ENHANCED CAMERA/VIDEO IMAGING SYSTEMS (E-C/VISs) FOR HEAVY VEHICLES

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ABSTRACT

Lane change and merge maneuvers represent approximately 20% of heavy truck crashes, resulting in loss of life and property damage. Tests were performed to determine the feasibility of developing an Enhanced Camera/Video Imaging System (E-C/VIS) to provide heavy-vehicle drivers with better awareness of their vehicle's position in relation to other vehicles on the roadway (situation awareness). It is well known that large blind spots currently exist in these areas. A previous phase of this program measured the field of view requirements for heavy trucks, resulting in an improved understanding of mirror performance and recommendations for the design of a camera based indirect viewing system. With indirect viewing requirements understood, the goal of the present research was to extend the operating envelope of a conventional video implementation of the requirements to nighttime and inclement weather conditions. A three-channel system was envisioned in which there would be a camera at each front fender of the tractor looking backward along the sides of the heavy vehicle. The third channel would be aimed rearward from the back of the trailer. Once developed, the three-channel system was tested in static and dynamic driving environments and it was found to work well in the nighttime and inclement weather environments, including various street lighting conditions.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) funded an earlier research project at Virginia Tech Transportation Institute (VTTI) involving the use of Camera/Video Imaging Systems (C/VISs) in heavy vehicles (earlier portion, Contract DTNH22-00-C-07007, Task Order 18, Track 2; later portion, Contract DTNH22-05-D-01019, Task Order 6, Track 2). This project was completed in June 2007 with both a supporting research document and a final specifications document submitted to NHTSA at that time [1, 2]. This project had the objective of devising, developing, and testing these systems so that recommendations could be made and specifications written. Both surrogates (which take the place of existing side mirrors) and enhancements (which provide augmented views not ordinarily available to the driver) were studied. Tests were limited to conventional video systems with cameras at appropriate locations on the exterior of the vehicle and with monitors in the cab at locations that were selected on the basis of human factors considerations and preliminary testing. Sixteen different video system concepts were studied both conceptually and experimentally. The concepts were then revised or discontinued, based on the results. A final set of 11 concepts was recommended, and specifications were written accordingly (note that several of the concepts were composed of pairs; that is, driver and passenger-side versions).

As the original work drew to a close, VTTI was awarded a contract addition (Contract DTNH22-05-D-01019, Task Order 6, Track 4). Its purpose was to extend the work of the original contract into less favorable environmental conditions, namely nighttime and inclement weather. This contract also introduced the concept of situation awareness to the sides and rear of the heavy vehicle. In other words, it was more specific in that a three-camera system was to be further developed: one camera on each side of the heavy vehicle and one at the rear.

The system was envisioned as an enhancement; that is, the side mirrors would remain on the vehicle even though the video system was to be added. Under such circumstances, malfunction of any of the three video chains would still allow the heavy vehicle to be driven in a conventional manner. It was also considered important to investigate enhancing the camera imagery with infrared illumination-sensitive cameras, visible and/or infra-red (IR) illuminators along the sides of the trailer, edge detection and image enhancement using machine vision techniques, adaptive video filtering, and the human factors design of viewing surfaces inside the tractor.

The intended purpose of the work was to reduce or eliminate blind spots and other uncertainties that might occur along the sides and to the rear of the heavy

vehicle. The objective in so doing was that the driver of the heavy vehicle would be better informed regarding the environment around the sides and rear of the heavy vehicle; that is, he or she would have better situation awareness. This was to be accomplished under the widest possible environmental envelope, while also considering costs. Clearly, costly technologies would not be appropriate because of the highly competitive nature of commercial motor carrier operations. Consequently, VTTI developed a system using "best available technologies" with consideration given to total cost of implementation of a final system for use in a heavy vehicle.

There were two phases to this current project. Phase 1 consisted of laboratory testing of “best available technologies” and development and human factors stationary testing of the passenger side E-C/VIS. Phase 2 consisted of an object detection and identification static experiment as well as human factors dynamic testing on the Virginia Smart Road. The purpose of this paper is to discuss the dynamic testing on the Smart Road used in Phase 2, and results obtained.

METHOD

Participants

Tests were run with CDL drivers, for two reasons: first, these individuals were typical of the ones who would eventually determine whether or not the system would be helpful and acceptable, and second, because these individuals were qualified to drive the equipped heavy vehicle. Drivers were recruited from a volunteer database. Recruiting was carried out without regard to gender, but drivers had to have at least two years of full time experience as a heavy vehicle driver. As it turned out, eight males agreed to participate and were found to be qualified.

Equipment & Materials

The heavy vehicle used for this project was a 1994 Peterbilt model 379 tractor with 53 ft trailer. The Virginia Tech motor pool had available a 2007 Chevrolet Malibu, olive green in color. This vehicle was used as a confederate vehicle. This color was believed to represent an "average" in that it was neither very light nor very dark. The vehicle was also midsized, that is, average size for an automobile. The E-C/VIS instrumented on the Peterbilt consisted of a three camera system. Preliminary outdoor testing in Phase 1 demonstrated that a Toshiba IK-64DNA camera had the capability of operating effectively both in daylight and at night. It was also sensitive to both visual and near IR illumination. This camera provided color capability for daytime use and black and white (B/W) capability for nighttime use. For use at night, a filter inside the camera was removed using an internal electromechanical device. The switching of this filter was automatic and simultaneous for all three cameras after certain ambient threshold conditions were met. Two cameras were placed on the front fenders of the Peterbilt (one camera on each fender), and one camera was also placed at the top rear of the trailer. The rear facing camera was placed at the top center rear of the trailer and had a camera horizontal field of view of 102 degrees. 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. The fender-mounted cameras had a horizontal field of view of 45 degrees. The inside edge of view in the image included the side of the tractor trailer. A diagram showing the coverage of the three cameras is shown in Figure 1.

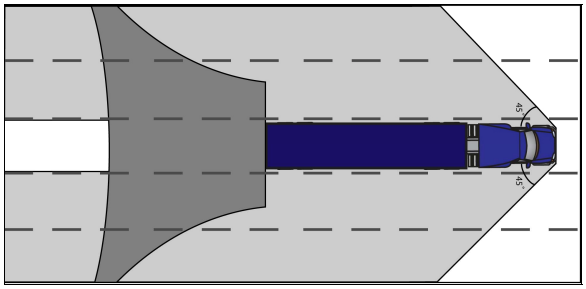

Figure 1. Coverage of the three cameras in the final design.

