Development of a Performance Specification for Indirect Visibility Systems on Heavy Vehicles

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ABSTRACT

Recent advances in video technology and image processing have heightened the prospect of improving commercial vehicle safety by enhancing the ability of the driver to perceive and respond safely to surrounding traffic. This paper describes the experimental method of an approach for testing the indirect viewing requirements, determined from previous research, using drivers performing maneuvers on a test track course. Various configurations of camera placement, camera optical characteristics, and image viewing surfaces were implemented for this research. These studies will be completed by April 2007. The purpose of this paper, therefore, is to present the experimental methodology and research protocols that were implemented to develop the performance specifications for these indirect viewing systems. This research provides the foundation for developing enhancements of the video imagery in order to implement an all-weather indirect viewing system for commercial drivers.

INTRODUCTION

Camera/video imaging systems (C/VISs) are expected to become prevalent in future heavy vehicles. As a result, the National Highway Traffic Safety Administration (NHTSA) has contracted with Virginia Tech Transportation Institute (VTTI) to develop concepts and specifications for these systems and also to test them in realistic environments. The purpose of these specifications is to maximize the effectiveness of future indirect viewing systems and ultimately increase driver awareness of traffic conditions around the truck. An increase in driver awareness is expected to result in safer heavy vehicle operations.

Based on preliminary tests (Wierwille, Spaulding, and Hanowski, 2005), six concepts were selected for drivers who were naïve to the systems and road tests. Concepts were selected on the basis of importance for the maneuverability of a heavy truck and the need for additional information that was apparent from the preliminary tests. The six concepts were divided into three groups of two, as follows:

Group 1
The backing/bobtailing rear view enhancement and the trailer wide angle rear multipurpose enhancement,

Group 2
The left and right merge/re-merge enhancements and the trailer look-down enhancement, and,

Group 3
The left and right convex mirror surrogates and these surrogates combined with the left and right west-coast (flat) mirror surrogates.

The groups were arranged so that the tests that each driver performed in each group ranged in time between 2 to 4 hours. This length of time made it possible for drivers to participate without becoming fatigued or losing interest.

METHOD

Participants

Each group was composed of eight Commercial Driver's License (CDL) qualified drivers (24 in total). There was a younger age group, made up of twelve drivers between 23 and 38 years, and an older age group made up of twelve drivers between 52 and 71 years. Each driver was required to have a current CDL and two or more years of experience in driving heavy vehicles. Gender was not considered in selection of drivers for the tests. As it turned out only male drivers volunteered.

Informed Consent

The informed consent form was written so that it applied to all three experimental groups.

Hardware Configurations

Generally, the hardware configuration found the most desirable for each concept in preliminary tests was used in the road tests. Also, where other modifications were recommended based on the preliminary tests, those recommendations were also implemented in the on-road tests.

Three flat-panel monitors were used: sizes 1, 2, and

3 as defined in the preliminary tests. Size 4 monitor used in the preliminary tests was found to be difficult to fit at the A-pillar location and also was less preferred than the size 3 monitor by the preliminary test drivers. A description of each is presented in Table 1.

One bobtailing configuration was tested using a 1997 Volvo VN series tractor. This tractor has a large windshield, which allowed a monitor to be placed at the top center without interfering with the driver's normal driving field of view. All other concepts were tested using a 1994 Peterbilt model 379 tractor with 48 ft trailer. Monitors for this tractor were placed at the center dash, at the top center of the windshield overlapping the area above the windshield, at the A-pillars, and on the side headers. The front headers in the two tractors were not used because preliminary tests indicated that drivers preferred other monitor locations.

Table 1. Monitor image sizes to be used in the on-road tests.

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
Size 4	15.8 cm 6.22 in	21.1 cm 8.31 in	26.4 cm 10.4 in

For highway tests, a 2001 Saab 9-5 served as a confederate (research) automobile. It was used for several maneuvers intended to bring out differences in passing and merging performance, to be explained later in this document.

Instrumentation for the first group of tests was installed and checked. Thereafter, tests were run for the eight subjects in the given group. Once data were collected, the instrumentation for the next group of tests was installed and checked. This process continued until all three groups of tests were completed.

