be able to respond to unexpected actions of other road users*)

121 = Too slow for traffic stream

123 = Following too closely to respond to unexpected actions (close proximity for 2 or more seconds)

124 = False assumption of other road user's actions

125a = Apparently intentional sign/signal violation

125b = Illegal U-turn

125c = Other illegal maneuver

126 = Failure to turn on head lamps

127 = Inadequate evasive action (*e.g., braking only not braking and steering; release accelerator only instead of braking*)

128a = *Aggressive driving behavior: Intimidation: any behavior emitted by a driver while driving that is intended to cause physical or psychological harm to another person.*

128b = *Aggressive driving behavior: Wanton, neglectful or reckless behavior: excessive risky driving behaviors performed without intent to harm others, such as weaving through traffic, maneuvering without signaling, running red lights, frequent lane changing, and tailgating*

138 = Other decision error

139 = Apparent, unknown decision error

DRIVER RELATED FACTOR: Performance Errors

149 = Apparent performance error

199 = Type of driver error unknown

VEHICLE RELATED FACTOR

200 = Tires/wheels failed

201 = Brakes failed

298 = Apparent other vehicle failure

299 = Unknown vehicle failure

ENVIRONMENT RELATED FACTOR: Highway Related

500 = Signs/signals missing

501 = Signs/signals erroneous/defective

503 = View obstructions by roadway design

504 = View obstructed by other vehicles crash circumstance

505 = Road design – roadway geometry (*e.g., ramp curvature*)

506 = Road design – sight distance

507 = Road design – other

508 = Maintenance problems (*potholes, deteriorated road edges, etc.*)

- 509 = Slick roads (low friction road surface due to ice, loose debris, any other cause)
- 518 = Other highway-related condition

ENVIRONMENT RELATED FACTOR: Weather Related

- 521 = Rain, snow [Note: code loss-of-control as 509]
- 522 = Fog
- 523 = Wind gust
- 528 = Other weather-related condition

ENVIRONMENT RELATED FACTOR: Other

- 530 = Glare
- 531 = Blowing debris
- 538 = Other sudden change in ambience
- 999 = Unknown reason for critical event

12. Which vehicle is considered to be at fault?

The “at fault” vehicle is defined as the vehicle with the assigned Critical Reason with a few exceptions:

1. Animal/pedestrian/pedal cyclist in roadway is considered to be “Vehicle 2” at fault
2. Object in roadway is considered to be “No fault”
3. All environmental factors are considered to be “No fault”

- 01 = Vehicle 1 (subject vehicle)
- 02 = Vehicle 2 (other vehicle, animal, pedestrian, pedacyclist)
- 03 = No fault (object, environmental)
- 04 = Unknown

13. Vehicle 1 Attempted Avoidance Maneuver

- 01 = No avoidance maneuver
- 02 = Braking (no lockup or *lockup unknown*)
- 03 = Braking (lockup)
- 05 = Releasing brakes
- 06 = Steered to left
- 07 = Steered to right
- 08a = *Braked and steered to left (no lockup or lockup unknown)*
- 08b = *Braked and steered to left (lockup)*
- 09a = *Braked and steered to right (no lockup or lockup unknown)*
- 09b = *Braked and steered to right (lockup)*
- 10 = Accelerated
- 11 = Accelerated and steered to left
- 12 = Accelerated and steered to right
- 13 = *Released gas pedal without braking*

- 14 = Released gas pedal (without braking) and steered to left
- 15 = Released gas pedal (without braking) and steered to left
- 98 = Other actions
- 99 = Unknown if driver attempted any corrective action

Note: LTCCS Variable 7 and also GES V27, Corrective Action Attempted. “Released gas pedal” elements added because this evasive maneuver by subject drivers is sometimes observed.

14. Vehicle 2 Attempted Avoidance Maneuver

- 00b = Not applicable (single vehicle event)
- 01 = No avoidance maneuver
- 02 = Braking (no lockup or lockup unknown)
- 03 = Braking (lockup)
- 05 = Releasing brakes
- 06 = Steered to left
- 07 = Steered to right
- 08a = Braked and steered to left (no lockup or lockup unknown)
- 08b = Braked and steered to left (lockup)
- 09a = Braked and steered to right (no lockup or lockup unknown)
- 09b = Braked and steered to right (lockup)
- 10 = Accelerated
- 11 = Accelerated and steered to left
- 12 = Accelerated and steered to right
- 13 = Released gas pedal without braking
- 14 = Released gas pedal (without braking) and steered to left
- 15 = Released gas pedal (without braking) and steered to left
- 98 = Other actions
- 99 = Unknown if driver attempted any corrective action

Note: LTCCS Variable 7 and also GES V27, Corrective Action Attempted. “Released gas pedal” elements added because this evasive maneuver by subject drivers is sometimes observed.

15. Vehicle 1 Accident Type

Other Codes: See
Table 59 below.

Comment: Since this variable “includes intent,” analysts should *project* likely scenario roles for incidents where outcomes are not definite. In other words, if the trigger-related event had resulted in a crash, what would the crash scenario be? When specific scenarios cannot be projected, use the “Specifics Unknown” choices (e.g., 5, 10, 16, 33, etc.).

Table 59 illustrates the Accident Types.
Additional clarifications:

- Drive off road codes (e.g., 01 and 06) are used when a vehicle has crossed, or is projected to cross, a roadside delineation such as a lane edge line (going onto the shoulder or median), curb, or the edge of the pavement. This includes scenarios involving parked vehicles and stationary objects if those objects are outside of the roadway delineation (e.g., on an unpaved shoulder).
- Forward impact codes (e.g., 11, 12) are used when the objects are in the travel lane or when there is no lane edge delineation as described above. Thus, a scenario involving a parked vehicle on the pavement where there is no lane edge delineation is coded 12.
- If Single Driver codes (01-16) are used for V1, the V2 Accident Type code is 00b.
- For left-side lane departures into the oncoming traffic lane, code 64/65 if the lateral encroachment is less than a few feet. Code 50/51 only if the lateral encroachment was sufficient to create a significant risk of a head-on crash.
- Hard-braking events at intersections in the absence of a specific crash or crash threat are coded 91 (Intersecting straight paths, specifics unknown).

16. Vehicle 2 Accident Type

999 = Not applicable (single vehicle event)

Other Codes: See Table 59 below.

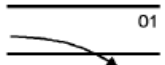
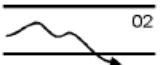
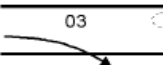
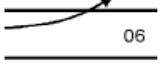
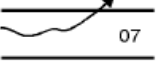
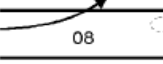
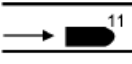
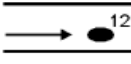
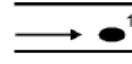
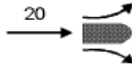
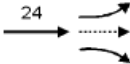
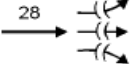
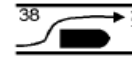
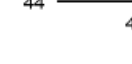
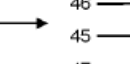
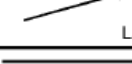
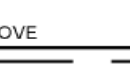
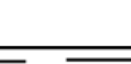
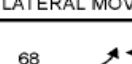
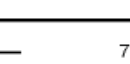
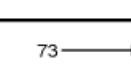
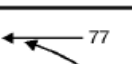
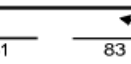
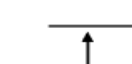
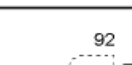
Comment: Since this variable “includes intent,” analysts should *project* likely scenario roles for incidents where outcomes are not definite. In other words, if the trigger-related event had resulted in a crash, what would the crash scenario be? When specific scenarios cannot be projected, use the “Specifics Unknown” choices (e.g., 5, 10, 16, 33, etc.).

Table 59 illustrates the Accident Types.

Additional clarifications:

- Single Driver codes (01-16) are not applicable to V2. If a Single Driver code (01-16) was used for V1, the V2 Accident Type code is 00b.
- For left-side lane departures into the oncoming traffic lane, code 64/65 if the lateral encroachment is less than a few feet. Code 50/51 only if the lateral encroachment was sufficient to create a significant risk of a head-on crash.

Table 59. Description of the Accident Types (Thieriez, Radja, & Toth, 2002)

Category	Configuration	ACCIDENT TYPES (Includes Intent)			
I. Single Driver	A. Right Roadside Departure	 01 DRIVE OFF ROAD	 02 CONTROL/ TRACTION LOSS	 03 AVOID COLLISION WITH VEH., PED., ANIM.	04 SPECIFICS OTHER
	B. Left Roadside Departure	 06 DRIVE OFF ROAD	 07 CONTROL/ TRACTION LOSS	 08 AVOID COLLISION WITH VEH., PED., ANIM.	05 SPECIFICS UNKNOWN
	C. Forward Impact	 11 PARKED VEHICLE	 12 STATIONARY OBJECT	 13 PEDESTRIAN/ ANIMAL	14 END DEPARTURE
II. Same Trafficway Same Direction	D. Rear-End	 20 STOPPED 21, 22, 23	 24 SLOWER 25, 26, 27	 28 DECELERATING 29, 30, 31	15 SPECIFICS OTHER
	E. Forward Impact	 34 CONTROL/ TRACTION LOSS	 36 CONTROL/ TRACTION LOSS	 38 AVOID COLLISION WITH VEHICLE	16 SPECIFICS UNKNOWN
	F. Sideswipe Angle	 44 45	 46 45	 47	(EACH - 32) SPECIFICS OTHER
III. Same Trafficway Opposite Direction	G. Head-On	 50 LATERAL MOVE	 51	 52	(EACH - 33) SPECIFICS UNKNOWN
	H. Forward Impact	 54 CONTROL/ TRACTION LOSS	 56 CONTROL/ TRACTION LOSS	 58 AVOID COLLISION WITH VEHICLE	(EACH - 42) SPECIFICS OTHER
	I. Sideswipe/ Angle	 64 LATERAL MOVE	 65	 66	(EACH - 43) SPECIFICS UNKNOWN
IV. Change Trafficway Vehicle Turning	J. Turn Across Path	 68 INITIAL OPPOSITE DIRECTIONS	 70 INITIAL SAME DIRECTION	 73	(EACH - 48) SPECIFICS OTHER
	K. Turn Into Path	 77 TURN INTO SAME DIRECTION	 80 TURN INTO OPPOSITE DIRECTIONS	 83	(EACH - 49) SPECIFICS UNKNOWN
V. Intersecting Paths (Vehicle Damage)	L. Straight Paths	 86	 88	 89	(EACH - 52) SPECIFICS OTHER
VI. Miscellaneous	M. Backing Etc.	 92 BACKING VEHICLE	 93 OTHER VEHICLE OR OBJECT	 98 OTHER ACCIDENT TYPE	(EACH - 53) SPECIFICS UNKNOWN

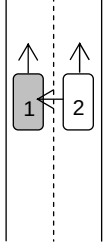
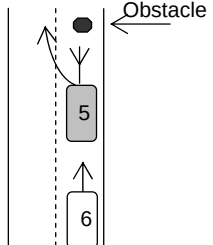
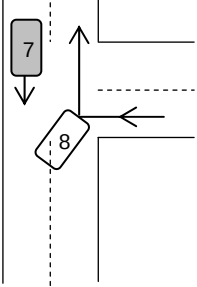
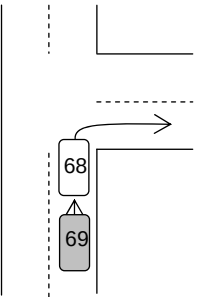
17. Vehicle 1 and Vehicle 2 Incident Type

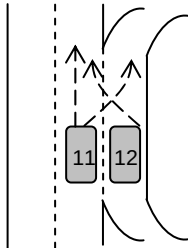
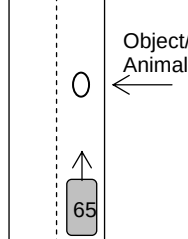
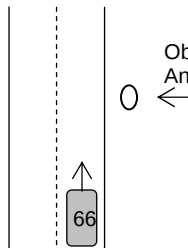
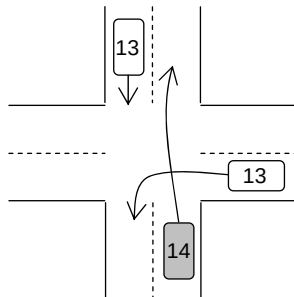
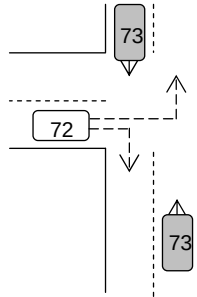
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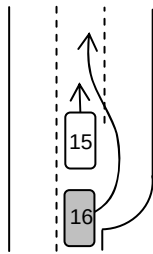
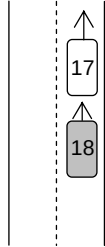
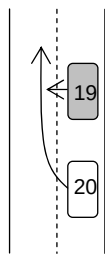
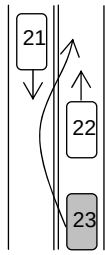
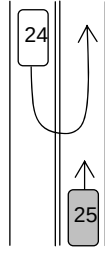
Table 60.

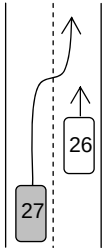
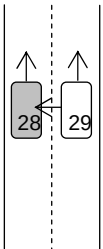
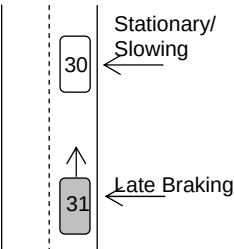
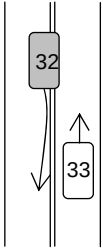
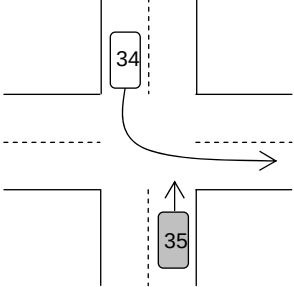
01/02 =	Aborted lane change
05/06/07/08 =	Backing in roadway
68/69 =	Close proximity to turning vehicle
11/12 =	Conflict between merging and existing traffic
65 =	Conflict with animal/pedestrian/pedacyclist/object in roadway (V1 only)
66 =	Conflict with animal/pedestrian/pedacyclist/object on side of road (V1 only)
13/14 =	Conflict with oncoming traffic
72/73 =	Conflict with through traffic
15/16 =	Exit then re-entrance onto roadway
17/18 =	Following too closely
19/20 =	Improper lane change
21/22/23 =	Improper passing
24/25 =	Improper u-turn
26/27 =	Lane change without sufficient gap
28/29 =	Lane drift
30/31 =	Late braking for stopped/stopping traffic
32/33 =	Lateral deviation of through vehicle
34/35 =	Left turn without clearance
36/37 =	Merge out of turn (before lead vehicle)
38/39/40 =	Merge without sufficient gap
41/42 =	Obstruction in roadway
43/44 =	Proceeding through red traffic signal
45/46 =	Roadway entrance without clearance
47/48 =	Slow speed
49/50 =	Slow upon passing
51/52/53 =	Sudden braking in roadway
54/55 =	Through traffic does not allow lane change
56/57/58 =	Through traffic does not allow merge
59/60 =	Turn without sufficient warning
61/62 =	Turn/exit from incorrect lane
63/64 =	Wide turn into adjacent lane
67 =	Other single vehicle event (V1 only)
70/71 =	Vehicle passes through intersection without clearance
98 =	Other

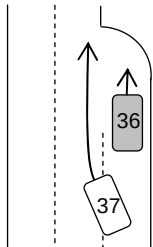
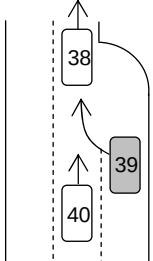
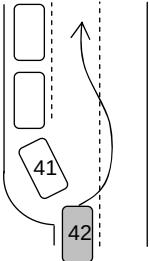
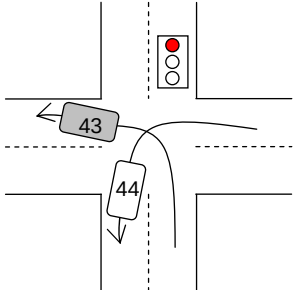
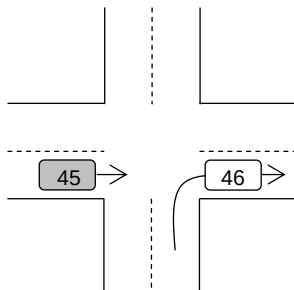
Table 60. Incident Type table (Hanowski, Olson, Hickman, & Dingus, 2006; Hanowski, Perez, & Dingus, 2005; Hanowski, Wierwille, Garness, & Dingus, 2000; Hickman et al., in press)

Incident Type	Description	Illustration
Aborted Lane Change	A driver tries to make a lane change into a lane where there is already a vehicle (driver doesn't see vehicle). The driver has to brake and move back into the original lane.	
Backing in Roadway	A driver backs the vehicle while on a roadway in order to maneuver around an obstacle ahead on the roadway.	
		
Close Proximity to Turning Vehicle	The lead vehicle is making a right/left turn or changing lanes to the right/left, and the following vehicle comes close to the rear of the lead vehicle as they pass.	