Three flat-panel monitors were used inside the cab. It was intended that all monitors be Size 2 (as defined in the previous research). These monitors produced an image that was 9.6 cm (3.78 in) high by 12.9 cm (5.08 in) wide, with a corresponding diagonal dimension of 16.1 cm (6.33 in). Tests demonstrated that the computer-processed image used in this research produced unacceptable delays if the processed computer image was re-converted to NTSC (National Television System Committee) format. Consequently, it became necessary to use a different monitor which would accept a signal in vector graphics array (VGA) format, making re-conversion unnecessary. This monitor had an image surface that was 10.2 cm (4.02 in) high by 13.4 cm (5.28 in) wide, with a corresponding diagonal dimension of 16.6 cm (6.54 in). The image produced was therefore very nearly the same size as the Size 2 monitor image. Two monitors, each corresponding to each fender-

mounted camera, were positioned near the lower end of both the driver side A-pillar (A) and passenger side A-pillar (B) (see Figure 2). One monitor was positioned at the top center of the windshield corresponding to the rear facing camera (C). All monitors were aimed toward the drivers' point of view and the image on each monitor was a mirror image; that is, it was horizontally reversed left to right .

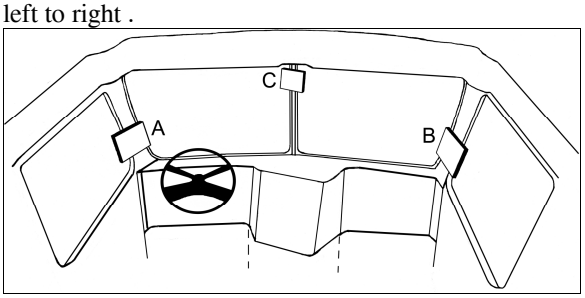

Figure 2. Monitor positions inside the cab.

Narrowband near IR sources of illumination were added to the heavy vehicle. Eight units were installed on the tractor-trailer combination. One unit was installed at the lower rear portion of each tractor front fender, two units were installed along each side of the trailer, and one unit was installed on each rear corner of the trailer. The IR illumination units were 140 LED units. An example of a mounted unit is shown in Figure 3. The units were located and aimed as shown in Figure 4.

Figure 3. Typical IR LED illuminator mounted under the side of the trailer.

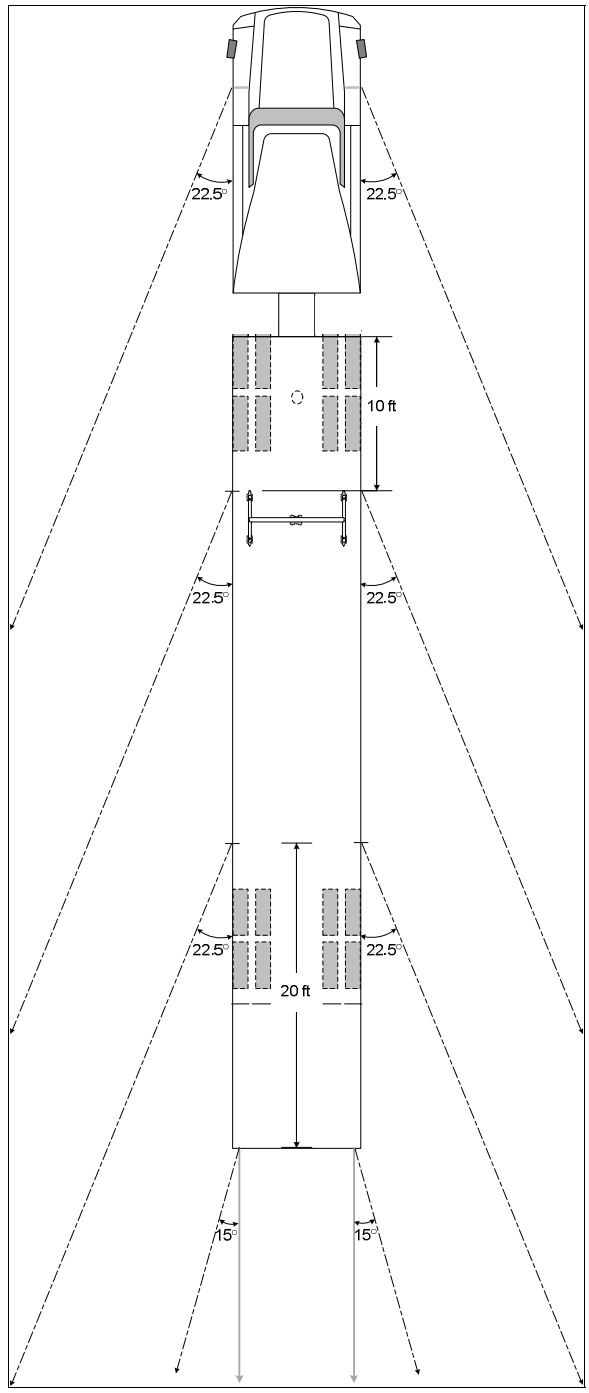

Figure 4. Mounting and centerline aim of the narrowband near IR LED illuminators.

Image processing was also implemented in the design. The fundamental idea was to take advantage of any changes in contrast in the raw video image and to use these changes for "outlining", the hypothesis being that driver pattern recognition would be capable of

identifying objects more easily if they contained outlines. The outlined processed video would then be superimposed over the original image, such that the original video would be seen with the outlines over the image. The amount of processing could be adjusted by a weighting scheme, which was specified at a given level (for the tests) by consensus of the developers.

An additional element of the processing was the concept of suppressing headlight bloom to the extent possible. Headlight bloom had been shown in both the indoor tests and in the preliminary outdoor tests to represent a problem; problem being more difficulty in viewing objects on the displays. However, in spite of being a problem, the camera handled headlight bloom well and did not produce either vertical or horizontal streaks caused by bleed-through. The large white blooms, which were more-or-less elliptical, consumed a substantial portion of the vehicle image, but they were contained and did not streak. The combined image tended to suppress the white blooms somewhat because the processed image showed all but the edges of the bloom image as dark grey. A thin white perimeter line remained so that the driver could still identify the bloom and not mistake it for part of the vehicle.

Image processing, after it was fully developed, seemed to work well. It was included in all formal outdoor static tests. For daytime conditions, it used white outlines to show changes in contrast in the image. White outlines were, of course, also used for the B/W nighttime image.

