DRIVER PERFORMANCE WITH A CAMERA/VIDEO IMAGING SYSTEM

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ABSTRACT
Camera/Video Imaging Systems (C/VISs) help drivers monitor the areas around their truck by relaying live video images collected from cameras mounted on the truck's exterior to monitors mounted inside the truck's cabin. The purpose of this study was to expand on the favorable results from previous C/VIS test-track research performed by NHTSA and FMCSA by evaluating the implementation of C/VISs in a real-world operation. Drivers' performance with and without a C/VIS was unobtrusively recorded using a naturalistic driving study approach. Twelve drivers from a fleet company participated in this research and drove a company truck on revenue producing routes. Each driver drove one truck that had either a commercially-available C/VIS, or an Advanced-C/VIS (A-C/VIS) developed by VTTI. The commercially-available C/VIS selected was called SIDETRACKER™ and had a side-view camera on each fender. The A-C/VIS had side-view cameras, a rear-view camera, and night-vision capabilities. The trucks that were driven in this study remained permanently coupled to 48-ft long trailers over the course of the twelve-month data-collection interval. Each driver drove a truck for one month with the C/VIS disabled (Baseline condition), and three months with the C/VIS enabled (Test condition). Drivers completed surveys regarding their driving performance and overall experience with C/VISs every two weeks. It was found that C/VISs are able to assist commercial motor vehicle (CMV) drivers in their daily driving task without deteriorating their driving performance. Specifically, the probability that drivers looked forward, their clearance to an adjacent vehicle when changing lanes, and their involvement in safety critical events (SCEs), did not change when driving with a C/VIS. Drivers also reported that the CVIS improved their awareness of surrounding objects and assisted them in performing lane changes and merge maneuvers, particularly when making right lane changes. The A-C/VIS's rear-view vantage point was the most frequently used feature and was highly rated by drivers. Even though drivers' positive subjective ratings can contribute to safety, it is important to note that drivers did not encounter fewer SCEs when driving with a C/VIS. A potential limitation with the study is that the driving data were collected when traffic density was low. Further research could observe drivers' performance with and without C/VISs in congested traffic. Performance in dense traffic could provide a continued analysis of the distribution of SCE's as an index of safety benefit. OEMs and tier-1 suppliers have developed multiple methods to implement C/VISs. The A-CVIS is an innovative approach to C/VIS that assists drivers to overcome blind spots; this paper presents a real-world evaluation of such a system including the identification of potential safety benefits.

INTRODUCTION

Data from the 2009 National Automotive Sampling System General Estimates System indicate that 20 percent of the 6,703 truck crashes were classified as a sideswipe in which both vehicles were travelling in the same direction (U.S. Department of Transportation, 2009). This statistic comprises 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 was indeterminable. In only considering the crashes were the truck was the striking vehicle, 20 percent (653 crashes) of the 3,397 striking truck crashes were classified as sideswipes in the same direction. Table 1 organizes these 653 sideswipe crashes by their pre-crash maneuver. These data indicate that a total of 457 crashes involved the truck changing lanes, merging, passing a lead vehicle, turning left or right, making a u-turn, leaving a parked position or starting in the traffic lane. These crashes comprise 6.8 percent of the 6,703 truck crashes, and are of interest because they may be related to the truck driver not having a complete view of the adjacent vehicles when executing a maneuver. It should be noted that sideswipes occurring when the truck was going straight, decelerating, or negotiating a turn may involve the driver drifting out of their lane, and may not represent cases where a crash occurred because the driver failed to observe an adjacent vehicle when executing a lateral maneuver.

Crashes involving truck drivers failing to observe an adjacent vehicle are of interest to the U.S. DOT. This is because trucks have large blind spots around the left, right, front and back of the vehicle. These blind spots, or 'No-Zones', allow vehicles to travel beside the truck unbeknownst to the truck driver and thus make them susceptible to a collision if the driver executes a lateral maneuver.