Order of Conditions

In all cases, drivers performed tests including a baseline for comparison. For enhancements, (Groups 1 and 2) the baseline configuration was simply the tractor or tractor-trailer without the enhancements. For surrogates, (Group 3) drivers experienced both standard mirrors and the corresponding mirror-surrogate C/VISs. (During surrogate runs, the mirrors that the surrogates replaced were covered.)

Each test group involved baselines combined with two C/VIS configurations. Drivers provided opinion data for baselines and for each C/VIS configuration. For each C/VIS configuration drivers also provided additional opinion data at the end of participation. These data were used to provide information on the receptiveness of the drivers to the C/VIS. Objective measures were taken during each baseline run and also during runs in which one or more C/VISs were used. Data comparisons were made between baseline and C/VIS run measures. The ordering of conditions always involved the presentation of baseline and corresponding C/VIS in counterbalanced order. Additional details in regard to counterbalancing are presented in the following sections.

Task A. Highway Driving

Task A included two major subtasks which were performed in a highway setting on the Virginia Smart Road (a 2.2 mile in each direction closed-course test track facility). The first subtask was the Clearance/Overlap Test. In this test, 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 1). The second major subtask involved having the tractor-trailer (or the tractor in the case of bobtailing) merge in front of the confederate automobile which maintained constant speed. This test was performed to determine differences in merging distances and variations in merging distances. For Group 1 (only) drivers also observed the confederate automobile directly behind the Volvo tractor in the bobtailing mode and moving away. When instructed by the experimenter, they gave an estimate of distance to the confederate automobile. This test was used so that drivers could provide opinion data regarding observation directly to the rear.

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. Every highway driving subtask with a given configuration (baseline or C/VIS) was practiced first and then repeated for data gathering. Test procedures were worked out so that all practice for a given configuration was accomplished in one complete loop of the Smart Road. Data gathering then followed with a second complete loop. It is important to note however that different clearance and overlap values were used in the practice loop and the data taking loop.

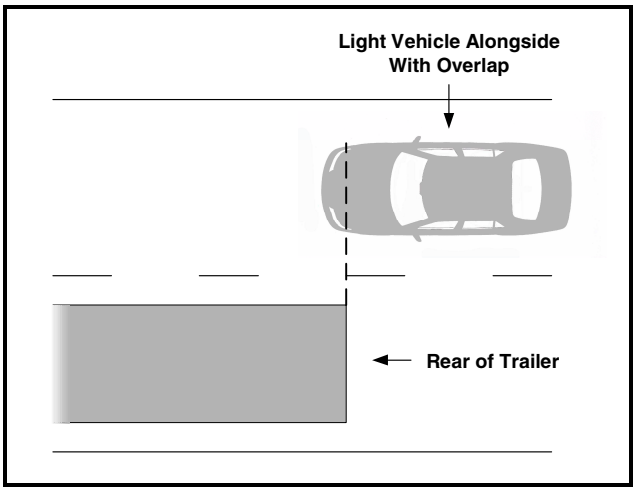

Figure 1. Diagram Showing Overlap in the Clearance/ Overlap Subtask.

Task B. Low Speed Backing

Parking Subtask.

A parking subtask was incorporated in several of the tests. For this subtask, a parked vehicle was used. This was an older automobile in which the engine, transmission, and driveshaft had been removed. Interior components were also removed to reduce the mass. The springs were compressed so that the parked vehicle had normal curb height at the front and rear. The vehicle had a parking brake automatic release/reapply mechanism to minimize coast if it was pushed. This subtask used a section of the two-lane road (without centerline) as shown in Figure 2. The driver was instructed to back into the right lane, as shown in the figure, and to park 5 ft (1.52m) from the parked vehicle. Final position was measured. In addition, if the parked vehicle was pushed, the distance it is pushed was measured.

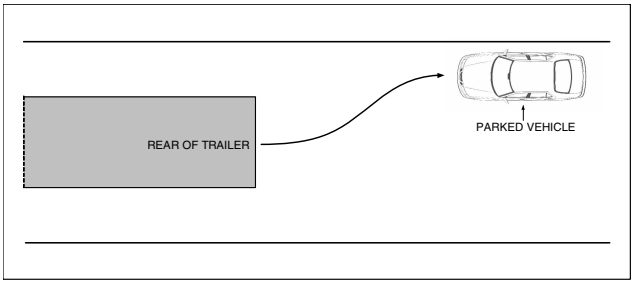

Figure 2. Parking Subtask.