In terms of hardware and software required, the image was first converted from NTSC (analog video) to digital form using a frame grabber. Thereafter, a custom program developed by VTTI personnel performed the processing operations, which involved use of Sobel filtering, additional processing as needed, and thresholding. The program was developed to run on a laptop computer, but could be easily converted to a dedicated processor. Once the processed image became available, it was superimposed over the unprocessed image in accordance with a specific weighting that had been selected experimentally. The composite image was then converted to VGA format and sent to the monitor. The use of this format was required in order to meet acceptable delay criteria. The final program using the VGA output displayed on the screen was capable of delays not exceeding 85 ms, which was considered fully acceptable. Figure 5 shows a video still-shot of a processed image. Daytime images placed white outlines around objects in color video.

Figure 5. Typical processed nighttime video image.

A Driver Vehicle Interface (DVI) was developed for processing and display control (see Figure 6). This interface was mounted at the wing panel.

Figure 6. Driver Vehicle Interface (DVI) for the E-C/VIS.

Data gathering instrumentation for the Smart Road testing was handled totally separately from the E-C/VIS instrumentation. Four cameras were added to the tractor-trailer. Two of these were used to determine the driver's eye glance position, and two were used to evaluate the clearance and overlap positions. The four camera outputs were recorded digitally as a quad-split image. This image contained a time stamp and an audio track with two microphones as inputs. The experimenter had one microphone attached near his position and the driver (subject) had a similar microphone mounted to the header. The microphones were aimed to pick up the voices of both the experimenter and the driver for recording on the audio track.

Eye glance position was determined by the use of two

small cameras, one just above each A-pillar monitor. Lenses were selected so that the two images of the driver's head were approximately the same size even though the distances from camera to driver differed for each A-pillar. Recorded video allowed for distinguishing between driver glances at the side mirrors and A-pillar monitors. This was considered an important distinction and was the reason for using two cameras; that is, one on each side. Each camera included its own IR illumination, which of course could not be seen by the driver. This illumination was necessary because of the need to record video at night.

The experimenter sat behind the driver, but in a centered position. The experimenter could look over the driver's right shoulder. The experimenter could also view a separate data gathering monitor on which the quad-split image was shown. (This ensured that the image was being recorded correctly.) The monitor was placed in front of the experimenter in a position that was unobservable by the driver. On the other hand, the experimenter could see all three E-C/VIS images directly to ensure that all elements of the E-C/VIS were operating properly.

Procedure

Testing was limited to nighttime conditions. The reason for this was that the daytime conditions were believed to have been studied sufficiently to demonstrate feasibility for such conditions. Both the stationary outdoor tests and the previous work with the original C/VIS project suggested that there would not be a problem with the E-C/VIS operating in daylight conditions. In addition, resources could then be placed where additional experimental results were needed.

The Virginia Smart Road (a 2.2 mile in each direction closed-course test track facility) was considered to be an ideal test bed for the testing because it provided a controlled environment in which the effects of rain and highway lighting could be studied under dynamic (that is, moving vehicle) conditions. For comparison purposes, it was considered important to test not only with rain, but also without rain; that is, under clear conditions. Roadway lighting was also considered to be important because it was a different condition from any that had been studied previously. In addition, it was considered likely that the luminaires might cause reduction in image quality for the side cameras, once the vehicle had passed them. The main problem was believed to be the fact that the luminaires might appear in the field of view of the side cameras and, therefore, might cause glare problems. This situation, as indicated, had not been studied previously in any of the indoor or outdoor tests. Figure 7 shows an example of nighttime testing in rain with roadway lighting.

Figure7. The tractor-trailer and confederate vehicle emerging from the artificial rain portion of the Smart Road with street lights on.

Also, to get an idea of how much improvement (if any) might be expected with the Enhanced C/VIS, it was considered necessary to test with the system operating and with the system not operating; that is, Baseline. Without the Baseline system (Enhanced C/VIS not operating) it would be difficult to determine the degree of improvement (if any) that the Enhanced C/VIS would provide.

The highway task performed by drivers was called the Clearance/Overlap task. Drivers first determined whether a confederate automobile alongside was clear of the rear of the trailer (or the tractor in the case of bobtailing). Immediately thereafter, drivers provided an estimate in feet of the amount of clearance or overlap (Figure 8). During this test, the confederate automobile approached in either the right or left adjacent lane. It then moved into a position in which there was some specified amount of lateral overlap with the trailer (no clearance) or some lateral clearance with the trailer (clearance). The driver was queried regarding clearance. Video captured the correctness of the driver's responses as well as the actual distances for comparisons. As described earlier, the equivalent of two merge/re-merge cameras were used to determine actual clearance or overlap and actual longitudinal distance of clearance or overlap. These values were used as ground truth values, as previously described. Optical measurement techniques were employed using standard, stationary video recordings (taken earlier) with the trailer and the

confederate vehicle at measured longitudinal distance differences. Prior to beginning driving, the driver was instructed to adjust the seat and mirrors to a comfortable level. The driver was told to perform the instructed tasks just as they would occur in a real world driving situation.

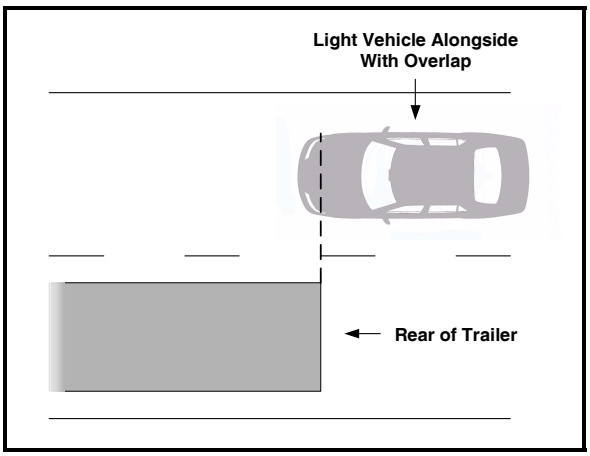

Figure 8. Diagram showing overlap in the Clearance/ Overlap task.

Independent Variables- The experiment had three main independent variables, as follows:

- Weather: rain or clear
- Lighting: presence or absence of street lighting
- Enhanced C/VIS: system operating or not operating (Baseline).

There were, as previously mentioned, three independent variables with two levels each, resulting in a total of eight factorial combinations of conditions. Tests were planned so that all eight conditions (not counting practice) could be examined in eight loops of the Smart Road for each driver. In four of the eight loops (for each driver), the rain towers were activated, producing the rain conditions, whereas in the remaining four loops the rain towers were deactivated (or not activated). Similarly, in four of the eight runs, the roadway lighting was activated and in the other four the roadway lighting was deactivated. Finally, on four loops, the Enhanced C/VIS was activated and on the other four it was deactivated; that is, Baseline.