Table 1.
Classification of sideswipe crashes by pre-crash maneuver

Pre-Crash Maneuver	Frequency	Percent (%)
Going Straight	175	26.8
Decelerating in Traffic Lane	5	0.77
Starting in Traffic Lane	4	0.61
Passing or Overtaking Another Vehicle	11	1.68
Leaving a Parked Position	3	0.46
Turning Right	54	8.27
Turning Left	26	3.98
Making U-turn	5	0.77
Negotiating a Curve	7	1.07
Changing Lanes	344	52.68
Merging	10	1.53
Other	1	0.15
Unknown	8	1.23
Total	653	100

A simple, low-cost countermeasure to No-Zone-related crashes is to provide drivers with a view of the areas surrounding their truck with a Camera/Video Imaging System (C/VIS) (Rau,

Schaudt, Wierwille, Hanowski, & Bocanegra, 2009). C/VISs help drivers monitor the areas around their truck by relaying live video images collected from cameras mounted on the truck's exterior to monitors mounted inside the truck's cabin. These C/VISs supplement the existing mirror system, and are not used to replace the mirror system. Various C/VISs have been developed and are commercially available. For instance, VTECH USA manufactures a C/VIS called SIDETRACKER™ and reports that this system has been installed on 8000 US XPRESS trucks (V-TECH USA LLC, 2009).

Both the National Highway Traffic Safety Administration and the Federal Motor Carrier Safety Administration have been interested in the potential benefits C/VISs offer the commercial driving industry. The indirect visibility research program has involved: 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, Spaulding, & Hanowski, 2008), and 3) developing an enhanced C/VIS (E-C/VIS) to provide all-around visibility to drivers during nighttime and inclement weather conditions (Schaudt, Wierwille, & Hanowski, 2008; Wierwille, Schaudt, Blanco, Alden, & Hanowski, in press). In addition, NHTSA and FMCSA contracted with the Virginia Tech Transportation Institute (VTTI) to perform a C/VIS Technology Field Demonstration (TFD) and evaluate driver performance with C/VISs in a revenue-producing environment. Findings from the TFD are presented in this paper.

METHOD

Participants

Twelve Commercial Driver's License (CDL)-qualified drivers participated in this study. All drivers were employees of Schneider National, Inc and worked at the Winchester, Virginia operation. This operation ran a daily-delivery service where each participant drove the same route each day. The majority of the participants' driving was performed at night. Their shifts began as early as 5:00 PM and as late as 1:00 AM. Participant shifts ended as early as 3:30 AM and as late as 11:00 AM. All participants traveled alone for the duration of their shifts. The drivers' average age was 39 years old (Min = 26 years old, Max = 53 years old). All participants had a minimum visual acuity of 20/40. Eleven drivers completed all four months of the study, while one driver completed three months of the study before he quit his employment.

Test Vehicles

Schneider National, Inc provided six Freightliner C120 Century tractors from their Winchester, Virginia operation for use in the TFD (Figure 1). 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 the trailers. This is atypical in the trucking industry. During the fleet company recruitment process Schneider National, Inc was the only company who agreed to operate under this constraint. The Winchester, Virginia operation was selected because it was the most cost-effective to travel to with respect to collecting data throughout the TFD.

Figure 1. Freightliner C120 tractor with 48-ft trailer

C/VISs

Two C/VISs were used in the TFD. The first was a commercially available C/VIS, while the second system was an Advanced C/VIS (A-C/VIS) developed by VTTI. Both are briefly described below, while additional information is presented in Fitch, Blanco, & Hanowski (2009).

Commercially Available C/VIS

The selected commercially available C/VIS was a cab-only solution, where one camera was mounted on the left fender pointing back along the left side of the trailer, and another camera was mounted on the right fender pointing back along the right side of the trailer (Figure 2). Each camera's Field-of-View (FOV) was 88 degrees, which provided wide coverage but also increased image distortion. 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 2). The Sidetracker settings were selected through an on-screen menu and included the ability to adjust the brightness, contrast, tint, and color of the video image.

a)

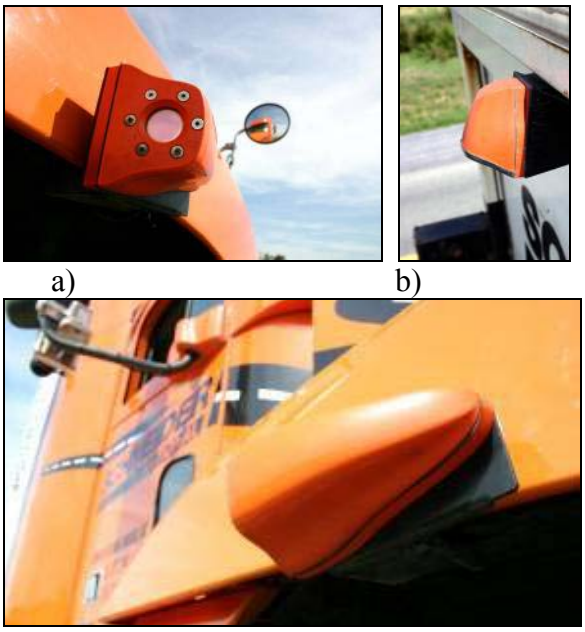
b)

c)