Loading Dock Backing Subtask.

An artificial loading dock was constructed as part of the backing subtasks associated with the backing maneuvers for the tractor-trailer. The 'loading dock' was capable of being pushed without damage during contact. The dock was 12 ft (3.7 m) wide and had a top height that was approximately the same as the trailer floor. Figure 3 shows a different section of the two-lane road used for the loading dock backing subtask. Drivers were instructed to stop 1 ft (0.305m) away from the dock. However, if they did strike the dock, measurements were made to determine how far the dock was pushed.

For Group 1, in the bobtailing mode, cones were used instead of a loading dock. The reasons for this were that the cones were lower and might have been more difficult to see, and that drivers seldom approach a loading dock while bobtailing. Drivers were instructed to stop 1 ft (0.305 m) away from the tips of the cones. Measurements were made of final distance as well as any movement of the cones (if struck).

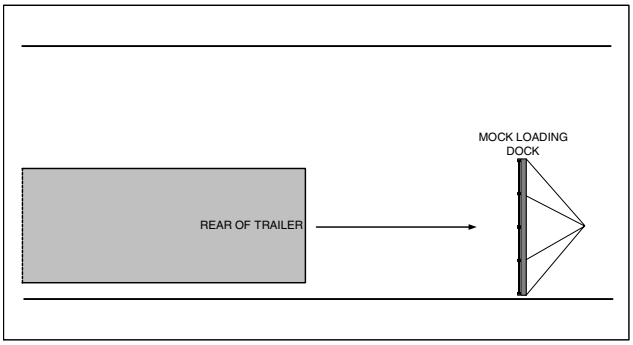

Figure 3. Loading Dock Subtask.

S-curve Backing Subtask.

The S-curve backing maneuver was used to determine whether or not a complex backing maneuver would be affected by the C/VIS being tested. In this case, there was the possibility that a given C/VIS might either facilitate or hinder the maneuver. Figure 4 depicts an asphalt area used for the maneuver. Construction barrels were placed so that the maneuver could be accomplished with the correct driving technique. The path laid out by the barrels was approximately 2 ft (0.61m) narrower when used for the Volvo tractor in the bobtailing mode.

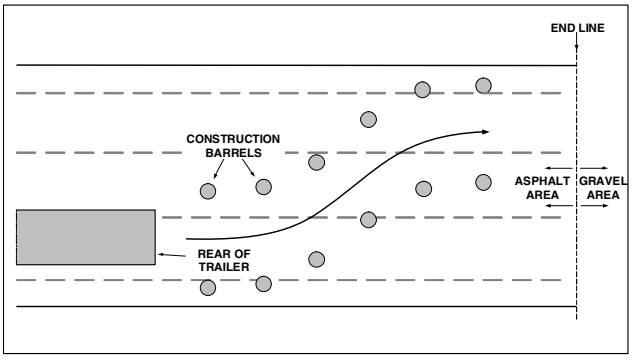

Figure 4. S-curve Backing Subtask.

All of the backing subtasks (under Task B) for each given configuration (baseline or C/VIS) were performed without practice. In other words, data were gathered during the first attempt. The reasons for not practicing were: (i) the backing maneuvers were performed at low speed and were similar to maneuvers the drivers normally encountered in everyday work (parking and loading dock subtasks) or in driver proficiency testing (S-curve subtask); and, (ii) drivers were not time-sharing between maintaining control of the vehicle on a highway and assessing the location of another vehicle (as was the case for Task A). Thus, the task was not considered to be as hazardous.

DGPS Instrumentation of the Tractor-Trailer and Confederate Vehicle

Both the tractor-trailer (with Peterbilt tractor) and the confederate automobile (2001 Saab 9-5) used in the tests had DGPS (differential global positioning system) capability. The confederate automobile was driven by a confederate experimenter. The data from the two DGPSs were compared to obtain distance between the two vehicles at the times of merge and to determine whether or not there was clearance between the trailer and the confederate vehicle alongside, as will be explained in future sections. In most cases DGPS distance measurements were backed up by video available to the experimenters on a quad-split screen that allowed the estimation of distance. Thus, the video served as a check and as an alternative method of determining distance, if and when necessary.