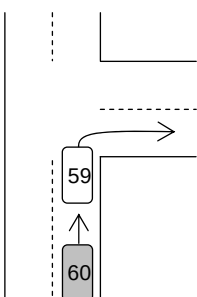
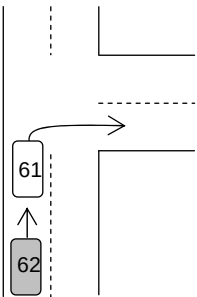
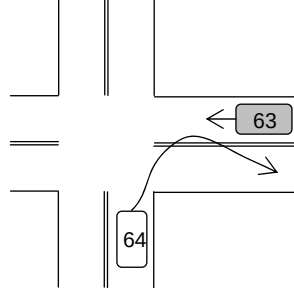
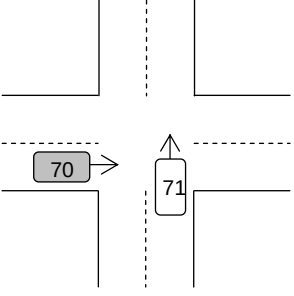
Incident Type	Description	Illustration
Conflict Between Merging and/or Exiting Traffic	Drivers entering and/or exiting a roadway, causing a conflict.	
Conflict With Animal/Pedestrian/Pedal cyclist/Object in Roadway	A vehicle approaches an animal/pedestrian/pedal cyclist/object in the roadway (on the pavement) and either makes contact with it, or performs an evasive maneuver in order to avoid it.	
Conflict With Animal/Pedestrian/Pedal cyclist /Object on Side of Roadway	A vehicle approaches an animal/pedestrian/pedal cyclist/object (including a guardrail) on the side of the road and either makes contact with it, or performs an evasive maneuver in order to avoid it.	
Conflict With Oncoming Traffic	A driver is approaching oncoming traffic (e.g., through an intersection, at an intersection) and has to maneuver back into the correct lane to avoid an oncoming vehicle.	
Conflict with Through Traffic	A vehicle starts to turn (right or left) at an intersection, but has to brake to avoid a conflict with traffic passing through the intersection.	

Incident Type	Description	Illustration
Exit Then Re-Entrance Onto Roadway	A driver exits a roadway then crosses a solid white line to re-enter.	 A diagram showing a vehicle (15) exiting a roadway to the right, crossing a solid white line, and then re-entering the roadway from the right side. A second vehicle (16) is shown following the first vehicle.
Following Too Closely	A driver does not allow adequate spacing between their vehicle and the lead vehicle (e.g., tailgating).	 A diagram showing two vehicles (17 and 18) traveling in the same direction. Vehicle 18 is following vehicle 17 very closely, indicating tailgating.
Improper Lane Change	A driver makes an improper lane change with regard to another vehicle (e.g., does not use blinker, changes lanes behind another vehicle then does not let vehicle change lanes, changes lanes across multiple lanes, etc.)	 A diagram showing a vehicle (19) attempting to change lanes from the right lane to the left lane behind another vehicle (20). The vehicle (19) is shown in the process of changing lanes without adequate clearance.
Improper Passing	A driver passes another vehicle when it is illegal or unsafe (e.g., passing across a double yellow line or without clearance from oncoming traffic).	 A diagram showing a vehicle (21) attempting to pass a vehicle (22) by crossing a double yellow line. A third vehicle (23) is shown in the opposite lane, indicating a potential conflict.
Improper U-turn	A driver makes a u-turn in the middle of the road (over the double yellow line) and blocks traffic in the opposite direction.	 A diagram showing a vehicle (24) making a U-turn in the middle of the road, crossing a double yellow line. A second vehicle (25) is shown in the opposite lane, blocked by the U-turning vehicle.

Incident Type	Description	Illustration
Lane Change Without Sufficient Gap	A driver enters an adjacent lane without allowing adequate space between the driver's vehicle and the vehicle ahead/behind it.	
Lane Drift	A driver drifts into an adjacent lane without intention to make a lane change.	
Late Braking (and/or steering) for Stopped/ Stopping Traffic	A driver fails to slow in advance for stopped or stopping traffic and must brake and/or steer abruptly.	
Lateral Deviation of Through Vehicle	A driver has substantial lateral deviation of a through vehicle. Vehicle may or may not deviate from the lane.	
Left Turn Without Clearance	A driver turns left without adequate clearance from either oncoming through traffic or cross traffic from the left. The driver crosses another driver's path while entering an intersecting roadway.	

Incident Type	Description	Illustration
Merge Out of Turn (Before Lead Vehicle)	A driver merges onto a roadway before the lead vehicle. The lead vehicle must wait for the merged vehicle to pass before it is safe to enter the main highway.	
Merge Without Sufficient Gap	A driver merges into traffic without a sufficient gap to either the front or back of one or more vehicles.	
Obstruction in Roadway	A stationary object blocks through traffic, such as traffic that is backed up.	
Proceeding Through Red Traffic Signal	A driver fails to respond to a red traffic signal, conflicting with a vehicle proceeding through the intersection legally.	
Roadway Entrance Without Clearance	A driver turns onto a roadway without adequate clearance from through traffic.	

Incident Type	Description	Illustration
Slow Speed	A driver is traveling at a much slower speed than the rest of the traffic, causing following traffic to pass the slow vehicle to avoid a conflict.	The illustration shows a two-lane road with a dashed center line. Vehicle 47 is in the right lane, moving slowly. Vehicle 48 is in the left lane, moving faster and passing vehicle 47. An arrow points to vehicle 47 with the label 'Slower Speed'.
Slow Upon Passing	A driver moves in front of another vehicle then slows, causing the second (passed) vehicle to slow as well, or to go around the first vehicle.	The illustration shows a two-lane road with a dashed center line. Vehicle 49 is in the left lane, having just passed vehicle 50. Vehicle 49 is slowing down, indicated by a curved arrow pointing back towards vehicle 50. Vehicle 50 is in the right lane.
Sudden Braking in Roadway	A driver is traveling ahead of another vehicle and brakes suddenly and improperly in the roadway for traffic, a traffic light, etc., causing the following vehicle to come close to their vehicle or to also brake suddenly.	The illustration shows a two-lane road with a dashed center line. Vehicle 51 is in the right lane, followed by vehicle 52, which is followed by vehicle 53. All three vehicles are moving slowly. An arrow points to vehicle 51 with the label 'Sudden Braking'.
Through Traffic Does Not Allow Lane Change	A driver is trying to make a lane change (with their turn signal on) but traffic in the adjacent lane will not allow the lane change to be completed.	The illustration shows a two-lane road with a dashed center line. Vehicle 54 is in the right lane, attempting to move into the left lane. Vehicle 55 is in the left lane, blocking the lane change. An arrow points to vehicle 54 with the label 'Turn Signal On'.
Through Traffic Does Not Allow Merge	Through traffic obstructs (either intentionally or unintentionally) a driver from entering the roadway or from performing any type of merging behavior.	The illustration shows a two-lane road with a dashed center line. Vehicle 56 is in the right lane, followed by vehicle 58. Vehicle 57 is in the left lane, attempting to merge into the right lane. An arrow points to vehicle 57 with the label 'Merge'.

Incident Type	Description	Illustration
Turn Without Sufficient Warning	A driver slows and turns without using a turn signal or without using a turn signal in advance.	
Turn/Exit From Incorrect Lane	A driver turns onto a side road from the incorrect lane (e.g., a driver makes a right turn from the left lane instead of the right lane).	
Wide Turn Into Adjacent Lane	A vehicle partially enters an adjacent lane when turning. Traffic in the adjacent lane may be moving in the same or opposite direction.	
Vehicle Passes Through Intersection Without Clearance	A vehicle passes through an intersection (signal or non-signal) without adequate clearance from through traffic.	
Other Single Vehicle Event	A vehicle is involved in a single vehicle event. For example runs off the side of the road without a threat of hitting a fixed object.	67
Other	An unidentified incident type occurs.	98

18. Driver 1 Actions/Factors/Behaviors Relating to Event

You may code up to four factors believed to have relevance to the occurrence of the incident; (e.g., as contributing factors). If there are more than four, select the four most important.

- 00b = None coded
- 01 = Apparent excessive speed for conditions or location (regardless of speed limit; does not include tailgating, unless above speed limit)
- 03 = Angry
- 04 = Other emotional state
- 05 = Inattentive or distracted (mark only if related to event, not just because a potential distraction is marked)
- 07 = Driving slowly; below speed limit or in relation to other traffic
- 08 = Illegal passing (i.e., across double line)
- 09 = Passing on right
- 10 = Other improper or unsafe passing
- 11a = Cutting in, too close in front of other vehicle
- 11b = Cutting in at safe distance but then decelerated, causing conflict
- 12 = Cutting in, too close behind other vehicle
- 13 = Making turn from wrong lane (e.g., across lanes)
- 14 = Did not see other vehicle during lane change or merge
- 15 = Driving in other vehicle's blind spot
- 16 = Aggressive driving, specific, directed menacing actions
- 17 = Aggressive driving, other; i.e., reckless driving without directed menacing actions
- 18 = Wrong side of road, not overtaking [includes partial or full drift into oncoming lane]
- 19 = Following too close
- 19a = Inadequate evasive action
- 20 = Failed to signal, or improper signal
- 21 = Improper turn: wide right turn
- 22 = Improper turn: cut corner on left turn
- 23 = Other improper turning
- 24 = Improper backing, did not see
- 25 = Improper backing, other
- 26 = Improper start from parked position
- 27 = Disregarded officer or watchman
- 28 = Signal violation, apparently did not see signal
- 29 = Signal violation, intentionally ran red light
- 30 = Signal violation, tried to beat signal change
- 31 = Stop sign violation, apparently did not see stop sign
- 32 = Stop sign violation, intentionally ran stop sign at speed
- 33 = Stop sign violation, "rolling stop"

- 34 = Other sign (e.g., Yield) violation, apparently did not see sign
- 35 = Other sign (e.g., Yield) violation, intentionally disregarded
- 36 = Other sign violation
- 37 = Non-signed crossing violation (e.g., driveway entering roadway)
- 38 = Right-of-way error in relation to other vehicle or person, apparent recognition failure (e.g., did not see other vehicle)
- 39 = Right-of-way error in relation to other vehicle or person, apparent decision failure (i.e., did see other vehicle prior to action but misjudged gap)
- 40 = Right-of-way error in relation to other vehicle or person, other or unknown cause
- 41 = Sudden or improper stopping on roadway
- 42 = Parking in improper or dangerous location; e.g., shoulder of Interstate
- 43 = Speeding or other unsafe actions in work zone
- 44 = Failure to dim headlights
- 45 = Driving without lights or insufficient lights
- 46 = Avoiding pedestrian
- 47 = Avoiding other vehicle
- 48 = Avoiding animal
- 48a = Avoiding object
- 49 = Apparent unfamiliarity with roadway
- 50 = Apparent unfamiliarity with vehicle; e.g., displays and controls
- 51 = Use of cruise control contributed to late braking (does not imply malfunction of cruise control system)
- 52 = Excessive braking/deceleration creating potential hazard
- 53 = Loss of control on slippery road surface
- 54 = Loss of control on dry (or unknown) surface
- 55 = Apparent vehicle failure (e.g., brakes)
- 56 = Other

Note: This variable was used in Dingus et al., 2005 although some new elements have been added. Analysts code all that apply and in no order of importance.

19. Comments

Note: This text variable will permit analysts to provide any comments on the event, including information not captured by data variables, assumptions made about the event affecting coding, and coding issues that arose. Ordinarily this will not contain information that is captured by the coded variables.

Environmental Variables:

Driver/Vehicle 1 Variables

Driver/Vehicle 1 (DV1) is always the study subject driver/vehicle (i.e., the truck or truck driver).

20. Driver Safety Belt Worn?

- 00 = No
- 01 = Yes
- 02 = Unknown

21. Lane Obstruction

Comment: You will mark whether there is enough of an obstruction (e.g., snow, construction cones, etc.) in the driver's lane of travel that he/she is forced to move into an adjacent or oncoming lane.

- 00 = Yes – forced out of lane
- 01 = Yes – not forced out of lane
- 02 = No obstruction

22. Driver 1 Vision Obscured by

- 00 = No obstruction
- 01 = Rain, snow, smoke, sand, dust
- 02 = Reflected glare, sunlight, headlights
- 03 = Curve or hill
- 04 = Building, billboard, or other design features (includes signs, embankment)
- 05 = Trees, crops, vegetation
- 06 = Moving vehicle (including load)
- 07 = Parked vehicle
- 08 = Splash or spray of passing vehicle [any other vehicle]
- 09 = Inadequate defrost or defog system
- 10 = Inadequate lighting system [*includes vehicle/object in dark area*]
- 11 = Obstruction interior to vehicle
- 12 = Mirrors
- 13 = Head restraints
- 14 = Broken or improperly cleaned windshield
- 15 = Fog
- 16 = *Other vehicle or object in blind spot*
- 97 = Vision obscured – no details
- 98 = Other obstruction
- 99 = Unknown whether vision was obstructed

Note: GES Variable D4. Element 16 added because of relevance to large trucks.

Environmental Variables

Environmental variables are coded at the time of the trigger

23. Light Condition

- 01 = Daylight
- 02 = Dark
- 03 = Dark but lighted
- 04 = Dawn
- 05 = Dusk
- 09 = Unknown

Note: GES A19

24. Weather

- 01 = No adverse conditions
- 02 = Rain
- 03 = Sleet
- 04 = Snow
- 05 = Fog
- 06 = Rain & fog
- 07 = Sleet & fog
- 08 = Other (smog, smoke, sand/dust, crosswind, hail)
- 09 = Unknown

Comment: GES A20.

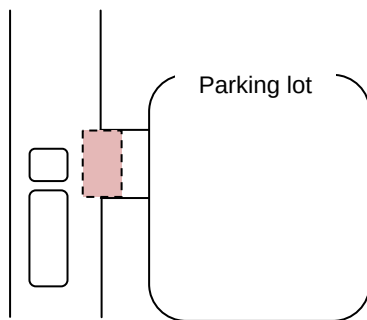
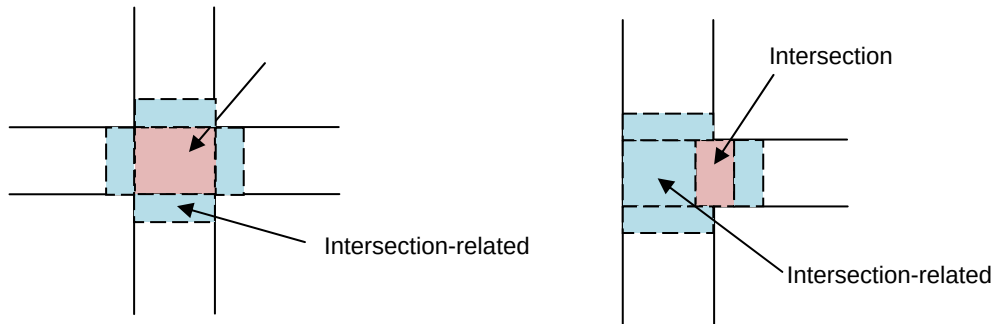
25. Roadway Surface Condition

- 01 = Dry
- 02 = Wet
- 03 = Snow or slush
- 04 = Ice
- 05 = Sand, oil, dirt
- 08 = Other
- 09 = Unknown

Comment: GES A15.

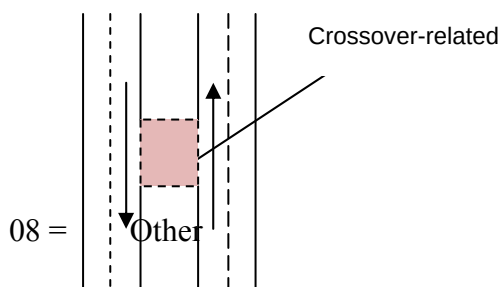
26. Relation to Junction

- 00 = Non-Junction
- 01 = Intersection
- 02 = Intersection-related



Note: If the truck is passing a parking lot (instead of a side street,) code as non-junction (instead of intersection-related). But if the truck is turning into the parking lot, code it as intersection.

- 03 = Driveway, alley access, etc. – the driver has to be completely on the driveway, alley access, etc. in order to code this variable
- 03a = Parking Lot – the driver has to be completely in the parking lot in order to code this variable; if the driver is turning into a parking lot, code as intersection
- 04 = Entrance/exit ramp
- 05 = Rail grade crossing
- 06 = On a bridge
- 07 = Crossover related – a crossover is a designated opening within a median used primarily for “U-turns”



09 = Unknown

Comment: GES variable A09.

27. Traffic-way Flow

00 = Not physically divided (center 2-way left turn lane)

01 = Not physically divided (2-way trafficway)

02 = Divided (median strip or barrier)

03 = One-way trafficway

09 = Unknown

Note: GES variable V A11. Coded in relation to subject vehicle.

28. Number of Travel Lanes

01 = 1

02 = 2

03 = 3

04 = 4

05 = 5

06 = 6

07 = 7+

09 = Unknown

Note: GES V A12. Per GES, if road is divided, only lanes in travel direction are counted. If undivided, all lanes are counted. Coded in relation to subject vehicle; baseline epoch coded at time of trigger. Count all contiguous lanes at the time & location of the incident; e.g., include entrance or exit lanes if contiguous and separated from through lanes by only painted lines. Do not include lanes if blocked by cones or barrels.

29. Roadway Alignment

01 = Straight

02a = *Curve right*

02b = *Curve left*

09 = Unknown

Note: GES V A13, with expansion of curve choices. Coded in relation to subject vehicle; baseline epoch coded at time of trigger.