Figure 2. Left (a) and right (b) fender cameras from a commercially available C/VIS mounted on a freightliner C-120 tractor. c) commercial C/VIS monitors mounted on dash.

A-C/VIS

The A-C/VIS was a roadworthy version of a prototype C/VIS developed and tested by VTTI (Wierwille et al., in press). The A-C/VIS met established C/VIS daytime performance specifications (Wierwille et al., 2008), and encompassed the day, night, clear, and inclement weather operational window set forth in Wierwille et al. (in press). The A-C/VIS consisted of three cameras mounted on the truck: a camera on each fender pointing back along the trailer (Figure 3a and 3c), and a rear wide-angle look-down camera mounted on the top-center of the back-side of the trailer (Figure 3b). The side cameras' 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.



a) b)

c)

Figure 3. Placement of A-C/VIS left fender camera (a), rear trailer camera (b), and right fender camera (c).

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 4). The Driver-Vehicle Interface (DVI) was built into the left monitor and allowed all functionality to be accessed using one button press. 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 was also used by the A-C/VIS to provide night-vision capabilities during night mode.

Figure 4. Placement of A-C/VIS monitors in truck cab.

Procedure

Six trucks were instrumented with a data acquisition system that allowed for the continuous recording of parametric data that included vehicle speed, distance travelled, and brake pedal application obtained from the truck's on-board network, vehicle position obtained from a Global Positioning System antenna, vehicle deceleration obtained from accelerometers, range to forward and trailing vehicles obtained from radar sensors, and vehicle lane position obtained from a camera-based lane tracking system. Video data of the driver and roadway were also continuously recorded. Four cameras recorded the driver's face and control of the steering wheel, while another four cameras recorded the forward roadway, the left fender camera, the right fender camera, and the rear look-down camera. Although trucks equipped with the commercially available system did not display the rear video image to drivers on a monitor, this view was recorded to assist with analyses of drivers' lane change performance.

Drivers had to be employed by Schneider National, Inc to participate in this study. Because there were only six routes at the Schneider National Winchester, Virginia operation that allowed the use of 48-ft-long trailers, and there were a limited number of drivers that were based out of Winchester, Virginia, drivers were recruited to participate in the study on a first-come, first served basis. After obtaining drivers' informed consent, an experimenter explained what a C/VIS was to the drivers, and then administered a questionnaire that measured drivers' opinions of their driving performance and the hypothetical C/VIS. Drivers were then assigned to one truck that had either an A-C/VIS or the commercial system installed. They drove one month with the C/VIS disabled (Baseline condition), and then three months with the C/VIS enabled (Test condition). Drivers completed surveys pertaining to their driving performance and the C/VIS they were using every two weeks. Drivers were compensated $100 per week plus a $100 bonus for completing surveys and cleaning the C/VIS fender cameras.

Technicians visited the trucks on a weekly basis to perform a health check of the data acquisition systems and C/VISs. The encrypted hard drives were transported back to the research institution where they were uploaded to a secure server. A series of quality control checks were then performed on the data and the results were used to identify additional maintenance issues. Algorithms were then used to trigger potential Safety-Critical Events (SCEs). These algorithms were successfully used in previous naturalistic driving studies (Blanco et al., in press) and in general, identified events when the truck performed a hard deceleration or a swerve maneuver. Data reductionists viewed the triggered events and verified whether an event was indeed an SCE. Valid SCEs were then reduced by one reductionist that recorded the environmental conditions present, vehicle maneuvers that were performed, and whether the driver was distracted. Another reductionist recorded the drivers' eye glance locations during the 10 s prior to the SCE and 5 s

following the SCE.

An algorithm was developed and applied to identify potential lane change maneuvers. One reductionist inspected these lane change triggers and identified valid lane changes performed above 35 mph in which an adjacent vehicle was tracked by the side radar system. Eleven valid lane changes per driver, per week were sampled. The same eye glance reductionist reduced drivers' visual behavior during the 10 s prior to a lane change and 5 s following the initiation of a lane change.