Rain simulation had certain constraints. The most important for the current research was the time required to initiate steady-state rain, and the time to "clear" the rain once it was turned off. Activation required close to 30 minutes, while clearing required about 15 minutes. Because of these lags, runs were planned so that turning on or off was performed only once for a given subject. This meant that once rain was activated, it was not turned off until all rain-related runs were completed. Similarly, once the sequence of clear runs was started, the clear runs were all completed.

In terms of Smart Road overhead lighting, that lighting could be turned on or off in a relatively short time. However, some of the lighting had a warm-up period estimated to be not more than 3 minutes. Consequently, switching to lighting from no lighting entailed a short delay. On the other hand, turning the Enhanced C/VIS system on and off was relatively easy, in that it was possible to simply blank or un-blank the monitors, leaving the video and all processing running. This had the effect of turning off the displays so that the driver was forced to use the standard side mirrors (only) for determining the situation around the heavy vehicle. As previously indicated, the plan called for the use of eight subjects (drivers) in the experiment, with each subject experiencing all eight factorial conditions appropriately counterbalanced. With this design, data gathered for each dependent variable could be analyzed statistically with an ANOVA using a within-subject model, as follows: 2 (Weather: Rain versus Clear) by 2 (Lighting: Street Lighting On versus Dark) by 2 (E-C/VIS: system operating or Baseline).

Practice was considered necessary to increase familiarity with the heavy-vehicle baseline operating condition as well as the E-C/VIS operating condition. Consequently, each driver performed the first two runs in his or her sequence twice: the first time for practice and the second time for data gathering. This plan assured equal practice across the eight conditions and eight drivers while at the same time allowing each driver to obtain exposure under dynamic conditions to an E-C/VIS condition and a corresponding baseline condition, prior to data gathering. Thus, each driver actually performed ten loops of the Smart Road, but only the last eight were data gathering runs.

Dependent Variables - Both performance and opinion data were gathered in the Smart Road tests. The main aspect of the performance testing was determining how well subjects could ascertain the position of an object vehicle at night under various conditions. This test was used previously for daytime runs in the original C/VIS project [1]. It was found to be an effective indicator of how well subjects could locate the position of the object vehicle when it was located in an adjacent lane near the rear end of the trailer. This indicator is believed to be valuable in assessing the potential for reduction in sideswipe crashes. Two measures were previously used:

whether there was longitudinal clearance or longitudinal overlap, and how much there was in terms of distance. Clearance/overlap was scored as correct or incorrect. How much clearance or overlap in feet was scored in terms of the amount of error. If the clearance/overlap decision was correct, then the estimated distance was subtracted from the actual distance to get the error. If the clearance/overlap decision was incorrect, the estimated distance was added to the actual distance. Thereafter, the absolute value was used as the measure of accuracy in estimation. Consequently, in the current experiment, the plan was to use two dependent measures, as follows:

- Number of correct responses (or percent correct) in the clearance/overlap determination, and
- Absolute error in the clearance/overlap estimate.

A measure not previously used was the total response time. It could be hypothesized that response time might be faster, the same, or slower with the Enhanced C/VIS, because of the greater, but more precise, information it provides. In any case, the idea of using this measure seemed reasonable in that it might shed light on how the subject used the Enhanced C/VIS and whether or not it compromised response time. Therefore, the following measure was determined:

- The amount of time required to determine clearance/overlap added to the amount of time required to estimate distance.

A final measure, taken for exploratory purposes, was glance position as a function of time. The directions of glances used were: forward, E-CVIS (right/left/center), mirrors (left/right), and dash/IP (instrument panel). Occasionally the driver would glance elsewhere, which was counted as a valid sample in calculating the glance probability. However, there were so few of these that they were not included in any of the graphs. The interval over which data were gathered was specified to be from the beginning of the instruction to determine clearance/overlap to the end of the driver's response regarding how much clearance or overlap there was in feet. The measure associated with this analysis was:

- Eye glance probability to specific locations.

This measure was calculated by pooling data across the eight subjects for the given condition, thereby allowing eye glance differences to be presented as a function of the condition under test.

For each loop of the rain generating and lighted area of the Smart Road, two replications could be accomplished during the outbound leg and two more replications could be accomplished during the inbound leg at an instructed speed of 25 mph (40.2 km/h). By performing one clearance/overlap determination and one corresponding longitudinal distance determination *on each side* of the heavy vehicle *in each direction*, there were a total of four replications per driver and condition. Note that Side could be treated as an additional independent variable in these tests. All conditions were tested using the same stretch of the Smart Road; that is, the stretch which had both rain and lighting capability. Of course, for some of the runs, these capabilities were deactivated.

During these tests an automobile driven by a confederate experimenter approached rapidly from the rear and then matched speed at a specified position relative to the rear of the trailer. The position was selected differently for each driver and each replication, but all values fell within 16 ft (4.88 m) of overlap and 23 ft (7.01 m) of clearance using the longitudinal distance between the rear of the trailer and the front of the automobile. Once the automobile reached position, the subject performed the estimation task (clearance/overlap and longitudinal distance estimation). The automobile then dropped back and approached again on the opposite side for the second replication of the task. Note that since the Smart Road has two lanes in the rain-producing area, it was necessary for the *subject* in the heavy vehicle to change lanes while the automobile was dropping back. The automobile then once again accelerated, approached, and positioned itself at a new specified distance for the second estimation task. This test did not require the automobile to be in exactly the specified position at the time of the estimation (as long as speed was matched) because the actual distance was measured by video using cameras located at the rear of the trailer (but not seen by the driver). These cameras were identical to the merge/re-merge cameras described in the original C/VIS project. These cameras were calibrated so that distance could be determined to the nearest 6 in (15.2 cm). Thus, the "ground truth" value was used in calculating correctness of the decisions by the subject and amount of error in the estimates, not the confederate vehicle driver's ability to get to and maintain the correct position.

To summarize, each subject (heavy-vehicle driver) experienced all factorial combinations of Weather, Lighting, and Enhanced C/VIS, as specified. The subject provided four decisions regarding clearance/overlap and

four estimates of distance of clearance or overlap for each of the eight different factorial combinations. In addition, the total time to perform these tasks was measured, as were the eye glance patterns. The data provided objective evidence of the degree of the relative performance of the E-C/VIS as compared with Baseline for a variety of nighttime conditions.

Driver opinion is important because it is likely to be one of the major factors that trucking companies might use to decide whether or not they should equip their fleets with Enhanced C/VISs. Clearly, if drivers do not accept these systems as useful, the systems are not likely to be implemented.