30. Roadway Profile

01 = Level (or unknown)

02a = *Grade up*

02b = *Grade down*

03 = Hillcrest

04 = Sag

Note: GES V A14, with expansion of grade choices. Coded in relation to subject vehicle.

31. Traffic Density

Code the traffic density for the time prior to the pre-crash event. LOS: Level-of-Service.

- 01 = LOS A: Free flow – Individual users are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to the motorist, passenger, or pedestrian is excellent.
- 02 = LOS B: Flow with some restrictions – In the range of stable traffic flow, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A, because the presence of others in the traffic stream begins to affect individual behavior.
- 03 = LOS C: Stable flow, maneuverability and speed are more restricted – In the range of stable traffic flow, but marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by the interactions with others in the traffic stream. The selection of speed is now affected by the presence of others, and maneuvering within the traffic stream requires substantial vigilance on the part of the user. The general level of comfort and convenience declines noticeably at this level.
- 04 = LOS D: Unstable flow: temporary restrictions substantially slow driver – Represents high-density, but stable traffic flow. Speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems at this level.
- 05 = LOS E: Flow is unstable; vehicles are unable to pass, temporary stoppages, etc. – Represents operating conditions at or near the capacity level. All speeds are reduced to a low, but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult, and it is generally accomplished by forcing a vehicle or pedestrian to “give way” to accommodate such maneuvers. Comfort and convenience levels are extremely poor, and driver or pedestrian frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.
- 06 = LOS F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity. Queues’ forming in particular locations – This condition exists whenever the amount of traffic approaching a point exceeds the amount which can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, and then be required to stop in a cyclic fashion. LOS F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which arrival flow exceeds discharge flow which causes the queue to form, and LOS F is an appropriate designation for such points.
- 07 = Unknown/unable to determine

32. Construction Zone Related

- 00 = Not construction zone-related (or unknown)
- 01 = Construction zone (occurred in zone)
- 02 = Construction zone-related (occurred in approach or otherwise related to zone)

Note: Any area with one or more traffic cones, barrels, etc. is considered to be a construction zone.

33. Driver Distraction

Note: You may code up to four distractions, in any order, from the following list; you will mark whatever behaviors occur within the 6 s prior to the **event onset** and 1 s after.

INTERNAL DISTRACTION: Person or Object

- 01 = Talk/sing/dance with no indication of passenger – Driver appears to be vocalizing either to an unknown passenger, to self, or singing to the radio. Also, in this category are instances where the driver exhibits dancing behavior or is whistling.
- 02 = Interact with or look at other occupant(s) – Driver is talking to a passenger sitting in the passenger’s seat or in the sleeper berth that can be identified by the person encroaching into the camera view or the driver is clearly looking at and talking to the passenger.
- 03 = Look at internal object – Driver removes attention from the forward roadway to look at an object inside the vehicle. This option should only be marked if the driver is not engaging in any other behavior at the same time (e.g., reaching for object, eating/drinking, etc.).
- 04 = Reach for object in vehicle (including cell phone, CB/other communications device) – Driver may or may not remove attention from the forward roadway to reach for an object inside the vehicle. This option should only be marked if it is unknown what the object is or if driver only reaches for object and does not perform any other behavior (e.g., if driver reaches for cell phone and then dials, then only “dial cell phone” would be marked).
- 05 = Look back in Sleeper Berth – Driver turns body to look behind him/her into the Sleeper Berth.
- 06 = Use calculator – Driver uses hand-held calculator. Assumes driver is looking at and may reach for object.
- 07 = Read book, newspaper, paperwork, etc. – Driver reads a book, newspaper, paperwork, etc, which is visible in the driver’s hands, on the driver’s lap, on the driver’s steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.
- 08 = Look at map – Driver reads a book, newspaper, paperwork, etc, which is visible in the driver’s hands, on the driver’s lap, on the driver’s steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.
- 09 = Write on pad, notebook, etc. – Driver reads a map which is visible in the driver’s hands, on the driver’s lap, on the driver’s steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.

- 10 = Put on/remove/adjust seat belt – Driver puts on, removes, or adjusts his/her seat belt. Assumes driver is looking at and may reach for object.
- 11 = Put on/remove/adjust sunglasses or reading glasses – Driver puts on, removes, or adjusts his/her sunglasses. Assumes driver is looking at and may reach for object.
- 12 = Put on/remove/adjust hat – Driver puts on, removes, or adjusts his/her hat. Assumes driver is looking at and may reach for object.
- 13 = Put on/remove/adjust clothing – Driver puts on or takes off an article of clothing (including gloves). This may also include unbuttoning/buttoning or unzipping/zipping a shirt, adjusting a collar, etc. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Electronic Devices

- 14 = Dial cell phone – Driver dials a cell phone. This may also include answering the phone or hanging up the phone, if the driver presses a key during this time. Assumes driver is looking at and may reach for object.
- 15 = Talk or listen to hand-held phone – Driver holds a hand-held phone to ear, appears to be talking and/or listening (if driver dials cell phone and then talks on cell phone, both options are marked).
- 16 = Talk or listen to hands-free phone – Driver talks or listens to a hands-free phone. This is apparent by an earpiece in the driver's ear.
- 17 = Adjust earpiece/headset – Driver adjusts, or puts on/takes off, an earpiece/headset that is being used to talk on a hands-free phone. Assumes driver is looking at and may reach for object.
- 18 = Text message on cell phone – Driver appears to be text messaging on a cell phone. Driver is focusing on the cell phone for an extended amount of time while continuously pressing keys. Assumes driver is looking at and may reach for object.
- 19 = Talk or listen to CB microphone – Driver talks or listens to a CB microphone. Assumes driver is looking at and may reach for object.
- 20 = Interact with dispatching device – Driver interacts with or looks at a dispatching device. The driver usually keeps the device on the passenger seat or on the floor between the two seats and holds the device on his/her lap or steering wheel while in use. Assumes driver is looking at and may reach for object.
- 21 = Interact with GPS – Driver interacts with an after-market GPS device that is mounted on the instrument panel or dash (does NOT include an in-dash satellite radio). This may involve the driver hooking up the system or pressing buttons. Assumes driver is looking at and may reach for object.
- 22 = Interact with Satellite radio – Driver interacts with an after-market Satellite radio device that is mounted on the instrument panel or dash (does NOT include an in-dash satellite radio). This may involve the driver hooking up the system or pressing buttons. Assumes driver is looking at and may reach for object.
- 23 = Use camera – Driver uses a camera (may be a cell phone camera) to take a picture from inside the cab. Assumes driver is looking at and may reach for object.

- 24 = Use/reach for other device – Driver reaches for or uses an alternate electronic device; does not include any of the devices listed above such as cell phone, camera, etc. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Dining

- 25 = Eating – Driver eats with, or without, a utensil (i.e., fork or spoon). This also includes the driver opening a food bag or anything closely related to eating just prior to or after the trigger. Assumes driver is looking at and may reach for object.
- 26 = Drink from a container – Driver drinks from a container, either covered or uncovered. This also includes the driver opening/closing a drink container or anything closely related to drinking just prior to or after the trigger. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Smoking-Related

- 27 = Smoking-related behavior – reaching, lighting, extinguishing – Driver is reaching (ashing), lighting, or extinguishing a cigarette. May include behaviors such as driver reaching for a lighter or reaching for a pack of cigarettes. Assumes driver is looking at and may reach for object.
- 28 = Smoking-related behavior – cigarette in hand or mouth – Driver has a cigarette in hand or mouth.
- 29 = Use chewing tobacco – Driver is using chewing tobacco. This may include putting tobacco into mouth or spitting into container. Assumes driver is looking at and may reach for object.

INTERNAL DISTRACTION: Grooming

- 30 = Personal grooming – Driver is grooming him/herself. This may include combing/fixing hair, applying make-up, shaving, and brushing teeth. Assumes driver is looking at and may reach for object.
- 31 = Bite nails/cuticles – Driver is biting nails and/or cuticles. Assumes driver is looking at hands.
- 32 = Remove/adjust jewelry – Driver is removing or adjusting jewelry. This may include, watch, bracelet, necklace or earrings. Assumes driver is looking at and may reach for object.
- 33 = Other personal hygiene – Driver is conducting some kind of other personal hygiene. This may include rubbing eyes/face, scratching face/neck, or picking nose.
- 34 = Adjust in seat – Driver adjusts his/her position in the driver's seat.

INTERNAL DISTRACTION: Vehicle-Related

- 35 = Adjust instrument panel – Driver is adjusting something on the instrument panel. This may include, radio, climate controls, head lights, and other switches to the front and right of the driver. Assumes driver is reaching for and/or looking at the instrument panel while adjusting.

- 36 = Pull air horn – Driver reaches up and pulls the air horn on the truck. The air horn is usually located in the upper left corner of the cab. Assumes driver is looking at and may reach for object.
- 37 = Turn on/off cab light – Driver turns on/off overhead cab light. Assumes driver is looking at and may reach for object.
- 38 = Clean cab interior – Driver uses some kind of cleaning material(s) to clean/dust the instrument panel, dash, interior windows, etc. Assumes driver is looking at and may reach for object.
- 39 = Put up/down window – Driver either manually rolls up/down the window or uses a button on the door.

EXTERNAL DISTRACTIONS

- 40 = Look at outside vehicle, person, animal, object – Driver looks outside the vehicle to another vehicle, person, animal, object or undetermined. May be out the front windshield or side window. Must be apparent that driver is focused on outside vehicle, person, animal, object.
- 41 = Look out rear window (day cab only with visible rear window) – Driver turns around and looks out the rear window on the cab. Must be apparent that driver is looking out window.
- 42 = Wave to passing vehicle/driver – Driver looks at and waves to a passing vehicle, either overtaking (same direction) or passing in the opposite direction.

DRIVING-RELATED INATTENTION TO FORWARD ROADWAY

- 43 = Look at left-side mirror – Driver looks at the left-side mirror (west coast/convex mirror or fender mirror).
- 44 = Look at right-side mirror – Driver looks at the right-side mirror (west coast/convex mirror or fender mirror).
- 45 = Look at left-side monitor – Driver looks at the left-side monitor.
- 46 = Look at right-side monitor – Driver looks at the right-side monitor.
- 47 = Look at center monitor – Driver looks at the center monitor.
- 48 = Check speedometer – Driver glances directly down to the speedometer. Must be apparent that the driver is looking at the speedometer and not in lap.

OTHER

- 49 = Other – Other potentially distracting behavior.

Note: Adapted from Hanowski, Olson, Perez & Dingus, 2001 and Olson, Hanowski, Hickman & Bocanegra, 2009.

34. Comments

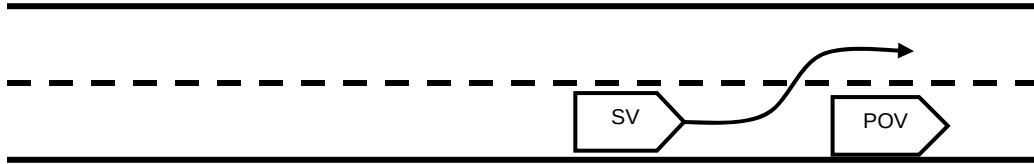
Note: This text variable will permit analysts to provide any comments on the event, including information not captured by data variables, assumptions made about the event affecting coding, and coding issues that arose. Ordinarily this will not contain information that is captured by the coded variables.

APPENDIX Y. LANE CHANGE MANEUVER DATA DIRECTORY

Valid Lane-Change Maneuvers

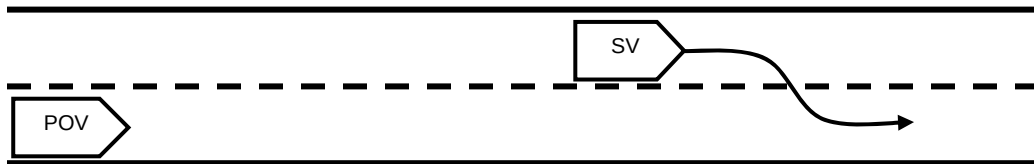
1. Classification name: Slow lead vehicle

Classification definition: Lane-change due to slow principal other vehicle (POV) in front.



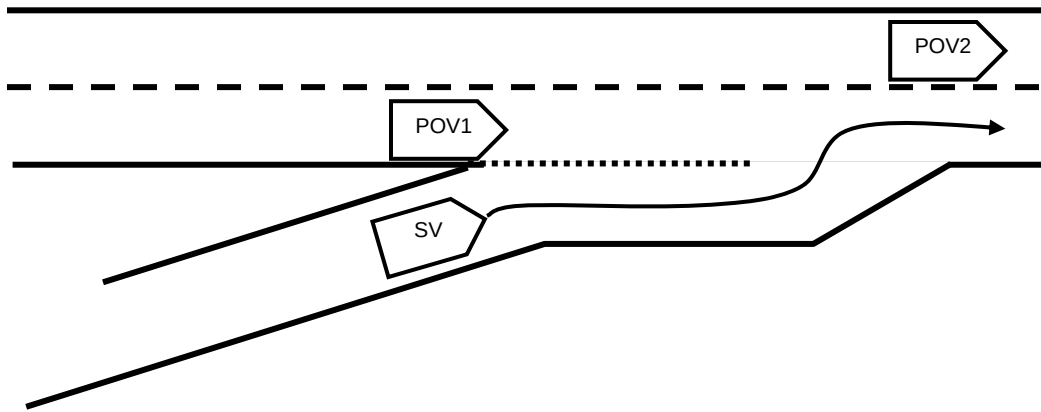
2. Classification name: Return

Classification definition: Lane-change to return to original lane after deviating from it for any reason.



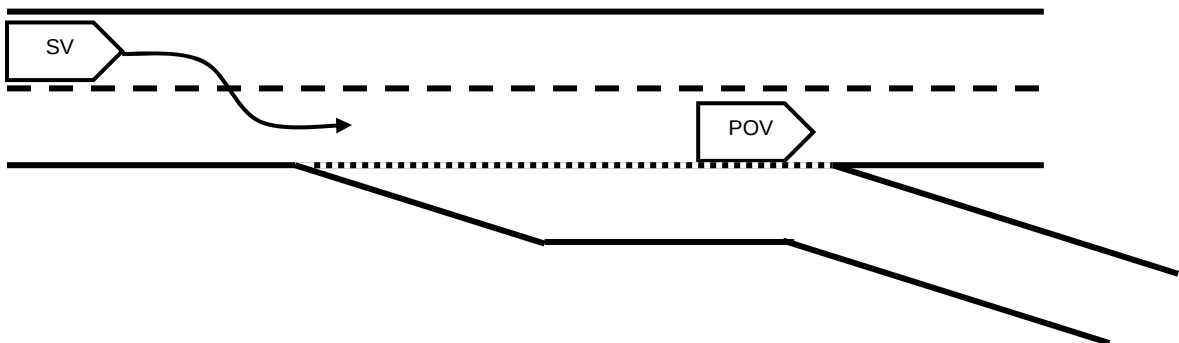
3. Classification name: Enter

Classification definition: Lane-change to enter the main highway. The TTC to POVs already on the highway are accounted for in the severity ratings.



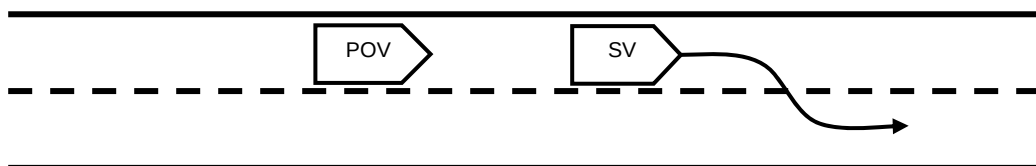
4. Classification name: Exit/prep exit

Classification definition: Lane-change to exit or to prepare to exit the main highway. The TTC to POVs are accounted for in the severity ratings.



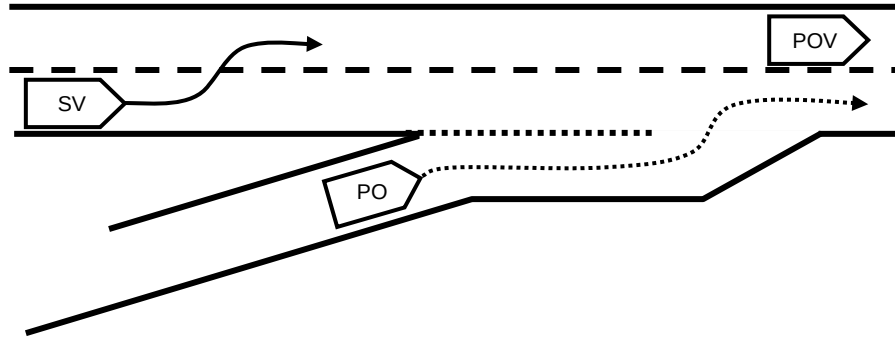
5. Classification name: Tailgated

Classification definition: Lane-change due to POV tailgating/approaching quickly; usually occurs while in the left lane. Driver of SV may make lane-change while POV is still at a considerable distance/TTC. If, in the analyst's judgment, this is the true reason for the lane-change, use this classification rather than any of the returning to original lane classifications. The TTC to POVs are accounted for in the severity ratings.