Experimental Design

The data was analyzed using a 2 (C/VIS) x 4 (Month) Mixed Factors Analysis of Variance. The two levels of the C/VIS between-subjects independent variable comprised the A-C/VIS and commercially available system. The four levels of the Month within-subjects independent variable comprised Month 1, Month 2, Month 3, and Month 4 of the study.

The following dependent variables were analyzed. Participants' driving performance was assessed by analyzing their SCE rate, which has been defined as the number of SCEs encountered per 100 hours of driving (Blanco et al., 2009). Drivers' clearance to an adjacent vehicle when initiating a lane change was analyzed to assess whether the clearance changed when driving with a C/VIS (Fitch, Wierwille, Schaudt, & Hanowski, 2008). The probability that drivers' looked forward was analyzed to assess whether the C/VIS compelled drivers to look away from the road. The eye glance probability was computed by summing the number of frames a driver looked forward in a specified period of time and dividing this number by the total number of frames in this period of time (Wierwille, 1981). Drivers' forward glance probability prior to encountering an SCE was computed using the 8 seconds prior to the SCE (8 s x 10 frames/s + frame of SCE = 81 frames), while drivers forward glance probability during a lane change was computed using the interval of time spanning 8 s prior to the initiation of the lane change to 5 seconds after initiating the lane change (13 s x 10 frames/s + frame of lane change initiation = 131 frames). Finally, drivers rated how easy it was to be aware of surrounding vehicles by completing a survey every two weeks during their participation.

RESULTS

Drivers' Involvement in SCEs

A total of 5,161 hours of driving that spanned 412,417 km was recorded by the 12 participants (comprising 3.35 Terabytes of data). These drivers encountered a total of 277 SCEs. One driver did not encounter any SCEs during his first two months of participation, while another driver did not have any data in his final month because he left the study shortly after completing Month 3. The SCE rate was computed for each driver for each month that they were in the study and analyzed. Drivers' mean SCE rate was not found to differ across the months that they were in the study ($F(3, 29) = 0.02$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.58$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 29) = 0.13$, $p > 0.05$). Figure 1 shows the mean SCE rates for drivers in the A-C/VIS-equipped and commercially available C/VIS-equipped trucks for each month that they were in the study. Table 2 presents descriptive statistics

pertaining to the computed SCE rates.

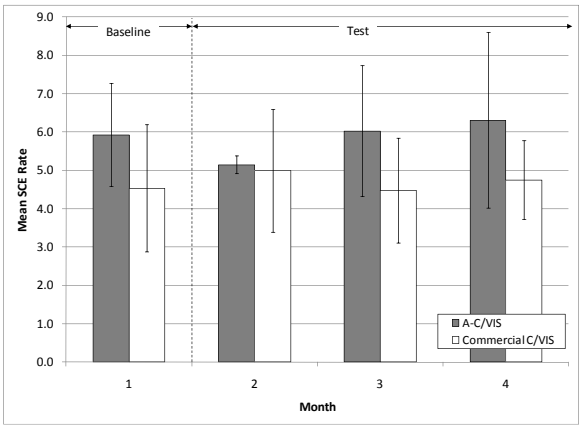


Figure 5. Drivers' mean SCE rates by month in study and type of C/VIS.

Table 2.
Drivers' Mean SCE Rates by Month in Study and Type of C/VIS

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	5.9	1.3	6	1.9	9.2
	2	5.1	0.2	6	4.4	6.2
	3	6.0	1.7	6	1.6	11.4
	4	6.3	2.3	5	0.8	13.6
Commercial C/VIS	1	4.5	1.7	6	0.0	10.7
	2	5.0	1.6	6	0.0	9.7
	3	4.5	1.4	6	0.9	8.3
	4	4.8	1.0	6	2.0	8.3

Drivers' Visual Behavior Prior to SCEs

An eye glance analysis was performed on 264 SCEs. This was because there was one SCE in which the driver did not look forward (he was stopped at an intersection) and because eye glance data was not available on 12 SCEs (e.g., drivers were wearing sunglasses during the SCE). The probability that drivers' looked forward was computed for each SCE and analyzed. Drivers' mean probability of looking forward was not found to differ across the month that they were in the study ($F(3, 27) = 0.25$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.42$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 27) = 0.49$, $p > 0.05$). Figure 2 shows the mean probability that drivers looked forward during the 8 seconds prior to an SCE across the four months of participation. Table 3 presents descriptive statistics pertaining to the computed eye glance probabilities.