Drivers performed tests in pairs in which one condition was Baseline and the other condition was the Enhanced C/VIS condition. This suggested that after every two loops of the Smart Road, the driver should be queried in comparing the two previously experienced conditions. Obtaining this opinion data at four different, two-loop intervals allowed comparison of the Enhanced C/VIS to Baseline for all four factorial combinations of Weather and Lighting. A final set of rating scales was also provided, following all runs on the Smart Road. These scales were intended to determine whether or not subjects were receptive to the Enhanced C/VIS, as determined by responses on several. After rating scale data were gathered, ratings were converted to numerical values and were then analyzed.

A final question solicited any additional information the subject wanted the investigators to have, using a simple ruled space for the subject to reply. This gave the subject a chance to provide any additional opinion regarding the Enhanced C/VIS and its comparison with Baseline.

RESULTS

The Smart Road Tests had the objective of serving as a means of determining operational qualities of the E-C/VIS when compared to Baseline. The tests were intended to examine the most critical aspect of situation awareness, namely, the amount of clearance or overlap when another vehicle is alongside but near the back of the trailer. This situation is critical to lane changing or merging while avoiding a sideswipe crash. There are other aspects of general situation awareness, but they are not as important as assessing clearance or overlap and their approximate magnitude.

Clearance/Overlap

Data for the clearance overlap tests were first examined using a within-subject 2 by 2 by 2 model for the ANOVA. Because of the small number of trials, Side was not examined as an independent variable. A given subject then would have four possibilities for each set of independent variables. He or she could be correct on 0, 25, 50, 75, or 100 percent of responses because there were four trials per factorial combination of Baseline versus E-C/VIS, Street Lighting versus Dark, and Rain versus Clear. Results indicated that only the main effect of Baseline versus. E-C/VIS was significant: $F(1,7) = 11.67$, $p = 0.0112$. None of the other main effects or interactions was significant. Figure 9 shows the significant main effect of Baseline versus E-C/VIS. Clearly, the E-C/VIS condition provided superior results in regard to clearance/overlap correctness, with almost all responses correct (126 of 128 responses correct).

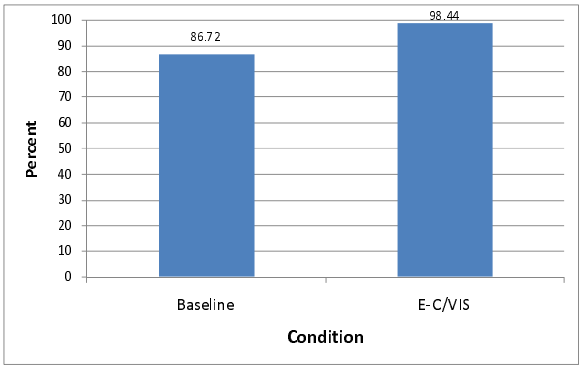

Figure 9. Clearance/Overlap correctness as a function of condition.

Subjects also provided an estimate of the amount of clearance or overlap in feet. If a given subject provided the correct answer in terms of clearance or overlap, then the subject's distance estimate was subtracted from the actual amount of clearance or overlap. Thereafter, the absolute value was obtained and was considered to be the error in feet. On the other hand, if the subject answered incorrectly on the query regarding clearance or overlap, the subject's distance estimate was added (algebraically) to the actual distance. Thereafter, the absolute value was obtained and was likewise considered to be the error in feet.

Absolute error values were analyzed by a four-way within-subject ANOVA. The independent variables were Condition (Baseline versus C-VIS), Side (Driver or Passenger), Lighting (Street Lighting versus Dark), and Weather (Rain versus Clear). Results of the analysis demonstrated significant main effects of Condition with $F(1,7) = 32.03$, $p = 0.0008$; and Side with $F(1,7) = 32.04$, $p = 0.0008$. There were two significant two-way

interactions: Condition by Side with F(1,7) = 11.29, p = 0.0121 and Lighting by Side with F(1,7) = 5.41, p = 0.0529 (this latter condition was treated as significant). For completeness, two additional non-significant interactions are noted: Lighting by Condition with F(1,7) = 3.77, p = 0.0934; and Lighting by Condition by Side with F(1,7) = 3.75, p = 0.0938.

Figure 10 shows the Condition main effect. Clearly, the size of the error in estimates is cut drastically using the E-C/VIS. This is an important finding and was also noted in the C/VIS daytime tests performed in the previous project. Figure 11 shows the Side main effect. Here the absolute error was found to be much larger on the passenger side than on the driver side. The reason for this is believed to be that the mirrors on the passenger side are much farther away from the driver and therefore have a smaller field of view, particularly the west coast mirror. This narrow view is potentially responsible for making distance estimation substantially more inaccurate. In Figure 12, the interaction of Condition and Side shows very clearly that large errors occur on the passenger side when the E-C/VIS is not used.

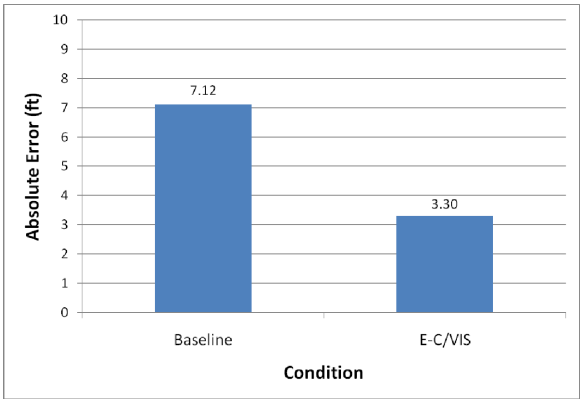

Figure 10. Effect of Baseline versus E-C/VIS on distance estimation errors.

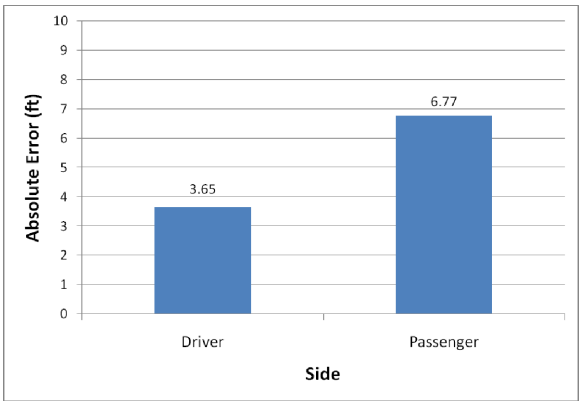

Figure 11. Effect of Side on distance estimation errors.