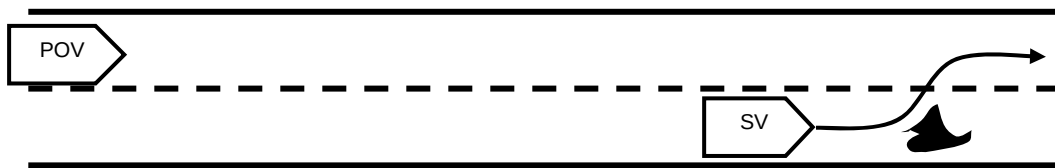
6. Classification name: Merging vehicle

Classification definition: Lane-change to allow POV to enter the main highway. The TTC to POVs are accounted for in the severity ratings.



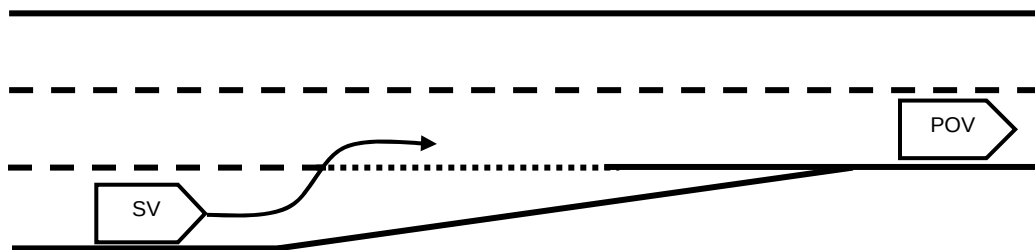
7. Classification name: Rough/obstacle avoidance

Classification definition: Lane-change due to road surface or obstacle in road. The TTC to POVs are accounted for in the severity ratings.



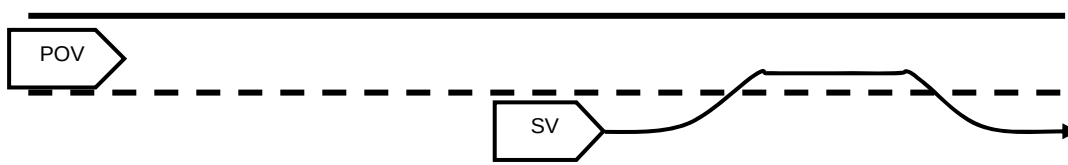
8. Classification name: Lane drop

Classification definition: Lane-change due to end of SV's lane (e.g., road goes from 3 to 2 lanes). The TTC to POVs are accounted for in the severity ratings.



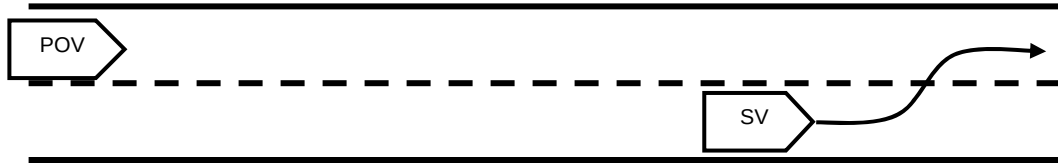
9. Classification name: Unintended

Classification definition: Unintended lane deviation due to distraction, drowsiness, poor driving, etc.; often only a partial lane-change. The TTC to POVs are accounted for in the severity ratings.



10. Classification name: Other

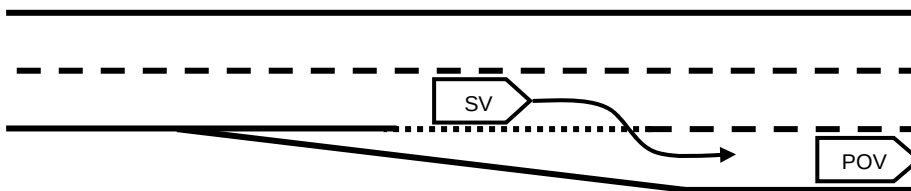
Classification definition: Lane-change for no discernible reason. The TTC to POVs are accounted for in the severity ratings, and POVs can be in any lane position relative to the SV.



Invalid Lane-Change Maneuvers

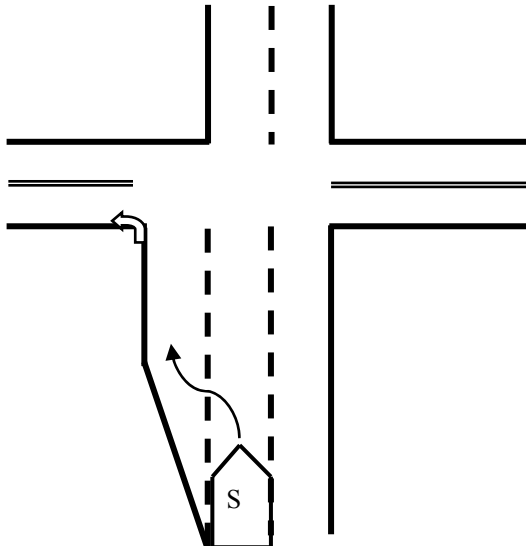
1. Classification name: Added Lane

Classification definition: Lane-change due to the addition of a lane (e.g., road goes from 2 to 3 lanes). This example cannot be considered a lane-change maneuver because it is not possible for another vehicle to already be in the exit lane.



2. Classification name: Intersection turn

Classification definition: Lane-change at an intersection in order to make a turn.



Lane-Change Variables

1. Lane Change Severity

Note: Categories adapted from Dingus et al., 2005 and Hickman et al., 2005. Crash: Tire Strike category only used in Hickman et al., 2005. This variable is extremely subjective and is determined using the best judgment of an analyst.

- **01 = Crash.** Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals.
- **02 = Crash: Tire Strike.** Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated where the contact occurs on the truck's tire only. No damage occurs during these events (e.g., a truck is making a right turn at an intersection and runs over the sidewalk/curb with a tire).
- **03 = Near-Crash.** Any circumstance requiring a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash, OR any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A rapid, evasive maneuver is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.
- **04 = Crash-Relevant Conflict.** Any circumstance that requires a crash avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive maneuver (as defined above), but greater in severity than a "normal maneuver" to avoid a crash OR any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance maneuver or response. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal maneuver" for the subject vehicle is defined as a control input that falls within the 99% confidence limit for control inputs for the initial study data sample. Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat, or proximity to other vehicles.
- **06 = No Conflict.** Lane change is performed without experiencing a conflict with another vehicle.

2. Lane-Change Initiation

Note: The lane-change initiation point is determined by stepping through the video frame by frame and looking for the initial steering input of the driver. The reflective tape mounted on the steering wheel will help you assess this. Enter the sync when the vehicle initiates the lane-change.

3. Lane-Change Direction

- Left – Driver moves from the right lane to the left lane
- Right – Driver moves from the left lane to the right lane

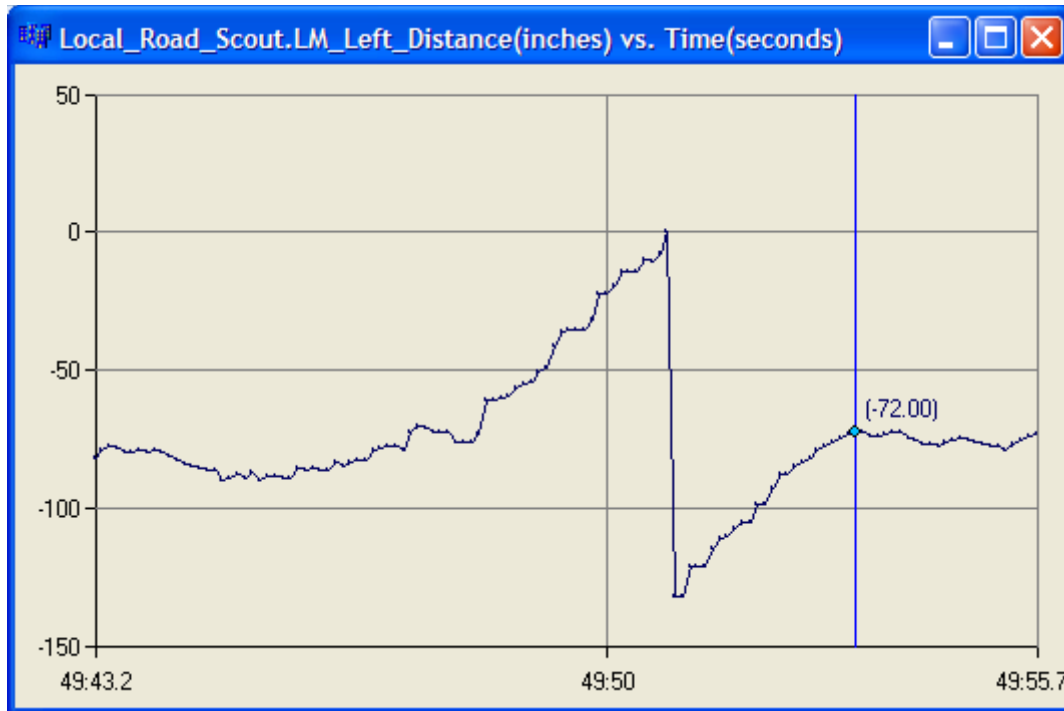
4. Lane Marking Cross Sync

Note: This represents the sync where the participant vehicle crosses the lane markings during the lane change. The rear-view video from the fender-mounted camera were used to see when the truck touches the center of the lane markings. The lower left and right views of the video capture seen below represent the left and right rear view videos used to produce this sync.



5. Lane-Change End Sync

Note: This is coded for the period when the vehicle stabilizes in the destination lane, as seen by the forward view of the roadway and lane tracker. This variable measures the distance from the center of the truck to the left lane marking. When the distance reaches steady state near the end of the lane change, the sync is recorded as the start of the steady state. A screenshot of the lane tracker data is seen below.



Note the large drop at approximately 49:51, which denotes the point where the participant vehicle crosses the center lane line (in this case it was originally to the left of the participant). As the participant crosses this lane line, lane tracker begins to pick up the far left lane line, which is several feet away, leading to the sharp change in values seen on the graph.

6. Lane-Change Magnitude

- Single lane-change – Single lane-change, ends in adjacent lane and remains in adjacent lane for at least 45 seconds (by definition, successful).
- Multiple lane crossing – Multiple lane-change, does not end in original lane or adjacent lane (by definition, successful). If two triggers are generated for a multiple lane change, please only use the first lane change trigger and invalidate the proceeding ones.
- Passing – Dual lane-change/passing maneuver, ends in original lane (two lane-changes within 45 seconds; by definition, successful).
- Partial lane-change – Lane-change that was not completed (by definition, unsuccessful).

7. Lane-Change Type (see diagrams under “Valid Lane Change Maneuvers)

- Slow lead vehicle (LV) – Lane-change to pass a vehicle which is moving slower than the SV’s preferred speed
- Return – Lane-change to return to preferred driving lane
- Enter – Lane-change to enter road (e.g. from on-ramp)
- Exit/prep exit – Lane-change associated with exiting
- Tailgated – Vehicle tailgating/approaching quickly
- Merging vehicle – Vehicle entering roadway causing SV to change lanes

- Rough/obstacle avoid – Maneuver to avoid obstacle or rough road surface
- Lane drop – End of driver's lane (e.g. road goes from 3 to 2 lanes)
- Added lane – Addition of a lane (e.g., road goes from 2 to 3 lanes)
- Unintended – Unintended lane deviation (e.g., distraction in car)
- Other – Lane-change for any other reason or for no discernible reason

8. Distance to Lead Vehicle in Original Lane

Note: This is the distance to the closest lead vehicle in the original lane at the time of the lane-change initiation. The following screen captions were used to determine the correct distance.

- Close = Lead vehicle is less than 20 meters away (vehicle is 10 meters away below)



- Medium = Lead vehicle is between 20 and 40 meters away (vehicle is 20 meters away below)



- Far = Lead vehicle is farther than 40 meters away (vehicle is 40 meters away below)



- No lead vehicle present

9. Actual Distance to Lead Vehicle in Original Lane

Note: The front radar was used to determine the actual distance to the closest lead vehicle.

- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

10. Radar Target ID to Lead Vehicle in Original Lane

Note: The radar Target ID for the closest lead vehicle used in Question 9 was recorded.

- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

11. Approach Rate of Lead Vehicle in Original Lane

Note: If a lead vehicle is present in the original lane, the front radar was used to determine the approach rate of the closest lead vehicle at the time of the lane-change initiation.

- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

12. Type of Lead Vehicle in Original Lane

- Heavy
- Light
- Motorcycle
- Other
- No Vehicle Present

13. Distance to Lead Vehicle in Destination Lane

Note: The distance to the closest lead vehicle in the destination lane at the time of the lane-change initiation was recorded. The following screen captions were used to determine the correct distance.

- Close = Lead vehicle is less than 20 meters away (vehicle is approximately 5 meters away below)



- Medium = Lead vehicle is between 20 and 40 meters away (vehicle is 20 meters away below)



- Far = Lead vehicle is farther than 40 meters away.



- No vehicle present

14. Actual Distance to Lead Vehicle in Destination Lane

Note: If a lead vehicle is present in the destination lane, the front radar was used to determine the actual distance to the closest vehicle. NOTE: Make sure you are looking at the radar data from the correct vehicle.

- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

15. Radar Target ID to Lead Vehicle in Destination Lane

Note: This represents the target ID associated with the range value recorded in question 14.

- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

16. Approach Rate of Lead Vehicle in Destination Lane

Note: If a lead vehicle was present in the destination lane, the front radar was used to determine the approach rate of the closest lead vehicle at the time of the lane-change initiation.

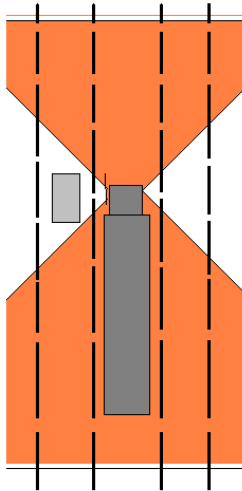
- “Radar drop out” if the front radar is not available
- “No Vehicle Present” if no vehicle is present

17. Type of Lead Vehicle in Destination Lane

- Heavy
- Light
- Motorcycle
- Other
- No Lead Vehicle Present

18. Adjacent Vehicle Present in Destination Lane, Not in View

Note: The forward and side fender cameras were used to determine if a vehicle is adjacent to the truck and in the destination lane, but the cameras cannot see the vehicle at the time of the lane-change initiation (The camera views are shown in orange below; The grey vehicle next to the truck can't be seen by the cameras). This vehicle is generally next to the cab of the truck. The video was watched for several seconds to determine if a vehicle is present, there because by definition, this car was not visible by the cameras at the point of lane change initiation.



- Yes = Vehicle present
- No = No vehicle present

19. Type of Adjacent Vehicle in Destination Lane Not in View

- Heavy
- Light
- Motorcycle
- Other
- No vehicle present

20. Distance to Rear Vehicle in Destination Lane

Note: This represents the distance to the closest rear vehicle in the destination lane at the time of the lane-change initiation. The following screen captions were used to determine the correct distance.

- Adjacent = Rear vehicle is actually beside the truck. Any vehicle less than 20 meters away should be considered “Adjacent”. (Vehicle is 14 meters away from front of truck below).



- Medium = Rear vehicle is between 20 and 40 meters away



- Far = Rear vehicle is farther than 40 meters away.



- No vehicle present

21. Actual Distance to Rear Vehicle in Destination Lane

Note: If a Rear Vehicle is present in the destination lane, the rear radar was used to determine the actual distance to the closest vehicle.

- “Radar drop out” if the rear radar is not available
- “No Vehicle Present” if no vehicle is present

22. Radar Target ID to Rear Vehicle in Destination Lane

Note: If a range value is recorded in question 19, this value represents the target ID associated with that range.

- “Radar drop out” if the rear radar is not available
- “No Vehicle Present” if no vehicle is present

23. Approach Rate of Rear Vehicle in Destination Lane

Note: If a Rear Vehicle is present in the destination lane, the rear radar was used to determine the approach rate of the closest rear vehicle at the time of the lane-change initiation. This represents the same target ID used in question 17.

- “Radar drop out” if the rear radar is not available
- “No Vehicle Present” if no vehicle is present

24. Type of Rear Vehicle in Destination Lane

Note: If a Rear Vehicle is present in the destination lane, the type of vehicle was determined.

- Heavy
- Light
- Motorcycle
- Other
- No Vehicle Present

25. Light Condition During Lane-Change

- Daylight
- Dark
- Dark but lighted
- Dawn
- Dusk
- Unknown

26. Traffic-way Flow at Lane-Change Initiation During Lane-Change

Note: This is the same time entered in Question 1.

- 00 = Not physically divided (with a center 2-way left turn lane)
- 01 = Not physically divided (2-way trafficway)
- 02 = Divided (median strip or barrier)
- 03 = One-way trafficway
- 09 = Unknown

27. Number of Lanes at Lane-Change Initiation

Note: Entrance or exit ramps present at the time of the lane change initiation counted towards the overall lane totals.