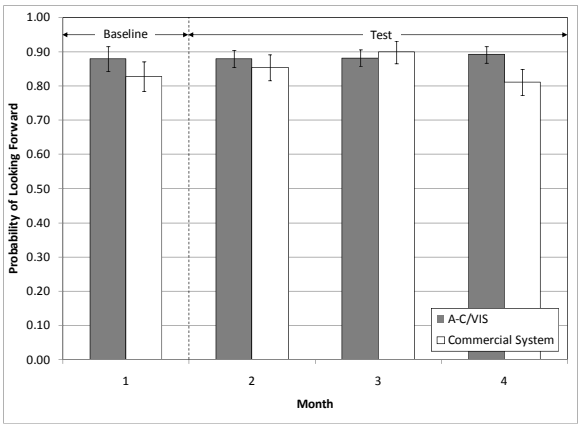


Figure 6. Mean probability that drivers looked forward in the 8 s prior to encountering an SCE by month in study

Table 3.
Mean probability that drivers looked forward in the 8 s prior to encountering an SCE by month in study

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	0.88	0.04	38	0.15	1.00
	2	0.88	0.03	32	0.38	1.00
	3	0.88	0.02	45	0.36	1.00
	4	0.89	0.02	42	0.19	1.00
Commercial C/VIS	1	0.83	0.04	27	0.10	1.00
	2	0.85	0.04	26	0.21	1.00
	3	0.90	0.03	25	0.27	1.00
	4	0.81	0.04	29	0.14	1.00

Drivers' Lane Change Performance

A total of 2,012 lane changes were sampled (528 lane changes in the Baseline condition and 1,484 lane changes in the Test condition). The truck had to be travelling above 56 km/h, and there had to be a vehicle travelling in the adjacent lane behind the truck, for a lane change to be included in this sample. The clearance between the back edge of the trailer and the front of an adjacent vehicle was analyzed. It was not found to differ across the months that drivers participated in the study ($F(3, 29) = 0.2$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.14$, $p > 0.05$), nor was a C/VIS x Month interaction found ($F(3, 29) = 1.28$, $p > 0.05$). Figure 7 shows the mean clearance for drivers of A-C/VIS-equipped and commercially available C/VIS-equipped trucks by month of participation. Table 4 presents descriptive statistics pertaining to the measured clearances.

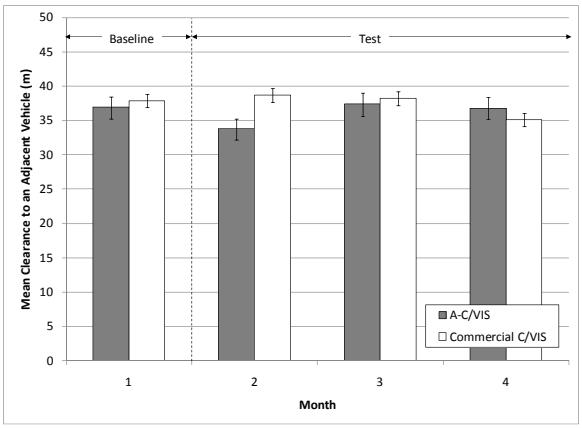


Figure 7. Drivers' mean clearance to an adjacent vehicle by C/VIS and month in study

Table 4.
Drivers' mean clearance to an adjacent vehicle by C/VIS and month in study

C/VIS	Month	Mean (m)	SEM (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 Visual Behavior during Lane Changes

An eye glance analysis was performed on 1,930 lane changes that had eye glance data available. The probability that drivers looked forward was computed for each lane change. Drivers' mean probability of looking forward was not found to differ across the months that they participated in the study ($F(3, 29) = 0.9$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 1.15$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 29) = 2.04$, $p > 0.05$). Figure 8 shows the mean probability that drivers looked forward when changing lanes by month in study. Table 5 presents descriptive statistics for these probabilities.