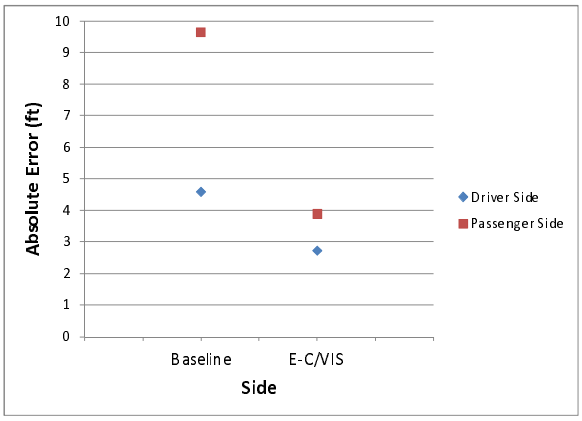

Figure 12. Interaction of Condition and Side on distance estimation errors.

An examination of the direction of error was performed regarding driver distance estimations during the clearance/overlap tasks. The purpose of this examination was to investigate whether drivers were overestimating or underestimating distance when using the E-C/VIS in comparison with the baseline. Overestimation during a clearance task is an event when the actual clearance distance of the light vehicle is less than the clearance distance estimated by the driver. Underestimation during a clearance task is when the actual clearance distance is more than the distance estimated by the driver. Overestimation during an overlap task is an event when the actual overlapping distance of a light vehicle is less than the overlapping distance estimated by the driver. Underestimation during an overlap task is when the actual overlapping distance is greater than the distance estimated by the driver. These driving tasks were not initially designed to investigate direction of error, therefore only the frequency of these events in which overestimation and underestimation occurred were examined for each condition.

Results indicated that when drivers used the E-C/VIS, there was a higher frequency of events in which drivers overestimated the amount of clearance (40 events) as compared to the events in which drivers made underestimations (16 events). Results also indicated that when drivers used the E-C/VIS, there was a higher frequency of events in which the drivers underestimated the amount of overlap (43) as compared to the events in which drivers made overestimations (13). A chi-squared test for independence was performed to examine the relation between the treatment and the clearance/overlap estimates. The relation was found to be significant, X^2 (3, N=236) = 56.68, p<0.0001. An examination of

the contribution each cell made to the chi-squared statistic indicated that the clearance tasks made the largest contribution, particularly when the driver overestimated the distance.

Figure 13 shows non-significant interactive effect of lighting on Condition (Baseline versus E-C/VIS). This interaction was not significant ($p = 0.0934$), but there is a reversal that takes place when lighting is used. Note specifically the reduction in absolute error when the E-C/VIS is in use. Figure 14 also shows a non-significant street lighting effect, but this effect is very close to significance ($p = 0.0529$). In this case, errors are seen to increase in the dark condition on the passenger side, probably because of large errors when the E-C/VIS was not in use. This latter effect is more easily seen in the triple interaction shown in Figure 15. This interaction is also not significant ($p = 0.0938$).

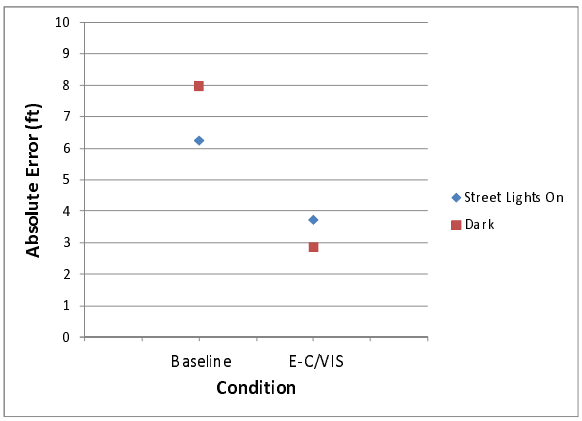

Figure 13. Interaction of Lighting with Condition (Baseline versus E-C/VIS); (note that $p = 0.0934$).

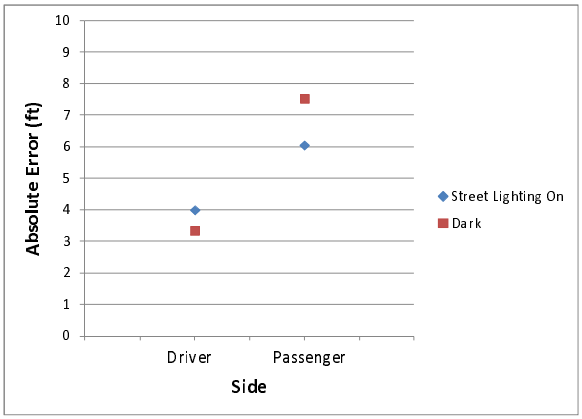

Figure 14. Interaction of Lighting with Side (driver versus passenger); (note that $p = 0.0529$).

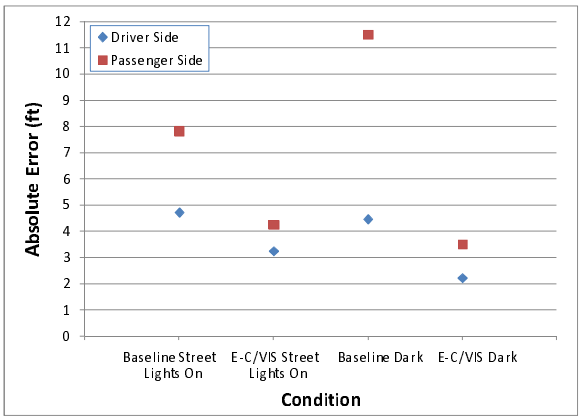

Figure 15. Three-way Interaction of Lighting, Condition (Baseline versus E-C/VIS), and Side (driver versus passenger); (note that $p = 0.0938$).

Eye Glance Analysis

While performance results show substantial improvement for the E-C/VIS condition, there is a question regarding the degree to which drivers (subjects) are using these added displays. Therefore, eye glance analyses were carried out for the Smart Road tests. These tests provide an indication of sources from which subjects gathered their information during decision making. Data were gathered and analyzed from the time that the experimenter completed the query regarding clearance or overlap, and ended when the subject provided an estimate of distance of clearance or overlap. Thus, the interval during which data were gathered was that associated with the two queries: clearance or overlap, and how much clearance or overlap in feet. There was no break (in the data gathering interval) during the experimenter's query regarding amount of clearance or overlap in feet.

The Smart Road tests were limited to passing/merging conditions; namely, determination of clearance or overlap, and corresponding amount of clearance or overlap in terms of distance. These conditions were chosen because they reflected realistic situations in which sideswipe accidents might occur. It would be expected that eye glance behavior would be strongly influenced by the conditions selected, but these conditions were believed to be the most critical and were therefore used for testing.