- 01 = 1
- 02 = 2
- 03 = 3
- 04 = 4
- 05 = 5
- 06 = 6
- 07 = 7+
- 09 = Unknown

28. Weather During Lane-Change

- 01 = No adverse conditions
- 02 = Rain
- 03 = Sleet
- 04 = Snow

- 05 = Fog
- 06 = Rain & fog
- 07 = Sleet & fog
- 08 = Other (smog, smoke, sand/dust, crosswind, hail)
- 09 = Unknown

29. Traffic Density During Lane-Change

- 01 = LOS A: Free flow – Individual users are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to the motorist, passenger, or pedestrian is excellent.
- 02 = LOS B: Flow with some restrictions – In the range of stable traffic flow, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A, because the presence of others in the traffic stream begins to affect individual behavior.
- 03 = LOS C: Stable flow, maneuverability and speed are more restricted – In the range of stable traffic flow, but marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by the interactions with others in the traffic stream. The selection of speed is now affected by the presence of others, and maneuvering within the traffic stream requires substantial vigilance on the part of the user. The general level of comfort and convenience declines noticeably at this level.
- 04 = LOS D: Unstable flow: temporary restrictions substantially slow driver – Represents high-density, but stable traffic flow. Speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems at this level.
- 05 = LOS E: Flow is unstable; vehicles are unable to pass, temporary stoppages, etc. – Represents operating conditions at or near the capacity level. All speeds are reduced to a low, but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult, and it is generally accomplished by forcing a vehicle or pedestrian to “give way” to accommodate such maneuvers. Comfort and convenience levels are extremely poor, and driver or pedestrian frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.
- 06 = LOS F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity. Queues’ forming in particular locations – This condition exists whenever the amount of traffic approaching a point exceeds the amount which can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, and then be required to stop in a

cyclic fashion. LOS F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which arrival flow exceeds discharge slow which causes the queue to form, and LOS F is an appropriate designation for such points.

- 07 = Unknown/unable to determine

30. Roadway Surface Condition During Lane-Change

- 01 = Dry
- 02 = Wet
- 03 = Snow or slush
- 04 = Ice
- 05 = Sand, oil, dirt
- 08 = Other
- 09 = Unknown

31. Roadway Alignment During Lane-Change

- 01 = Straight
- 02a = *Curve right*
- 02b = *Curve left*
- 09 = Unknown

32. Roadway Profile During Lane-Change

- 01 = Level (or unknown)
- 02a = *Grade up*
- 02b = *Grade down*
- 03 = Hillcrest
- 04 = Sag

33. Turn Signal Use

- Yes = Turn signal present prior to or during lane-change maneuver
- No = NO turn signal present prior to or during lane-change maneuver

34. Turn Signal Activation

- NA: turn signal was not activated

35. Turn Signal Deactivation

- NA: turn signal was not activated

36. Comments

Note: This text variable will permit analysts to provide any comments on the event, including information not captured by data variables, assumptions made about the event affecting coding,

and coding issues that arose. Ordinarily this will not contain information that is captured by the coded variables.

APPENDIX Z. LANE CHANGE EYE GLANCE REDUCTION PROTOCOL

1. Open DART II
2. Open the **IVS** collection (File → Open Collection → IVS).
3. Open the Excel Log: <\\Blackjack\425859\Reduction\Eyeglance Reduction Log.xlsx>
 - On the **Driver Sign Out tab**, sign out a driver for Safety-Critical Events
 - On the **Lane-Change Maneuver tab**, sign out an event for that driver to begin working on
4. Load the Open File ID (file → Open File ID). Paste in the File ID from the Excel log. Click Go, and open the event.
5. Load the following views:
 - File → Video/Play Controller
 - Tools → Video Reduction
 - Variables → HEL_CAN_Port → Video_Frame
6. From the Excel log, note the lane change initiation sync, as well as the eyeglance start and stop sync numbers for your File ID. Using the Play Controller, go to the Eyeglance start sync.
7. Play through and watch the lane change. Note the direction of the lane change, driver actions, and any other characteristics of the lane change (vehicle flashing lights, etc).
8. Go to the Lane Change Initiation Sync. Determine if a vehicle is located directly behind the trailer **at the lane change initiation sync**. Use the rear-facing look-down camera.
 - If a vehicle is present directly behind the trailer, enter Record the type of vehicle that is present. Options in the drop down box are:
 - o None
 - o Unknown Type
 - o Heavy
 - o Light
 - o Motorcycle
 - o Other
 - If a vehicle is not present directly behind the trailer, enter “**None**” into the excel spreadsheet.
9. If a vehicle is present, determine the distance to the vehicle into the excel spreadsheet. Use the screen captions below to help determine the distance.
 - Enter “**CLOSE**” into the excel spreadsheet if a good portion of the vehicle can be seen in the camera. (see image below)



- Enter “**FAR**” into the excel spreadsheet if only the bumper can be seen in the rear-facing look-down camera.



- Enter “**HEADLIGHTS ONLY**” if you cannot see any part of the vehicle, but the light from the headlights is visible. This option will only be used at night.

10. Assess the severity of the lane change. Use the rear look down camera to observe the interaction of the trailer with the adjacent vehicle.
 - **Possible Conflict:** If any interaction or close proximity to another vehicle is seen. This includes if the adjacent vehicle is still visible in the rear look-down camera at the lane change initiation sync, as well as any time headlights are flashed. If you suspect that the rear vehicle had to brake or slow to give way to the truck, use this option.
 - **No Conflict:** Lane change is performed without experiencing a conflict with another vehicle.
11. Load the Video Reduction Chart so that you can see at a glance all the data that you've entered. (Tools → Video Reduction)

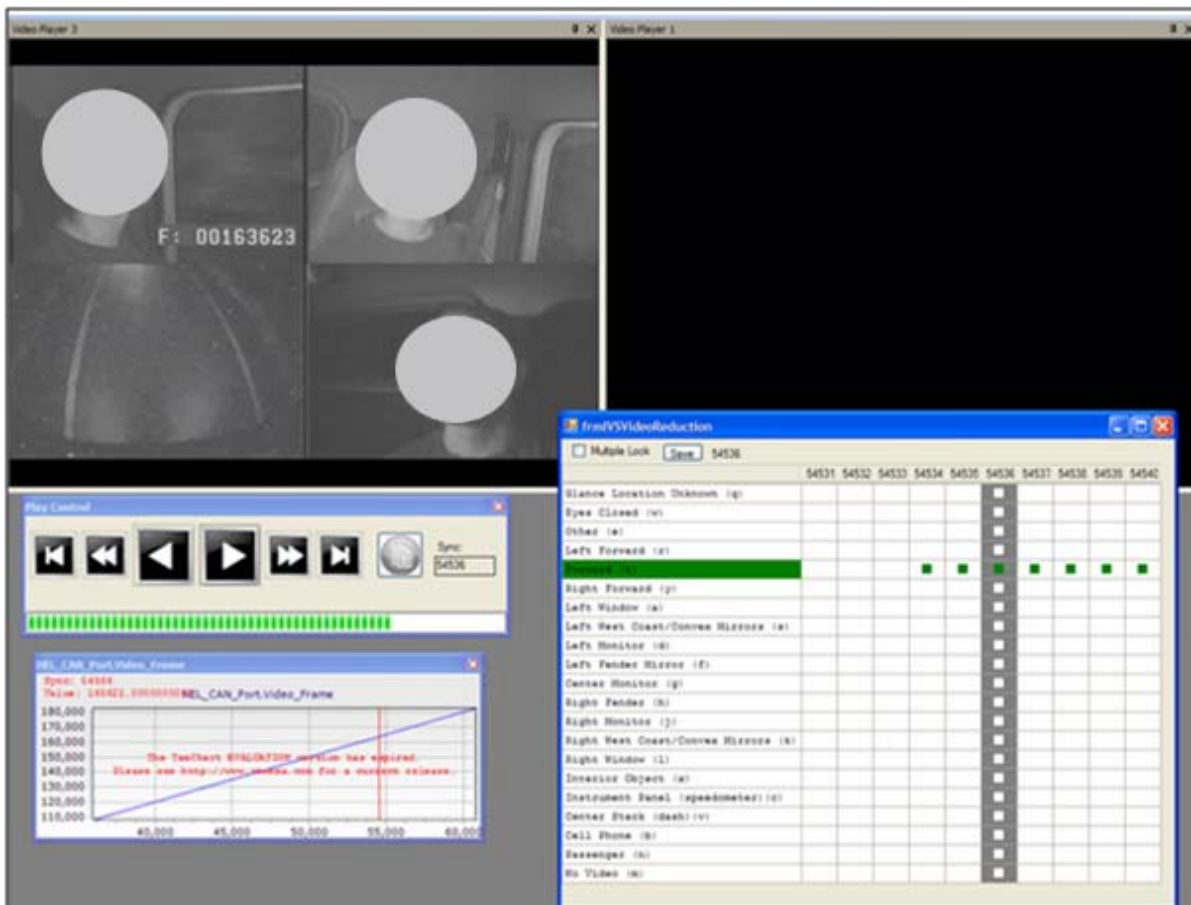
	20125	20126	20127	20128	20129	20130	20131	20132	20133	20134
Glance Location Unknown (q)						■				
Eyes Closed (w)						■				
Other (e)						■				
Left Forward (r)						■				
Forward (t)						■	■	■	■	■
Right Forward (y)						■				
Left Window (a)						■				
Left West Coast/Convex Mirrors (s)						■				
Left Monitor (d)						■				
Left Fender Mirror (f)						■				
Center Monitor (g)						■				
Right Fender (h)						■				
Right Monitor (j)						■				
Right West Coast/Convex Mirrors (k)						■				
Right Window (l)						■				
Interior Object (x)						■				
Instrument Panel (speedometer) (c)						■				
Center Stack (dash) (v)						■				
Cell Phone (b)						■				
Passenger (n)						■				
No Video (m)						■				

12. Review the event first from the start sync to the stop sync to verify that you are able to complete eye glance. Some reasons for being unable to complete eyeglance are:
 - Driver is wearing dark sunglasses and it is not possible to see eyes for the majority of the necessary time frame.

- Video is bad/dark/out of alignment and it is not possible to see eyes for the majority of the necessary time frame.

If either of the above is true, mark down on the log that the event could not be reduced and the reason why.

13. You should watch the face view quadrant of the video to get an idea of the type of glances made during the lane change. However, it is also important to pay attention to the other quadrants as well. For example, seeing that the driver is trying to change lanes, by watching the video of the roadway.
14. When you are ready to begin entering in eyeglance data, make sure you are at the start of the first sync indicated in the Excel Log.
15. Arrange the DART modules on your desktop to ensure that both the **video reduction** screen (buttons and codes) and the **video** screen are in full view.



16. Select the **video reduction** screen, and using your keyboard, enter in the first glance location. Please see the end of this Appendix for the glance location definitions, glance codes, and diagrams that illustrate different locations in vehicles.

17. Each time you press the glance location key, the video will advance one sync. You will need to press the key for each sync. DO NOT hold down a key when performing eyeglance in DART 2, because the video will not advance smoothly.
18. Notice that when you press a specific key, the corresponding sync will be highlighted in red on the video reduction screen. Any unsaved data that you've entered will show up as red squares. Data that has already been saved will show up as green squares.

The screenshot shows a software window titled "frmIVSVideoReduction". It has a "Multiple Lock" checkbox and a "Save" button. Below these is a table with columns for sync numbers 789 through 798. The rows list various glance locations. Red squares indicate unsaved data, and green squares indicate saved data.

	789	790	791	792	793	794	795	796	797	798
Left Window (a)						■				
Cell Phone (b)						■				
Instrument Panel (speedometer) (c)	■					■				
Left Monitor (d)						■				
Left Forward (e)				■	■	■				
Center Monitor (f)						■				
Right Monitor (g)	■	■	■			■				
Right West Coast/Convex Mirrors (h)						■				
Right Window (j)						■				
No Video (m)						■				
Passenger (n)						■				
Glance Location Unknown (q)						■				
Forward (r)						■				
Left West Coast/Convex Mirrors (s)						■				
Right Forward (t)						■				
Center Stack (dash) (v)						■				
Eyes Closed (w)						■				
Interior Object (x)						■				
Other (y)						■				

19. If you want to go back and review your data entry and the video, you can use the left and right arrows on your keyboard to shuttle the video and the corresponding eyeglance entries (as noted on the **video reduction** screen). If upon your review, you wish to change a glance location, shuttle the video reduction tool to the sync of the erroneous entry, and re-key in the correct glance location. This will overwrite your previous data.
20. A glance begins with a fixation on one of the glance locations defined in the table and ends when the next glance starts (with the next fixation). Any transition time from one fixation to another is kept with the first glance. For example, if the participant is looking forward and shifts their gaze to the instrument panel, you would mark **Forward** until their eyes are fixated on the instrument panel (at which point you would start marking **Instrument panel**).
21. Blinking is not recorded

22. Continue reducing continuously until you have reached the end sync indicated in the Excel log.

23. Save the eyeglance.

	789	790	791	792	793	794	795	796	797	798
Left Window (a)						■				
Cell Phone (b)						■				
Instrument Panel (speedometer) (c)	■					■				
Left Monitor (d)						■				
Left Forward (e)				■	■	■				
Center Monitor (f)						■				
Right Monitor (g)	■	■	■			■				
Right West Coast/Convex Mirrors (h)						■				
Right Window (j)						■				
No Video (m)						■				
Passenger (n)						■				
Glance Location Unknown (q)						■				
Forward (r)						■				
Left West Coast/Convex Mirrors (s)						■				
Right Forward (t)						■				
Center Stack (dash) (v)						■				
Eyes Closed (w)						■				
Interior Object (x)						■				
Other (y)						■				

24. In the Excel log, describe any special conditions that characterized the event (e.g. eyes obstructed by visor or glare for part of event).

25. Document in the log's comments sections any situations that are unique and might affect interpretation of the glances. For example, note anything unusual in any camera view, or reasons for any unusually long glances to glance locations off of the roadway (e.g. the participant looks at the radio continuously for 5 seconds because he/she is stopped at a red light).

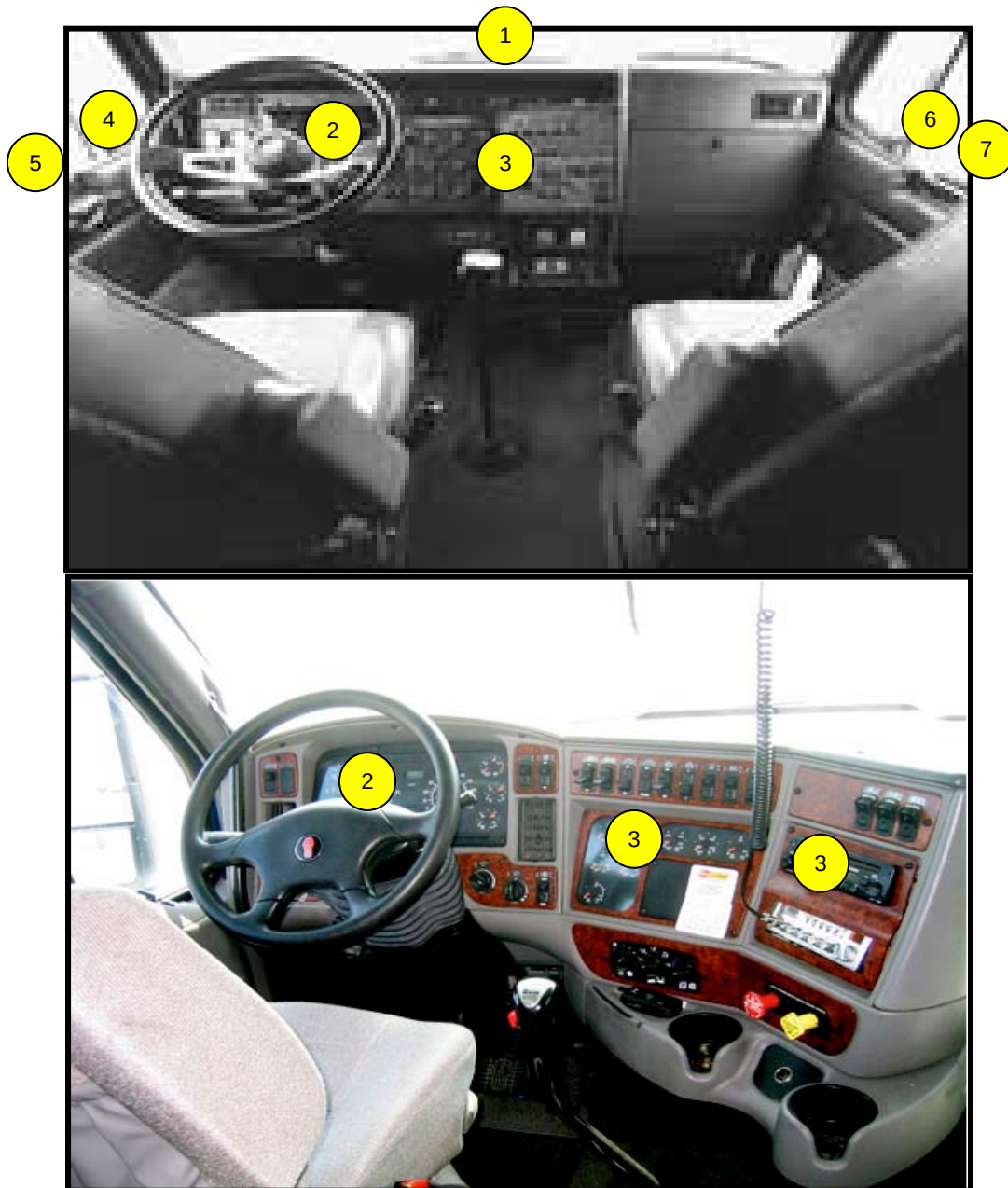
26. Move on to the next event indicated in the Excel log.