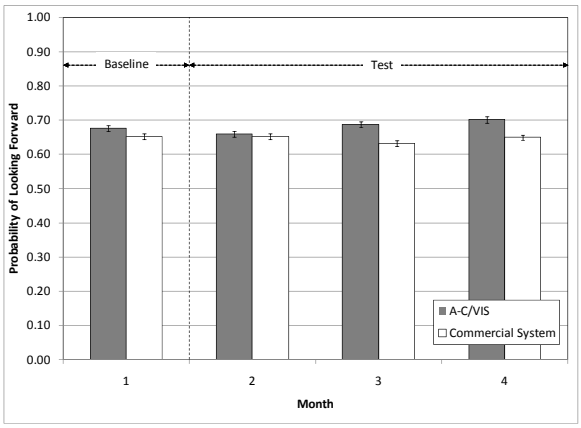


Figure 8. Mean probability that drivers looked forward when changing lanes by month in study

Table 5.
Mean probability that drivers looked forward when changing lanes by month in study

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	0.68	0.01	256	0.30	0.95
	2	0.66	0.01	252	0.35	0.95
	3	0.69	0.01	226	0.30	0.97
	4	0.70	0.01	202	0.20	0.93
Commercial C/VIS	1	0.68	0.01	256	0.30	0.95
	2	0.65	0.01	250	0.27	0.92
	3	0.63	0.01	255	0.26	0.91
	4	0.65	0.01	233	0.29	0.89

Drivers' Awareness of Surrounding Objects

Drivers rated the difficulty of being aware of objects located in the area around their truck while driving in various environmental conditions. Because drivers responded to this question twice per month, their mean rating from each month was used when performing a Friedman Two-Way ANOVA to investigate whether their opinion changed over time. Drivers of A-C/VIS equipped trucks indicated that maintaining spatial awareness at night and in inclement weather became easier when driving with a C/VIS ($\chi_F^2(3) = 8.02$, $p < 0.05$). Drivers' mean ratings are shown in Figure 9. Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found ($p > 0.05$). For drivers of trucks equipped with the commercially available C/VIS, a significant Month in Study effect was not found ($\chi_F(3)^2 = 0.23$, $p > 0.05$).

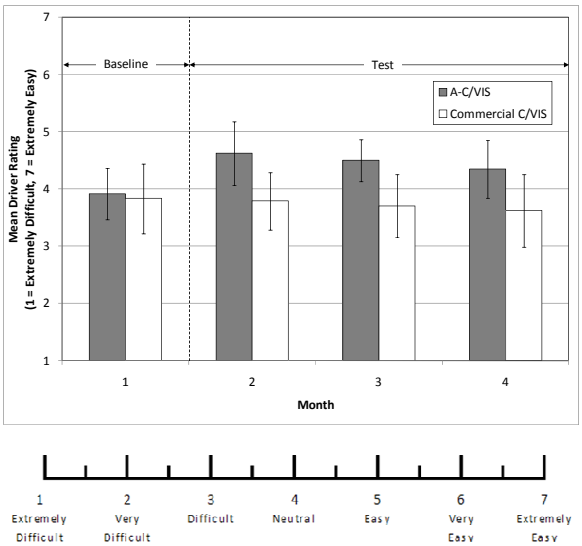


Figure 9. Drivers' mean monthly ratings in response to the question, "During the night and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck while driving?"

Drivers' Rating of Merging into Traffic

Drivers rated the difficulty of merging into traffic while driving in various environmental conditions. A Friedman Two-Way ANOVA was performed to investigate whether their opinion of this task changed over time. Drivers of A-C/VIS equipped trucks indicated that merging into traffic during the day and in inclement weather became easier when driving with a C/VIS ($\chi_F^2(3) = 8.4116$, $p < 0.05$). Their mean rating using the scale in Figure 9 was 4.0 in Month 1 (*SEM* = 0.2), 4.7 in Month 2 (*SEM* = 0.4), 4.6 in Month 3 (*SEM* = 0.4), and 4.7 in Month 4 (*SEM* = 0.3). Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found ($p > 0.05$). Drivers of trucks equipped with the commercially available C/VIS indicated that merging into traffic during clear daytime conditions became easier when driving with a C/VIS ($\chi_F(3)^2 = 9.2449$, $p < 0.05$). Their mean rating using the scale in Figure 9 was 4.4 in Month 1 (*SEM* = 0.4), 5.3 in Month 2 (*SEM* = 0.2), 5.4 in Month 3 (*SEM* = 0.2), and 5.1 in Month 4 (*SEM* = 0.7). Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found ($p > 0.05$).