Probabilities were calculated by careful examination and reduction of video files associated with the two face cameras mounted just above the two E-C/VIS side

monitors. The probability of looking at a given object or area was defined as the number of video frame samples to that object or area divided by the total number of readable video frame samples in the measurement interval.

Figure 16 shows the overall eye glance behavior for the Smart Road experiments. This figure is quite revealing. It shows that during Baseline runs (that is, runs without the E-C/VIS operating) drivers relied heavily on their side mirrors with glances to the forward view. There is also an occasional short glance to the instrument panel (believed to be primarily the speedometer). On the other hand, when the E-C/VIS was operating, drivers relied heavily on the rear wide-angle look-down monitor (center E-C/VIS) with glances to the forward view. In this condition, they also looked occasionally at the mirrors, the two side monitors, and the instrument panel. Driver information gathering was very different when the E-C/VIS was operating. Specifically, drivers relied very heavily on the rear wide-angle look-down monitor when it was available. The reason appears to be that this monitor contained precise information regarding the longitudinal clearance or overlap between the rear of the trailer and the light vehicle in the adjacent lane.

Also worth mentioning in Figure 16 is the fact that the drivers had slightly higher probabilities of looking at the forward view when the E-C/VIS was operating. This occurred even though there were more sources for the drivers to view and also drivers had less experience with the E-C/VIS. Glance probability to the forward view represents a safety factor, in that a given driver can maintain better control of his/her heavy vehicle while assessing the location of the vehicle alongside.

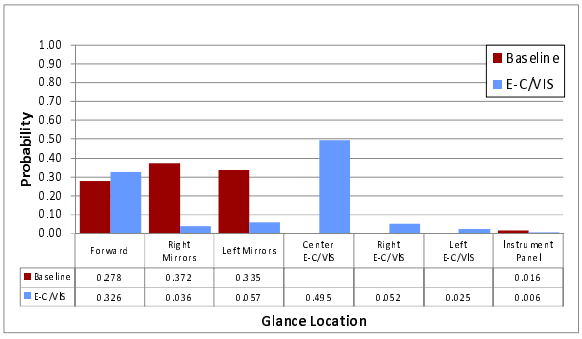

Figure 16. Glance probabilities (as a function of Baseline versus E-C/VIS) for all conditions tested in the Smart Road experiments

Subjective Ratings

Subjects performed two types of ratings: those comparing the Baseline to E-C/VIS conditions for all combinations of Weather (Rain versus Clear) and Street Lighting: (Street Lighting versus Dark). Thus, each subject provided four ratings of these combinations using 9-point rating scales. In addition, on completion of all testing, subjects were asked to provide overall ratings associated with their experience using the E-C/VIS in the various experiments.

A center rating was provided a grading of 5 and was associated with the word "moderate". Thus, a response of 5 would suggest moderate acceptance. Any value between 5 and 9 (the uppermost rating) was considered to be favorable, whereas scores below 5, and down to the lowermost score of 1, were considered to somewhat unfavorable or more so. The ends of the scale represented extreme positions, with 9 being extremely favorable and 1 being extremely unfavorable. All analyses were performed using the numerical equivalent of scores provided by the subjects.

A two-way, repeated measures ANOVA was performed on the four responses each subject provided for each comparison of Baseline versus E-C/VIS immediately following pairs of runs on the Smart Road. The independent variables in this analysis were Weather (Rain versus Clear) and Lighting (Street Lighting On versus Dark). The single dependent variable was the rating of "how helpful was the E-C/VIS compared to Baseline". The analysis demonstrated no significant main effects or interactions. The interpretation of these results is that the ratings are not significantly different whether or not Rain is present or absent, and whether Street Lighting is On or Off. Figure 17 shows the mean ratings for the various conditions, indicating that even though there are no significant differences, all ratings are relatively high, averaging 7.67. This represents a high value of acceptance of the E-C/VIS by the subjects.

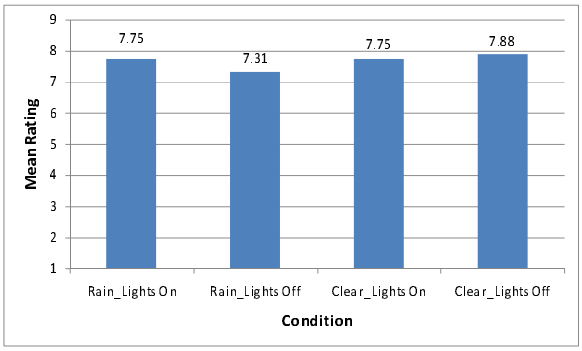

Figure 17. Mean ratings of E-C/VIS Helpfulness as a function of Weather and Street Lighting. Differences are not Significant; average rating is 7.67.

Overall Ratings. As indicated, once the experimental runs were completed, subjects rated the E-C/VIS along three dimensions. Paraphrasing, these were: "How useful overall?", "Would you like to have this integrated system on your rig?", and "Does the E-C/VIS improve your situation awareness (where situation awareness was defined for the subjects)?" The objective of these ratings was to determine whether or not subjects were receptive to the E-C/VIS after using it and to determine the degree to which they were receptive.
Figure 18 shows the mean values for the responses to the three questions. As can be seen, average responses for the three ratings demonstrate a high overall level of acceptance, with a grand mean of 7.88.

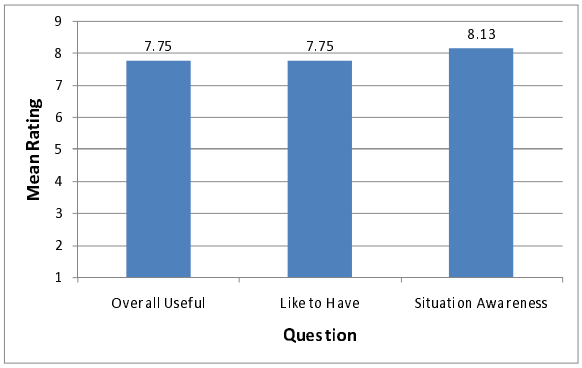

Figure 18. Mean values for post-experiment ratings regarding receptiveness to the E-C/VIS.

CONCLUSIONS

This research indicates that a promising approach to an Enhanced Camera/Video Imaging System has been developed and tested in realistic experiments. The system has been configured to have three channels of video, one on each side of the tractor and one looking down from above at the rear of the equipped trailer. This system would use cameras sensitive to both visible and near IR illumination and would be suitable for day or night conditions and for clear or rain conditions. The system would provide color images in daytime and B/W images at night.