Eyeglance Location Definitions and Codes

Key	Position	Description
T	Forward	Any glance out the forward windshield. Note that when the vehicle is turning, these glances may not be directed directly forward but towards the vehicle's heading. Count these as forward glances. Note also that 'forward' glances may be directed to vehicles ahead in the adjacent lane or other external distractions slightly ahead of the subject. Also count as forward side glances that are taken in the process of turning into or crossing a road (e.g. the vehicle is stopped at an intersection and waiting for a gap in traffic to enter or cross the intersecting road, the driver looks left and right to check traffic conditions).
C	Instrument Panel	Any glance to the instrument cluster underneath the dashboard. This includes glances to the speedometer, control stalks, and steering wheel.
V	Center Stack	Any glance to the truck's center stack, located to the right of the Instrument Panel. This is where radio, climate, etc. controls are located. Glances below the Center Stack (e.g., to the cup holder area or the gear shift) would be coded as Interior Object.
S	Left West Coast/ Convex Mirror	Any glance to the left-side west coast/convex mirror.
K	Right West Coast/ Convex Mirror	Any glance to the right-side west coast/convex mirror.
B	Cell Phone (electronic communications device)	Any glance at a cell phone no matter where it is located. THIS DOES NOT INCLUDE THE ELECTRONIC TRACKING DEVICES THAT DRIVERS USE; PLEASE MARK THAT AS INTERIOR OBJECT.
A	Left Window	Any glance out the left-side window.
D	Left Monitor	Any glance at the left-side monitor.
F	Left Fender Mirror	Any glance to the left fender mirror, located on the front part of the truck's front fender.
R	Left Forward	Any glance to the left out the front window.
G	Center Monitor	Any glance at the center monitor.
Y	Right Forward	Any glance to the right out the front window.
J	Right Monitor	Any glance at the right-side monitor.
H	Right Fender Mirror	Any glance to the right fender mirror, located on the front part of the truck's front fender.
L	Right Window	Any glance out the right-side window.
n	Passenger	Any glance at a passenger.

Key	Position	Description
X	Interior Object	Any glance to an identifiable object in the vehicle other than a cell phone. These objects include personal items brought in by the participant (e.g., purse, food, papers), any part of their body that may look at (e.g., hand, ends of hair), electronic devices other than cell phones (e.g., iPod, laptop, CB radio), and also OEM installed devices that don't fall into other categories (e.g., door lock, window and seat controls). Glances to the center console (cupholder area between passenger seat and driver seat) and gear shifter (if located in that area) will also be included in this category. The object does not need to be in the camera view for a specific frame to be coded with this category. If it is clear from surrounding video that the participant is looking at the object, this category may be used. This category can be used regardless of whether the participant's hands are/aren't visible. Note: in truck studies such as this, Interior Object also includes glances to the instruments at the top of the windshield/overhead.
M	No Video	Unable to complete glance analysis because the face video view is unavailable.
Q	Glance Location Unknown	Unable to complete glance analysis due to an inability to see the driver's eyes/face. Video data is present, but the driver's eyes and face are not visible due to an obstruction (e.g. visor, hand,), or due to glare.
W	Eyes Closed	Any time that the participant's eyes are closed outside of normal blinking (e.g., the subject is falling asleep). As a rule of thumb, if the eyes are closed for five or more syncs (1/2 a second) during a slow blink, code it as Eyes Closed.
E	Other	Any glance that cannot be categorized using the above codes (e.g., specific built-in vehicle features). If you come across anything that could fall under this category, please inform the Lab Manager and leave an explanation in the Excel log for appropriate follow-up.

Illustrations of Truck Interior



- 8- Forward
- 9- Instrument Panel
- 10- Center Stack
- 11- Left Mirror
- 12- Left Window
- 13- Right Mirror
- 14- Right Window

APPENDIX AA. ADDITIONAL ANALYSIS OF DRIVER OPINION DATA

Additional analyses of the data collected from the Driver Opinion questionnaire are presented in this appendix.

How Pleasant is the C/VIS

Figure 249 presents the drivers' mean ratings in regard to the statement, "I think the C/VIS is pleasant." A Friedman Two-Way ANOVA using each A-C/VIS driver's median rating in Month 1, Month 2, Month 3, and Month 4 was performed to analyze within-subject differences between their ratings in the four months. A statistically significant difference between drivers of A-C/VIS-equipped trucks' ratings in Month 1, Month 2, Month 3, and Month 4 was found ($X^2 = 9.75$, $p = 0.0208$). Post hoc multiple comparison tests were performed on statistically significant Friedman Two-Way ANOVA results as specified in Siegel & Castellan (1988). A statistically significant difference between pairwise comparisons of drivers' mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$). Drivers indicated that the A-C/VIS was significantly more pleasant in Month 4 than what was expected in Month 1. Statistically significant differences for the mean ratings of drivers of commercial C/VIS-equipped trucks were not found.

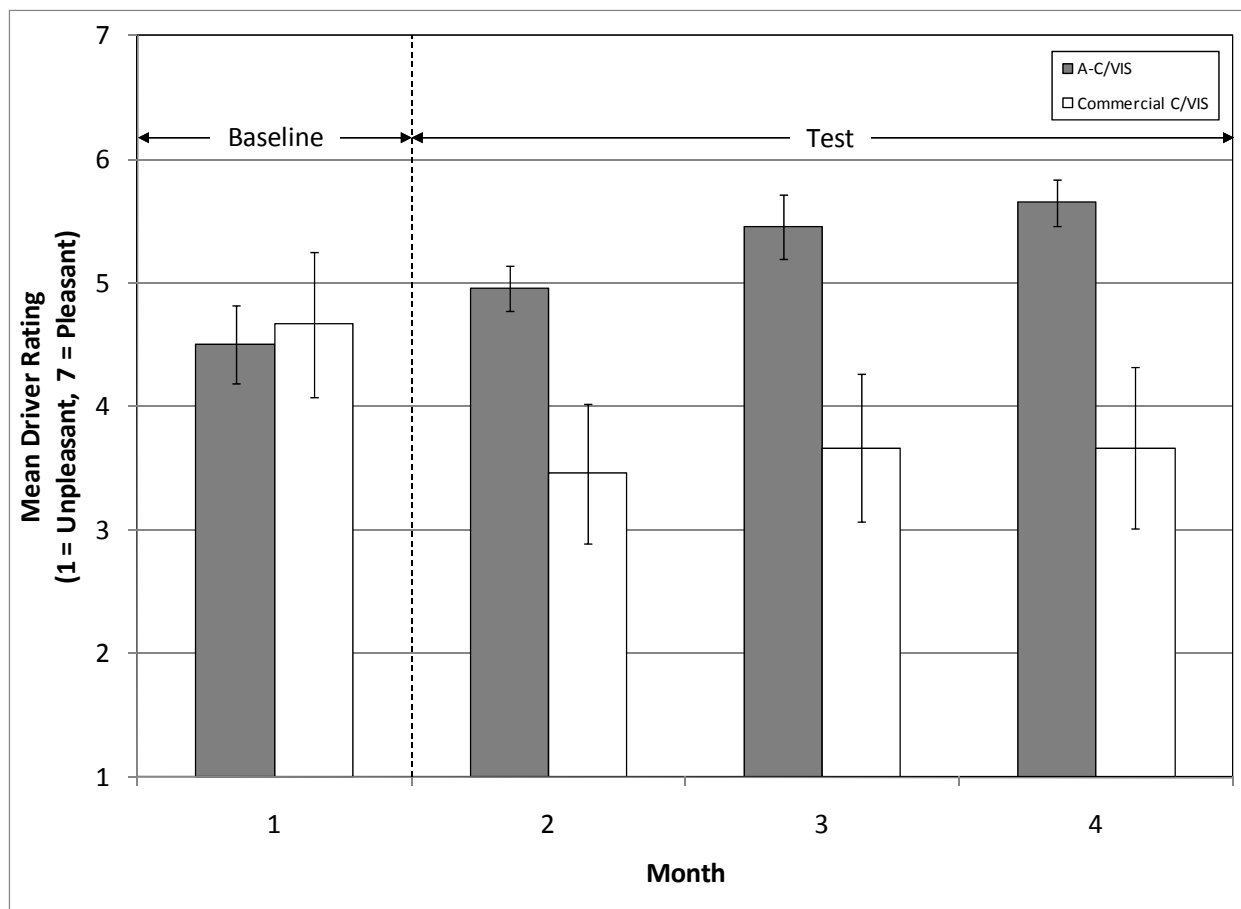


Figure 249. Comparison of A-C/VIS and the Commercial C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Pleasant.” (D = number of drivers; R = number of responses)

How Good is the C/VIS

Drivers’ mean ratings in response to the statement, “I think the C/VIS is good,” are presented in Figure 250. A statistically significant Month in Study effect was found for drivers of A-C/VIS-equipped trucks ($X^2 = 12.46, p = 0.006$). These drivers found the A-C/VIS better the longer they were in the study. A statistically significant pairwise comparison between the drivers’ mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$). Drivers of A-C/VIS-equipped trucks found the A-C/VIS to be better in Month 4 than what they expected in Month 1.

A statistically significant Month in Study effect was also found for drivers of commercial C/VIS-equipped trucks ($X^2 = 10.59, p = 0.0142$). The longer these drivers used this C/VIS, the lower they rated it. A statistically significant pairwise comparison between the drivers’ mean ratings in Month 1 and Month 4 were found ($\alpha = 0.05$). Drivers of commercial C/VIS-equipped trucks found the C/VIS to be worse in Month 4 than what they expected in Month 1.

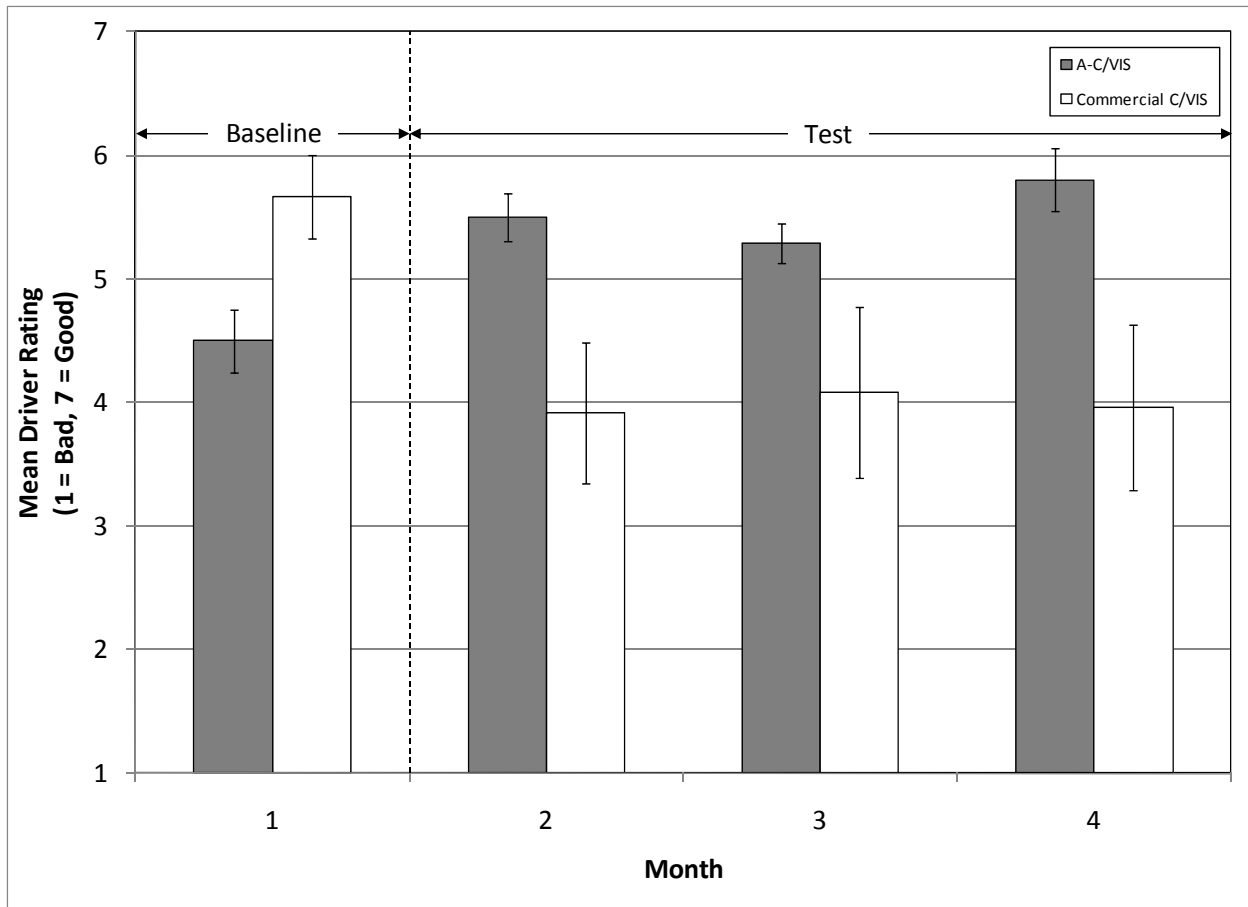


Figure 250. Comparison of A-C/VIS and the Commercially Available C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Good.” (D = number of drivers; R = number of responses)

How Nice is the C/VIS

Figure 251 presents drivers’ mean ratings in regard to the statement, “I think the C/VIS is nice.” A statistically significant difference between drivers of A-C/VIS-equipped trucks’ ratings in Month 1, Month 2, Month 3, and Month 4 was found ($X^2 = 11.73$, $p = 0.0084$). Thus, A-C/VIS drivers perceived the system as more nice over the four months. A statistically significant pairwise comparison of drivers’ mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$). Drivers indicated the better in Month 4 than they expected in Month 1.

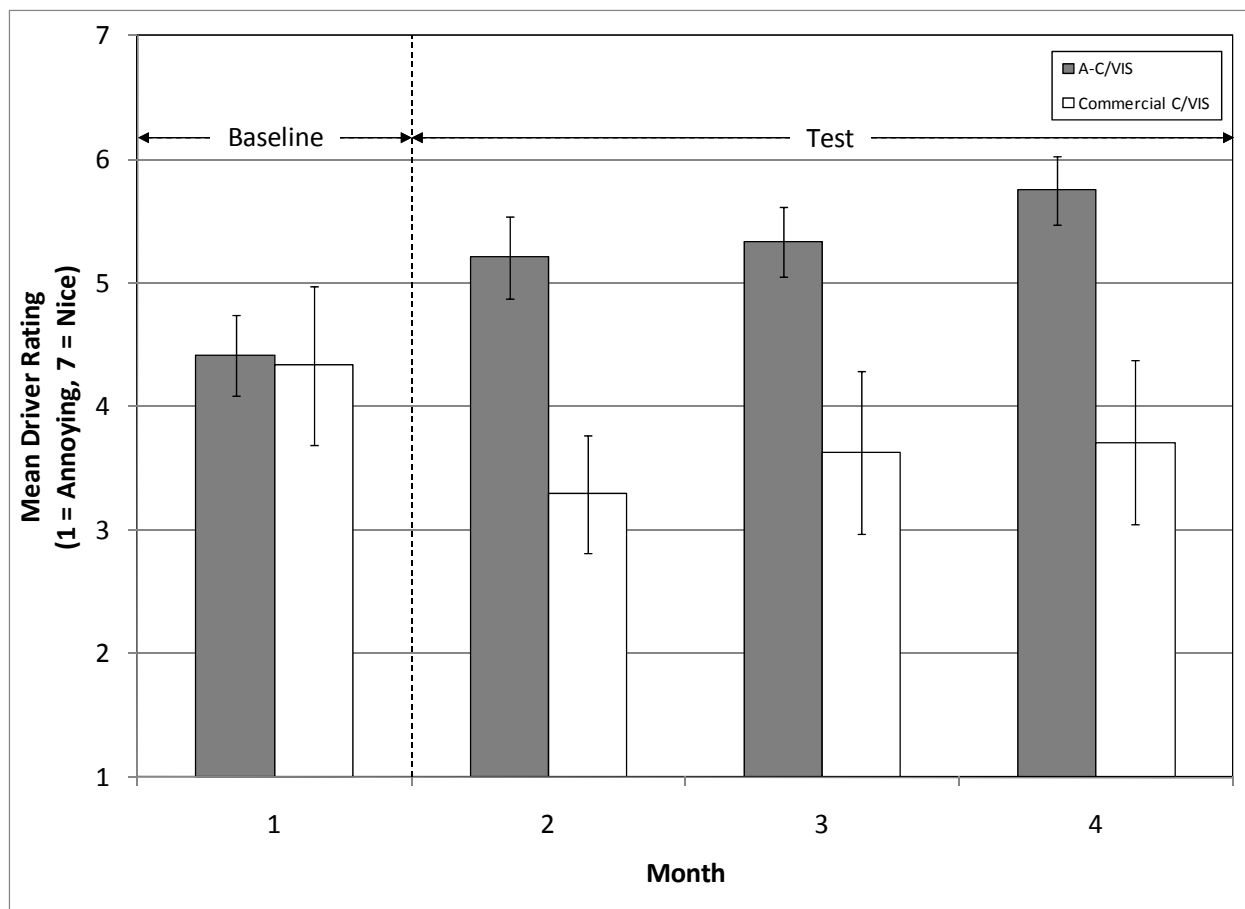


Figure 251. Comparison of A-C/VIS and the Commercially Available C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Nice.” (D = number of drivers; R = number of responses)

How Effective is the C/VIS

Drivers’ mean ratings in response to the statement, “I think the C/VIS is effective,” are presented in Figure 252. A statistically significant difference in the ratings for drivers of commercial C/VIS-equipped trucks in Month 1, Month 2, Month 3, and Month 4 was found ($X^2 = 12.70$, $p = 0.0053$). Drivers indicated that the commercially available C/VIS became less effective over the four months. Statistically significant pairwise comparisons were found between Month 1 and Month 3 and between Month 1 and Month 4 ($\alpha = 0.05$). Drivers of the commercial C/VIS-equipped trucks indicated that the system was less effective in Months 3 and 4 than they expected in Month 1.