Driver Ratings of C/VIS Monitors

Partway through data collection, it was determined that additional information regarding drivers' opinions on the usefulness of specific monitors was desirable. Modifications to the experimental protocol were made and were approved by the IRB. Since these modifications were approved after four drivers had completed the study, the additional questions were posed to only eight drivers. Five drop A-C/VIS equipped trucks, while three drove commercially available C/VIS-equipped trucks.

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, *SEM* = 0.18, *Min* = 4, Max = 7), while drivers of the commercially available C/VIS-equipped trucks rated the left monitor to be

"Useless" (*M* = 3.18, *SEM* = 0.42, *Min* = 1, *Max* = 5.5). However, the ratings of the commercially available C/VIS' 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, *SEM* = 0.12, *Min* = 5, *Max* = 7), while drivers of the commercially available C/VIS-equipped trucks were neutral when rating the right monitor (*M* = 4.2, *SEM* = 0.3, *Min* = 1, *Max* = 6). Again, the ratings of the commercially available 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* = 5.8, *SEM* = 0.1, *Min* = 4, *Max* = 7).

The eight drivers were also 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 four drivers. The three drivers of the commercially available C/VIS-equipped trucks ranked the right monitor as more useful than the left monitor.

DISCUSSION

This study evaluated whether providing CMV drivers with enhanced visual information improves their spatial awareness and leads to an improvement in driving performance. It was found that when driving with a C/VIS: 1) drivers' involvement in safety-critical events did not change, 2) the clearance to an adjacent vehicle when changing lanes did not change, and 3) the likelihood that drivers looked forward did not change. Although a reduction in safety-critical events was not observed when driving with a C/VIS, drivers indicated that the C/VISs helped them see other vehicles around their tractor-trailer and made it easier to merge into traffic. These ratings indicate that C/VISs can help drivers with the driving task, which may lead to an improvement in safety when deployed on a larger scale. It should be noted that a limitation of the study is that 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' involvement in SCEs may have differed had they operated their tractor-trailers in rush-hour traffic when traffic density is higher.

A concern with introducing any visual display inside a vehicle is that it may be a source of visual distraction. An important finding from this study is that drivers were not less likely to look at the forward roadway when driving with a C/VIS. This finding suggests that the C/VIS display did not compel drivers to look away from the road. The interested reader is referred to Fitch et al. (in press) for an in-depth analysis of drivers' visual behavior.

Previous research that evaluated driver performance with a C/VIS prototype on a closed-course test track found that drivers cut in closer to an adjacent vehicle when changing lanes with a camera view obtained from a wide-angle rear-lookdown camera mounted on the rear of the tractor-trailer (Fitch et al., 2008). There was therefore a concern that drivers in the TFD would exhibit similar behavior. However, drivers' mean clearance to an adjacent vehicle was not found to vary when changing lanes with either the A-C/VIS or commercially available C/VIS. This suggests that the CMV drivers recognize the importance of keeping a safe clearance to an adjacent vehicle when executing lane changes on a public road. This finding also demonstrates

the importance of field testing driver assistance systems in real-world driving conditions where driver performance is affected by the environmental constraints.

Drivers using the advanced C/VIS rated its features highly and ranked the rear-view camera more than the left or right fender cameras. This was likely because the rear camera provides a bird's-eye-view of the area behind the trailer as well as the adjacent lanes. Drivers can use this vantage point to perceive whether the back edge of the trailer overlaps a vehicle travelling in the adjacent lane. During the day, drivers are known to use the shadow cast by the trailer to assess the clearance to adjacent vehicles, but must perform a relative-judgment task using less distinctive roadway and trailer cues when changing lanes at night. For this reason, there is merit in adopting this advanced feature when implementing a C/VIS in a commercial trucking operation.

CONCLUSION

OEMs and tier-1 suppliers have developed multiple methods to implement C/VISs. The A-CVIS is an innovative approach to C/VISs that assists drivers in overcoming blind spots. This paper presents a real-world evaluation of both commercially available, and advanced, C/VISs. Overall, although a reduction in safety-critical events was not observed, this study shows that providing CMV drivers with enhanced visual information does improve their situational awareness and simplifies the execution of lane change maneuvers. It is possible that the simplification of these tasks could lead to a safety benefit in situations where the driving task demands are great.

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