The system would use IR LED illuminators in the 940 nm range, which would produce illumination at night, visible only with the video system and not with the unaided eye. Processing would be used to "outline" target objects such as other vehicles. The level of processing would be set but could be adjusted in each direction (that is, more or less processing) by the driver.

Monitors for the two side cameras would be placed at the A-pillars of the tractor, making it possible to view them without great eye travel to and from the conventional side mirrors. (Note that if side mirror reflections become a problem, another location for the two side monitors might be needed.) This location (that is, the A-pillars) would have the advantage of not creating additional blind spots. The monitor for the rear wide-angle look-down camera would be placed in the upper center windshield area of the tractor, similar to that of an interior rearview mirror. All images would be horizontally reversed so that they would appear as familiar mirror images.

A three-channel system was implemented and was tested on the Virginia Smart Road. All results were encouraging and indicated that driver performance was better and driver opinion of the Enhanced C/VIS was high. The results of the dynamic tests have been positive and the following principles have been developed:

- Video cameras differ radically in their capabilities, and appropriate cameras must be used. The camera type selected (based on indoor tests) was the Toshiba IK-64DNA. This camera had the correct sensitivity to visible and near IR illumination, it would switch from daytime color to nighttime B/W, and it provided good resolution and image rendition. However, because of its high sensitivity at night it was also sensitive to blooming from headlights. This was partly offset by the fact that the bloom did not bleed horizontally or vertically. Camera output was digitally processed externally to minimize the effect of the bloom. Headlights are extremely bright compared with the nighttime background illuminance level. Thus, any camera sensitive enough to be used at night is quite likely to have the same problem.
- Near IR sources were implemented in dynamic tests because they produced *no* glare for other drivers and provided adequate illumination. These sources are at 940 nm wavelength and are totally invisible in terms of light output. If, however, such illuminators could not be used for a reason that is currently unknown to the investigators, visible illuminators could still be

used. The main reason for using illuminators is to illuminate objects at night when there is no other major source of illumination. It should also be reiterated that the IR illuminators do not provide any change or improvement in mirror detection or mirror identification of objects. It is only when they are used with an E-C/VIS that improvements are obtained.

- The three-camera Enhanced C/VIS should consist of the two fender-mounted cameras and a rear wide-angle, look-down camera. All cameras should be IK-64DNA or equivalent. The monitors for the three cameras should be at the A-pillars for the fender-mounted cameras and at the approximate rearview mirror position for the rear look-down camera. All images should be reversed horizontally, because drivers are accustomed to mirror images when glancing to the rear using mirrors.
- Driver control of the E-C/VIS should be by means of an IP or wing-panel mounted control. The driver should have the ability to offset the amount of processing from nominal to a higher or lower weighting. The reset button should reset the processing to the nominal setting. In addition, the driver should have the ability to offset the brightness/contrast to either a higher or lower setting. Again, the reset button should return the system to the nominal setting. There should be a daytime and a nighttime nominal setting of the monitor brightness and contrast, because the daytime setting will be too bright for nighttime and the nighttime setting will be too dim for daytime. These settings could be determined by cab interior brightness or possibly by the switching of the cameras from daytime to nighttime settings, or vice versa. Another important aspect is to get the legend brightness correct for the control itself. If it is too bright, it will create glare for the driver. If it is too dim, it will be difficult to see at night.
- The rear channel of the E-C/VIS was designed specifically to be used to help in locating adjacent lane vehicles and their corresponding positions. Drivers were able to take advantage of this additional capability under all of the conditions tested. Although the E-C/VIS was shown to result in less absolute error in estimating distance, there tended to be an overestimation of the amount of clearance and an underestimation of the amount of overlap. Due to the convex characteristic of E-CVIS lens, this result is consistent with results found of drivers using convex mirrors in which an overestimation of distance was found. Driving tasks designed to further measure the direction of error while using the E-C/VIS for distance estimation should be examined in future studies in order to gain a better understanding of this phenomenon.
- Eye glance data taken during the clearance/overlap and distance estimation tasks indicate that drivers relied heavily on the rear wide-angle look-down channel of the E-C/VIS. They used this portion of the E-C/VIS even though their side mirrors remained available. These results indicate that they gave preference to the E-C/VIS over their mirrors for the task, a finding that demonstrates the effectiveness of the configuration.
- Drivers tended to use both their side mirrors and their side E-C/VIS channels during the E-C/VIS conditions. This result suggests that drivers found both to be useful. However, use of the rear channel of the E-C/VIS was much more pronounced.
- Opinion data taken from the drivers during the Smart Road tests demonstrated high levels of ratings when compared to Baseline. Values were in the numerical range of 7.31 to 7.88 for the various combinations of driving conditions. These values correspond to "Very Helpful" or better. Drivers also rated overall usefulness, whether or not they would like to have an integrated E-C/VIS on their own rig, and whether or not the E-C/VIS improved situation awareness (defined as being aware of the situation along the sides and to the rear of the heavy vehicle). In all three cases, ratings were very high ranging from 7.75 to 8.13. These average values fall well above the "moderate" level and are in the range of "very" to "extremely". Thus, acceptance of the E-C/VIS by CDL drivers was very high.
- Finally, drivers provided comments on a lined sheet intended to help with further development. The comments generally reflected problems the investigators had seen previously. However, side glass reflections and lack of marker lights at the rear were problems the investigators had not addressed sufficiently and should be taken into account in any future efforts.
- Low position of the side cameras on the fenders would prevent small vehicles from

going undetected alongside the tractor. This is an important consideration in camera placement and E-C/VIS development. Although fender placement presents some design problems, the fender position should definitely be retained in any future developments. It would be expected that such placement would help in reducing the number of sideswipe crashes; namely, those occurring at the sides of the tractor or front portion of straight trucks.

An E-C/VIS is believed to represent a distinct step forward in heavy-vehicle design and safety. These systems are expected to improve over time, addressing solutions to camera artifacts such as blooming and various physical size/reliability characteristics of truck-mounted cameras. As a result of the success of this work, a Technology Field Demonstration (TFD) beginning in 2009 has been planned over a 2 year period, in co-sponsorship with FMCSA.

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[2]Wierwille, W. W., Schaudt, W.A., Gupta, S.K., Spaulding, J.M., and Hanowski, R. J. (2007). *Development of a performance specification for camera/video imaging systems on heavy vehicles final report specifications.* (Contract DTNH22-05-D-01019, Task Order 5) Blacksburg, VA: Virginia Tech Transportation Institute.