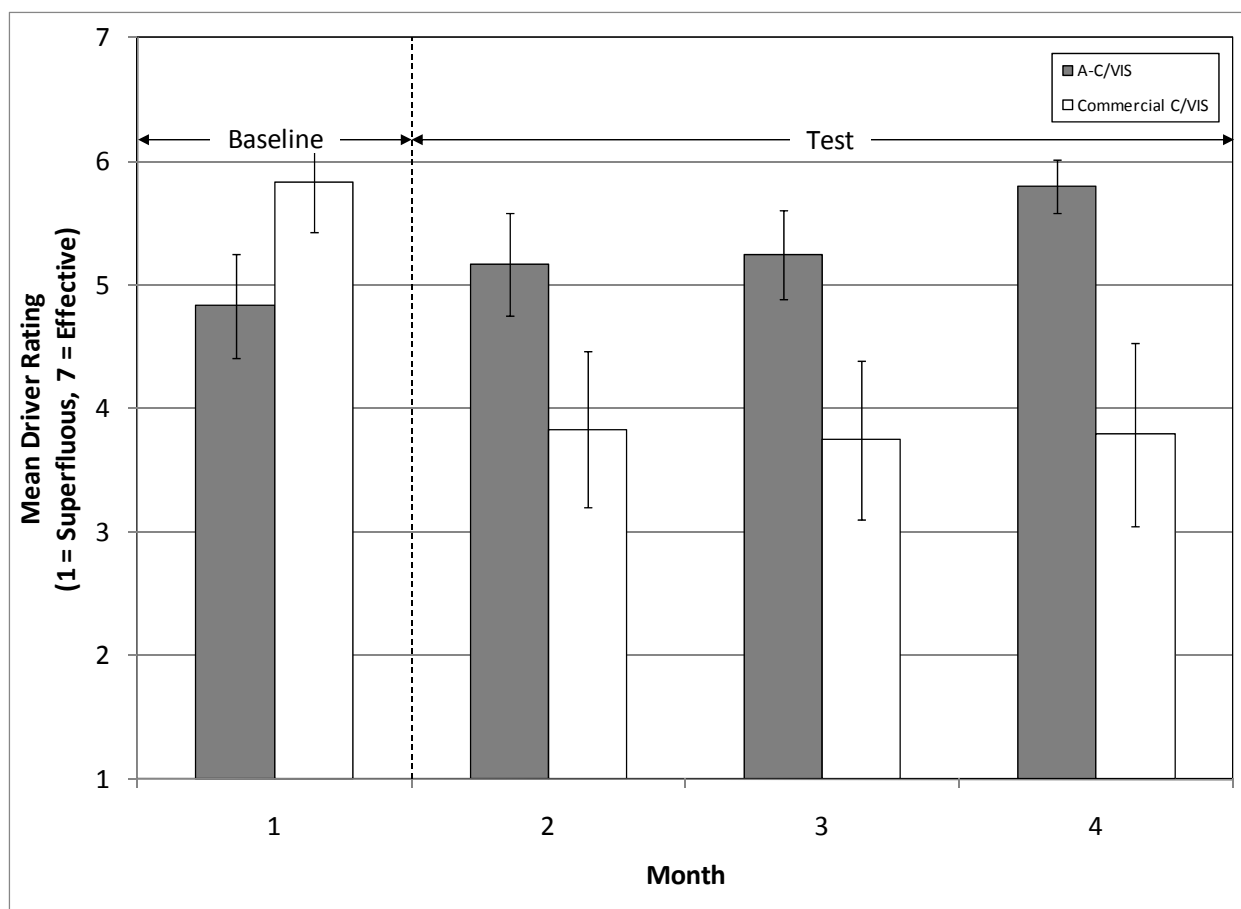


Figure 252. Comparison of A-C/VIS and the Commercially Available C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Effective.” (D = number of drivers; R = number of responses)

How Assisting is the C/VIS

Figure 253 presents the mean driver ratings in regard to the statement, “I think the C/VIS is assisting.” A statistically significant difference between drivers of A-C/VIS-equipped trucks’ ratings in Month 1, Month 2, Month 3, and Month 4 was found ($X^2 = 12.87, p = 0.0049$). Drivers of A-C/VIS-equipped trucks found the system to be more assisting as their time in the study progressed. A statistically significant pairwise comparison between drivers’ mean ratings in Month 1 and Month 4 was found ($\alpha = 0.05$). Drivers of A-C/VIS-equipped trucks reported the system was more assisting in Month 4 than they expected it to be in Month 1.

A statistically significant Month in Study difference was found for the mean ratings of drivers of commercial C/VIS-equipped trucks ($X^2 = 12.00, p = 0.0074$). These drivers indicated that the commercially available C/VIS became less assisting as their time in the study progressed. Statistically significant pairwise comparisons between Month 1 and Month 2 and between Month 1 and Month 3 were found ($\alpha = 0.05$). Drivers of the commercial C/VIS-equipped trucks indicated that the C/VIS was less assisting in Months 2 and 3 than they expected it to be in Month 1.

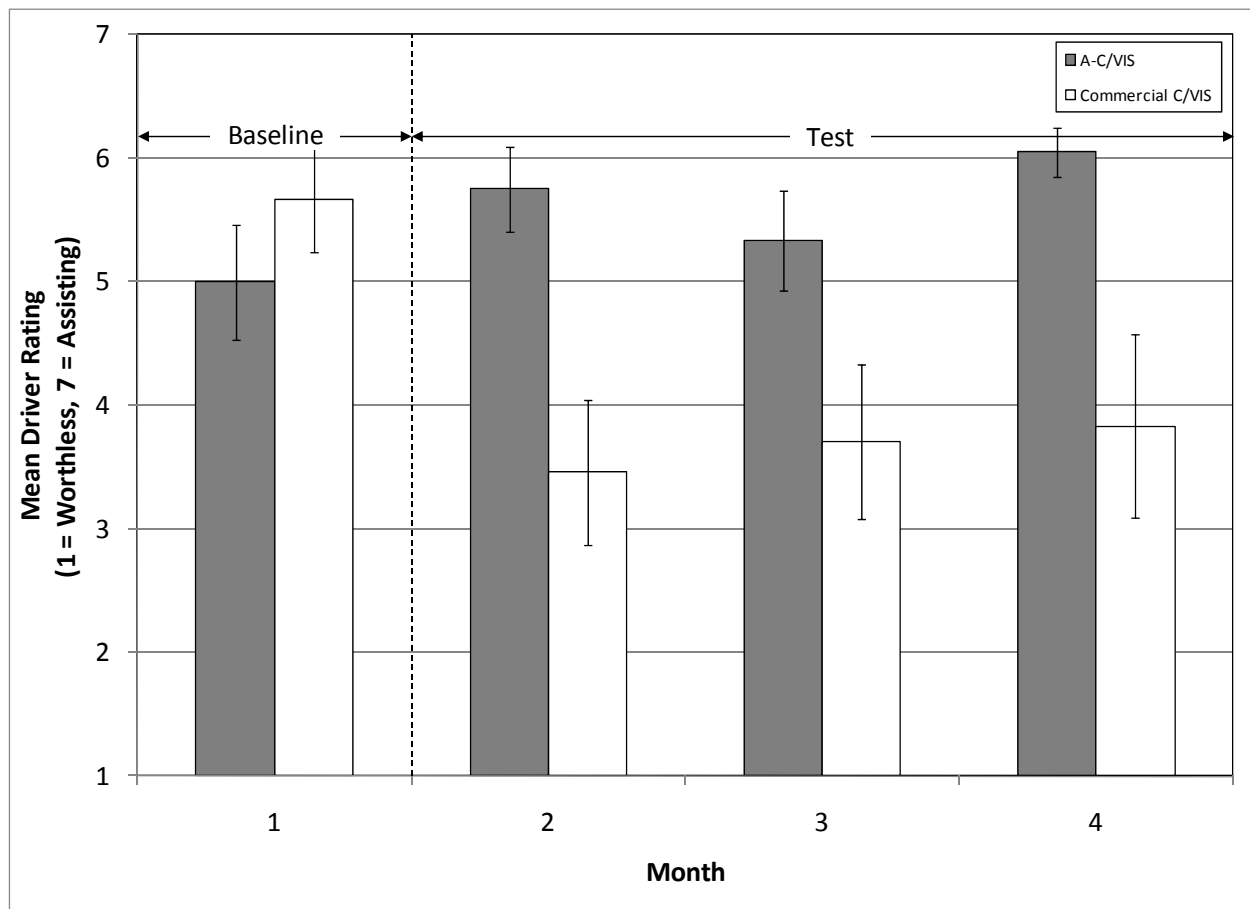


Figure 253. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Assisting.” (D = number of drivers; R = number of responses)

How Sleep-Inducing is the C/VIS

Figure 254 presents the drivers’ mean ratings in response to the statement, “I think the C/VIS is sleep-inducing.” Statistically significant within subject differences between drivers’ ratings in Month 1, Month 2, Month 3, and Month 4 were not found.

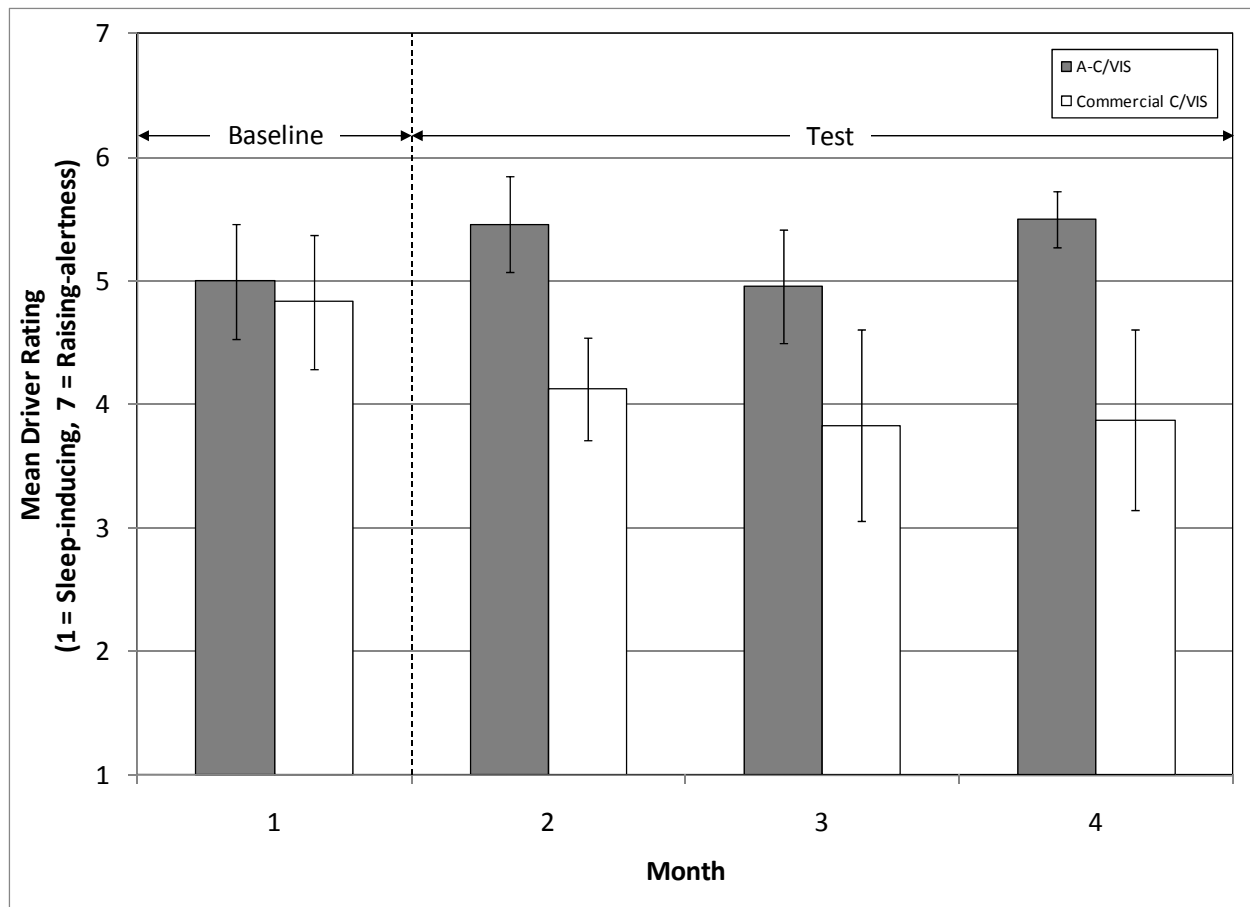


Figure 254. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 1, Month 2, Month 3, and Month 4 in Response to the Statement, “I think the C/VIS is Sleep-Inducing.” (D = number of drivers; R = number of responses)

Comparison of Driving Performance with a C/VIS to Driving Performance without a C/VIS

Figure 255 presents drivers’ mean ratings in regard to the question, “How does your driving performance with a C/VIS compare to your driving performance without a C/VIS?” Statistically significant within-subject differences between drivers’ mean ratings in Month 2, Month 3, and Month 4 were not found.

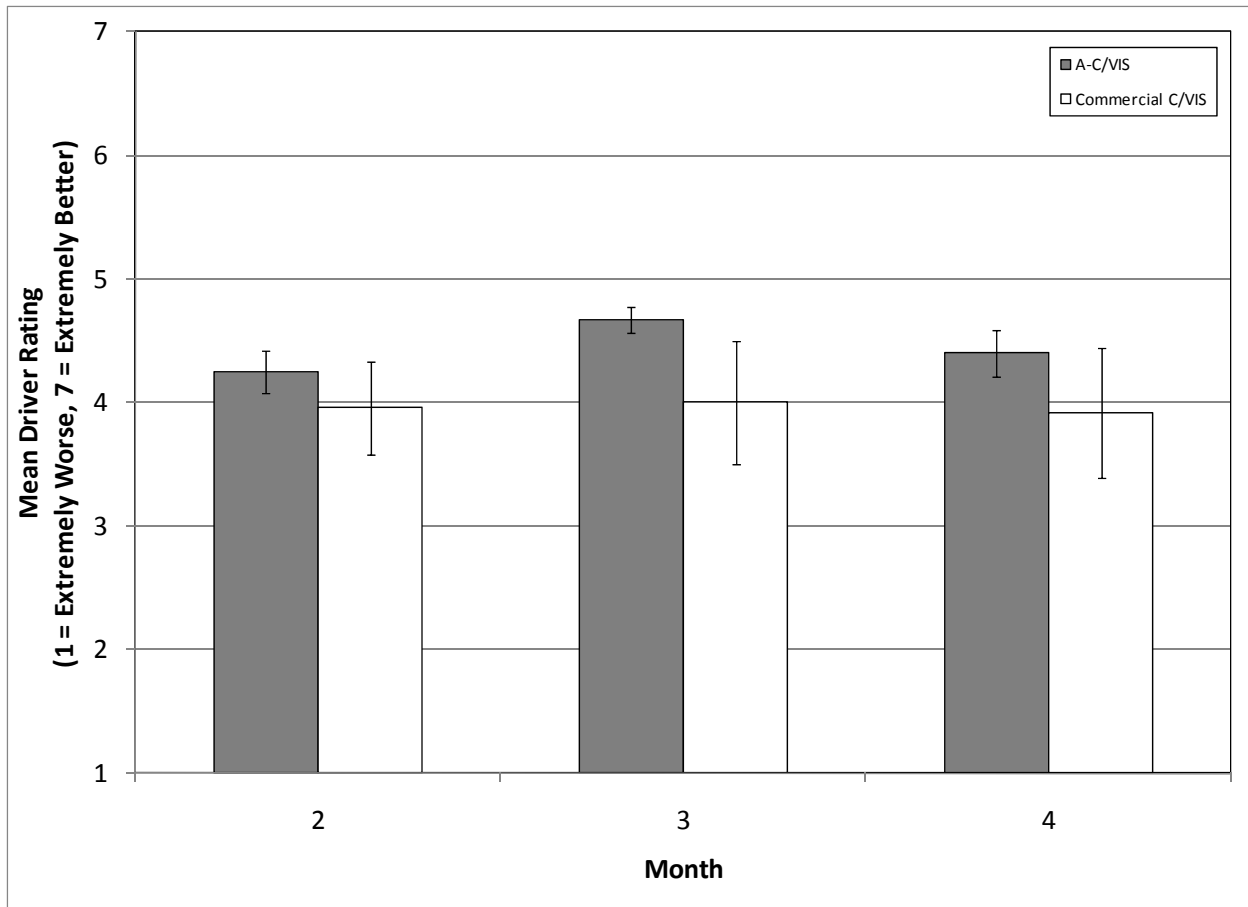


Figure 255. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 2, Month 3, and Month 4 in Response to the Question, “How does your Driving Performance with a C/VIS Compare to your Driving Performance without a CVIS?” (D = number of drivers; R = number of responses)

Desire to have this C/VIS in the Truck

Drivers’ mean ratings in regard to the question, “How much do you agree with the statement, ‘I would like to have this C/VIS in my truck?’” are presented in Figure 256. Statistically significant within-subject differences in drivers’ mean ratings in Month 2, Month 3, and Month 4 were not found.

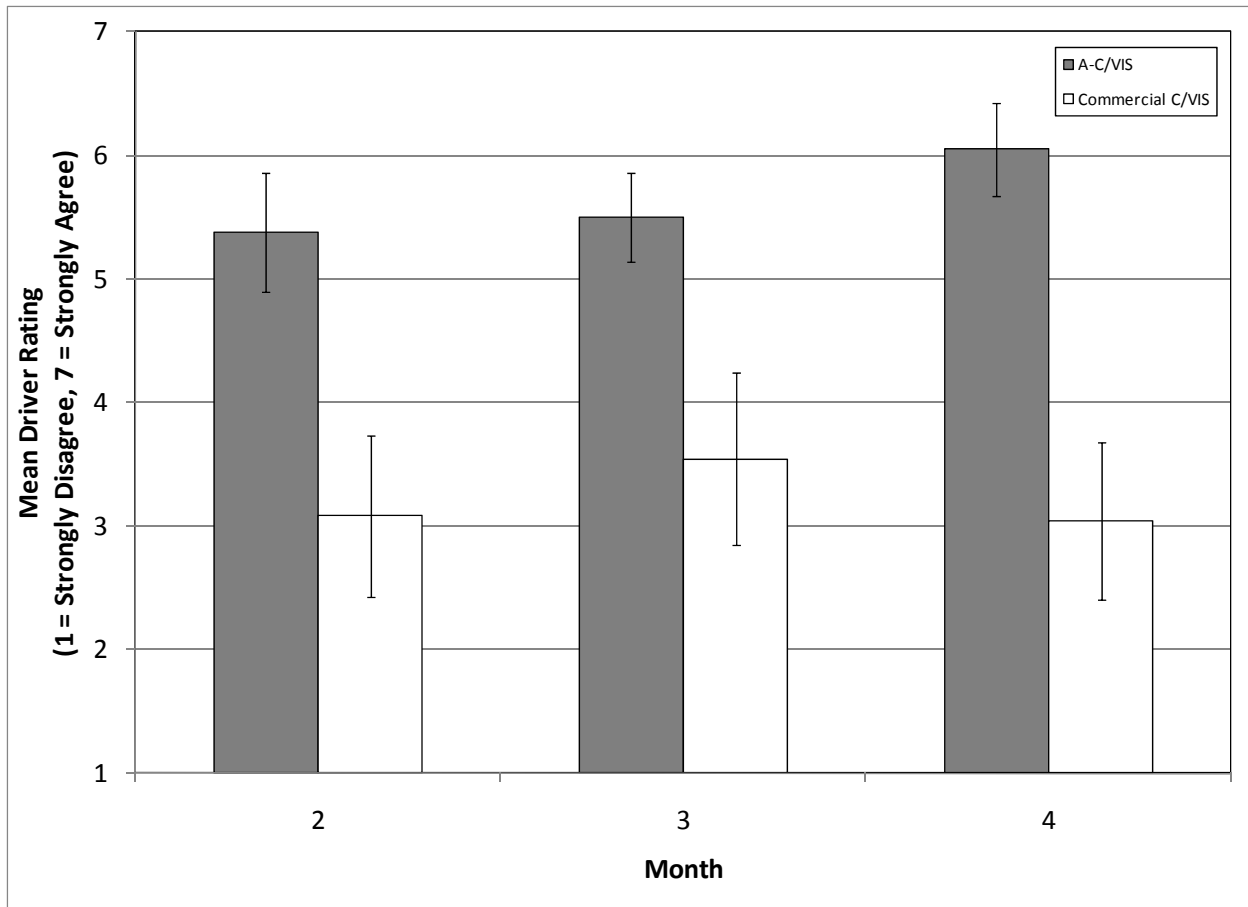


Figure 256. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 2, Month 3, and Month 4 in Response to the Question, “How Much do you Agree with the Statement, ‘I Would Like to have this C/VIS in My Truck’?” (D = number of drivers; R = number of responses)

Ability to use all Features the C/VIS Offers

In regard to the question, “How much do you agree with the statement, “I know how to use all the features the system offers’?” drivers’ mean ratings are presented in Figure 257. Statistically significant within-subject differences between drivers’ mean ratings in Month 2, Month 3, and Month 4 were not found.

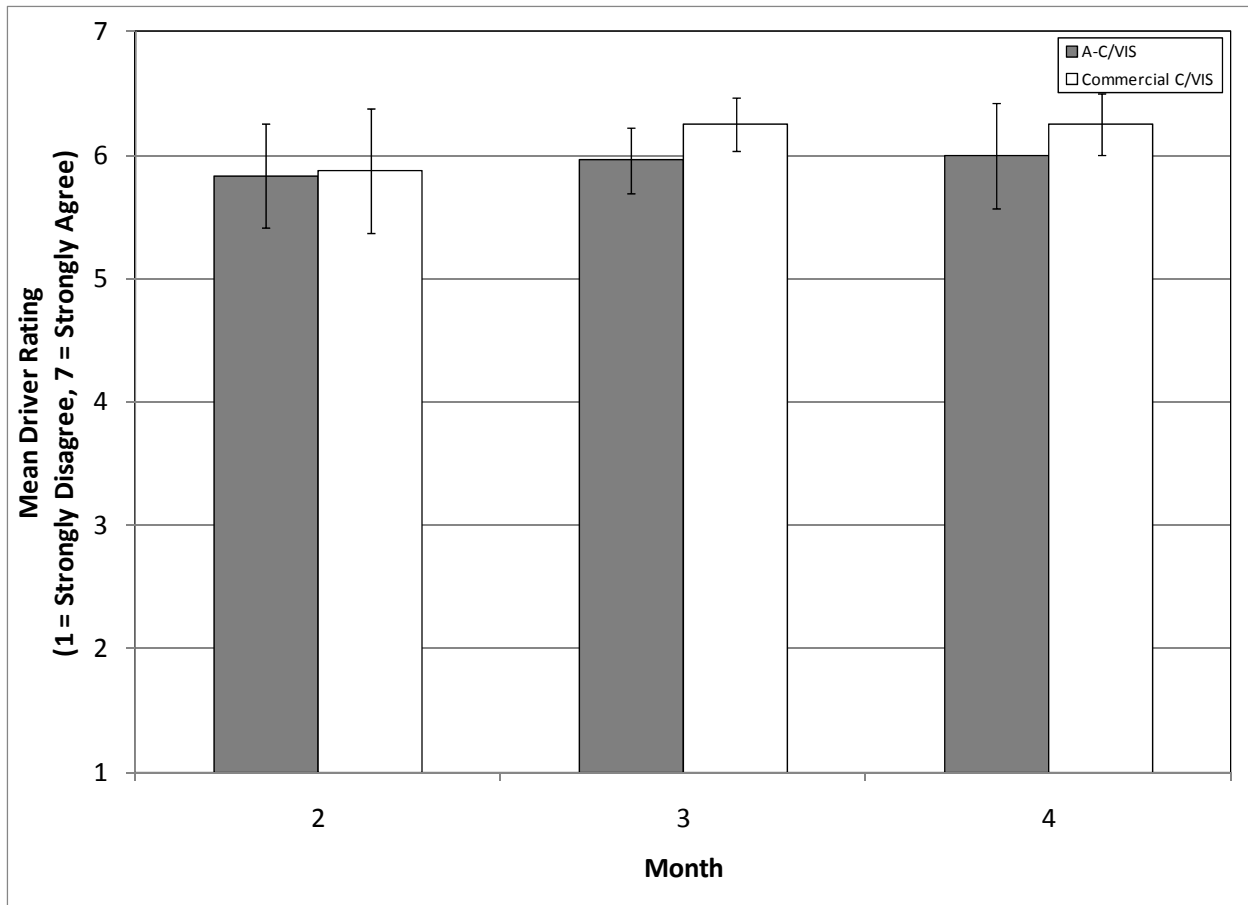


Figure 257. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 2, Month 3, and Month 4 in Response to the Question, “How Much do you Agree with the Statement, ‘I Know How to Use All the Features the System Offers?’” (D = number of drivers; R = number of responses)

Frequency of Camera Becoming Dirty when Weather is Clear

Figure 258 presents the drivers’ mean ratings in response to the question, “When it’s clear outside, how often does the camera lens get dirty to the point where it affects the view of the road?” Statistically significant Month in Study differences between drivers’ mean ratings were not found.

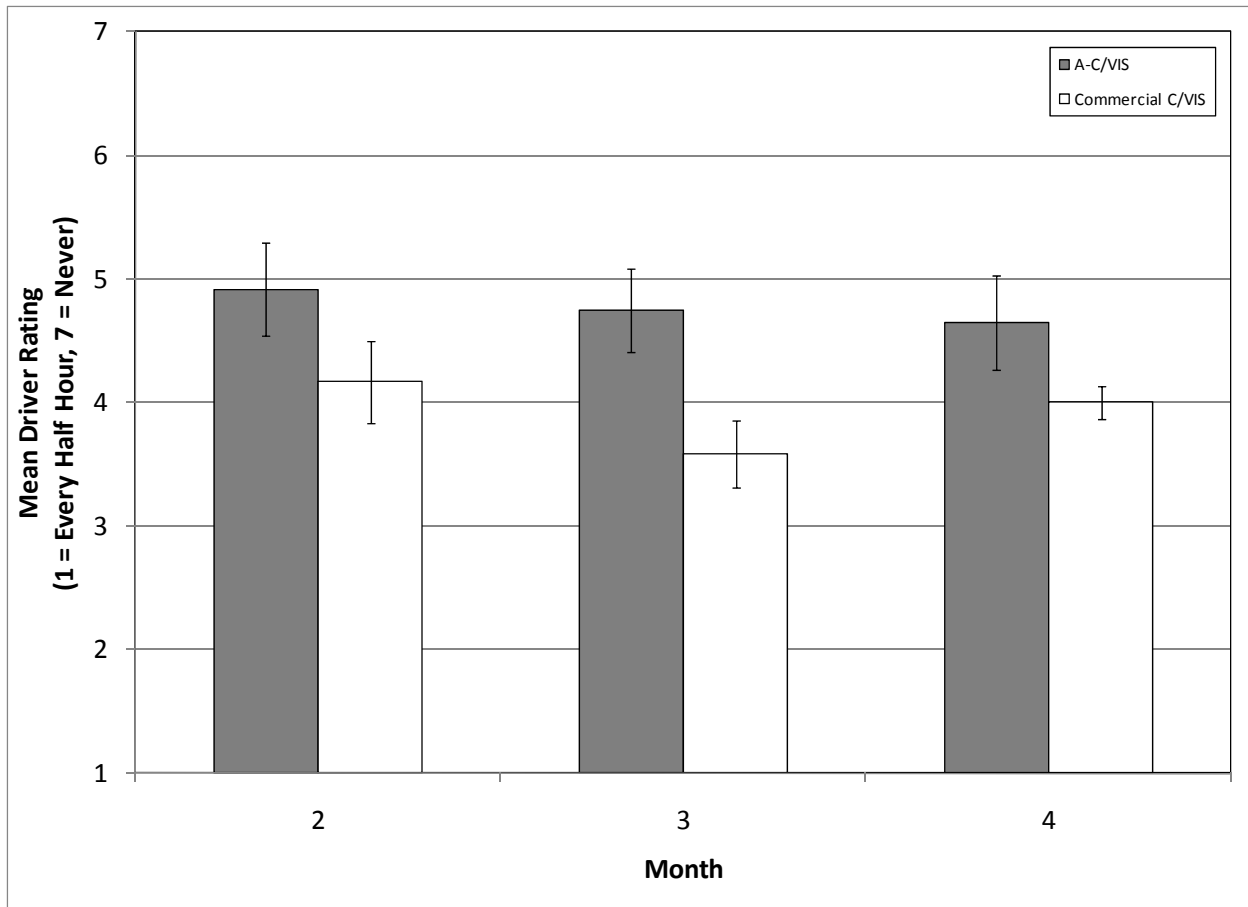


Figure 258. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 2, Month 3, and Month 4 in Response to the Question, “When It's Clear Outside, How Often Does the Camera Lens Get Dirty to the Point Where It Affects the View of the Road?” (D = number of drivers; R = number of responses)

Frequency of Camera Becoming Dirty when Weather is Raining

Drivers’ mean ratings in regard to the question, “When it's raining, how often does the camera lens get dirty to the point where it affects the view of the road?” are presented in Figure 259. Statistically significant Month in Study differences between drivers’ mean ratings were not found.

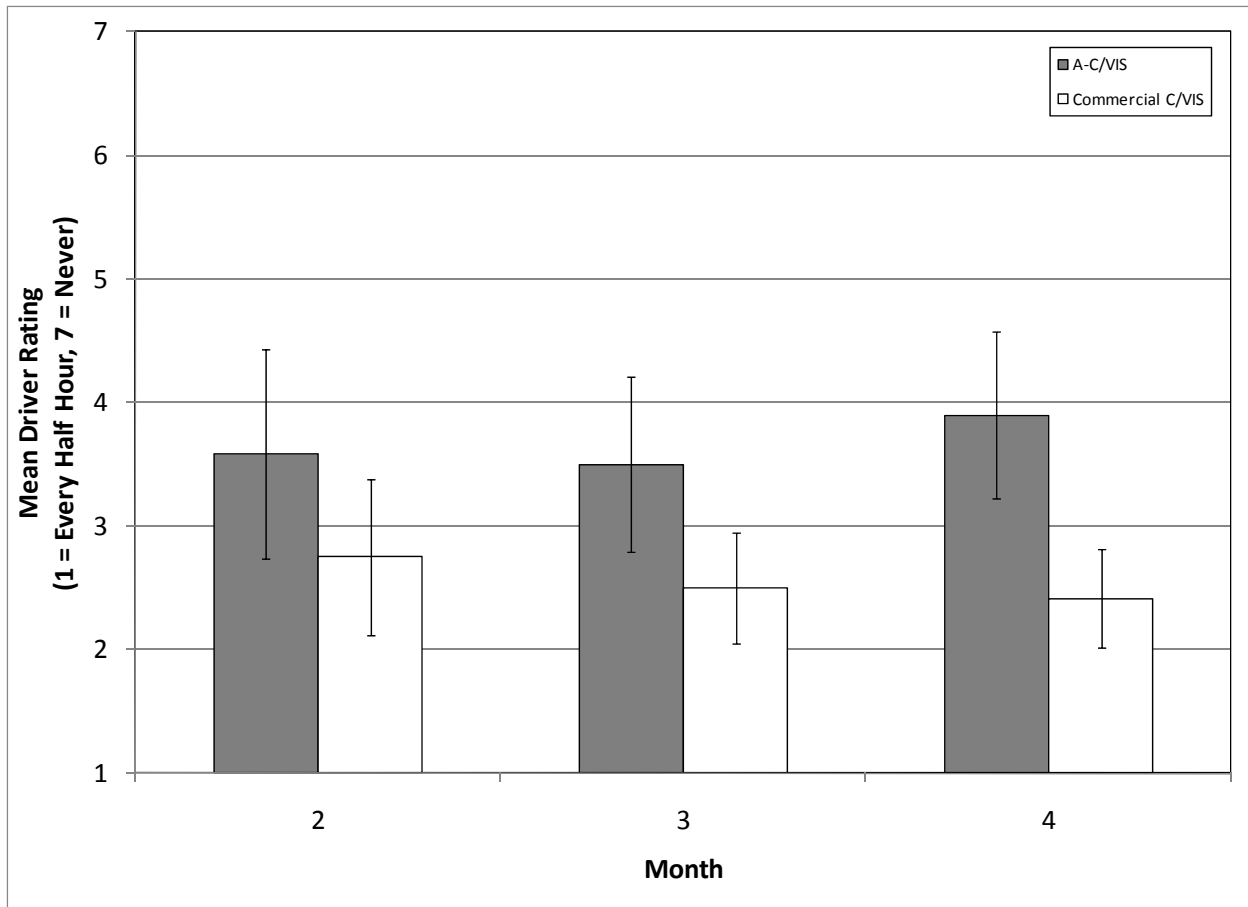


Figure 259. Comparison of A-C/VIS and Commercial C/VIS Mean Driver Ratings in Month 2, Month 3, and Month 4 in Response to the Question, “When It’s Raining, How Often Does the Camera Lens Get Dirty to the Point Where It Affects the View of the Road?” (D = number of drivers; R = number of responses)

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