It should be noted that the DGPS antenna on the tractor-trailer was placed at the center-rear of the cab and the DGPS antenna on the confederate automobile was on the center of the trunk. Thus, the longitudinal distance between antennas at the beginning of merge was large, on the order of 70 ft (21.3 m), compared with the lateral separation. Consequently, the lateral separation could be assumed to be 12 ft (3.66m), or one lane width, without introducing appreciable error in calculating longitudinal gap or overlap. To calculate the gap or overlap, the resultant obtained from the DGPS and the 12 ft lateral offset were used to calculate the longitudinal distance. Then, the length from the tractor-trailer antenna to the rear of the trailer was subtracted, and the length from front bumper of the confederate vehicle to its antenna was subtracted. The result was the gap (for positive values) or the overlap (for negative values). This system was tested and found to be accurate to about + or – 2.5 in (6.35 cm). In addition to the C/VISs and DGPS, video data on a quad split screen were recorded on digital hard drives.

The video images were also available to the experimenters during the runs (but not to the driver/subject) as a means of checking that various cameras were working properly and as backup in case problems occurred with the DGPS. Three views were used throughout all experiments, and a fourth varied with the condition. A camera with a 50 degree field of view was mounted at the center of the windshield and provided a view of the driver's face and eyes. This image was used to determine eye glance positions. Two other cameras provided views that were the same as the merge/re-merge camera views. These cameras allowed determination of the amount of clearance or overlap, based on video image interpretation. Both the Peterbilt tractor with trailer and the Volvo tractor had these cameras. For the Peterbilt with trailer the images served as backup, and for the Volvo tractor the images served as the primary means of determining clearance or overlap, since the tractor did not have DGPS. The fourth view varied with the particular C/VISs being tested and was used simply as a quality check.

Group 1: Tests

Backing/Bobtailing Enhancement

As indicated, the backing/bobtailing (rear-view) enhancement was implemented in the Volvo tractor, used in the uncoupled mode. The C/VIS camera was placed behind the cab at a height of 10 ft (3.05m) above the road surface. It was aimed so that the top edge of the field of view was slightly above the horizon, and the lower edge included the rear wheels of the tractor. The camera (itself) had a horizontal field of view of 70 degrees. The monitor (size 2) was placed at the top center of the windshield.

The test scenario involved two aspects: Task A: highway driving and Task B: low-speed backing. The highway driving portion consisted of two separate components. The first involved having a confederate vehicle maneuver along each side of and behind the tractor. Similarly, the second portion involved the tractor merging to the right and to the left. The primary reason for performing these tests was to obtain opinion data. (The Volvo tractor was not as fully instrumented as the Peterbilt tractor with trailer, which was used for all other tests.)

The low speed backing maneuvers (Task B) involved the parking subtask, the backing to cones subtask and the S-curve subtask. Measures obtained included completion times and final distances for all three subtasks, as well as number barrels (S-curve subtask) or cones displaced. The measures were treated in such a way as to provide an indication of quality of the corresponding maneuver.

Trailer Wide-angle Multipurpose Rear Enhancement

This multipurpose enhancement was similarly tested in both highway driving and in backing, 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 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 bumper. The monitor was placed at the upper edge of the tractor windshield (with overlap above the windshield) and was size 2. 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 field of view. In particular, the roadway lines appeared curved without image re-mapping. 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.

The highway driving portion of the scenario consisted of three separate but related components. The first component involved having the confederate vehicle approach from the rear in the adjacent left lane, the adjacent right lane, and in the same lane as the tractor trailer. The second component of the tests consisted of tractor-trailer merges to the right and left. This C/VIS was intended to provide helpful information for merges. The DGPSs installed on the tractor-trailer and on the confederate automobile provided distance information that could be used to determine such aspects as clearance at merge and uniformity of distance at merge. During the "clearance/overlap (no clearance)" tests (Figure 1), 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. Both the DGPSs and an actual recording of video captured the correctness of the driver's responses.

For the low-speed backing maneuvers, the routines depicted in Figures 2 through 4 were used. The driver performed the parking subtask first (Figure 2), followed by the loading dock subtask (Figure 3), and then the S-curve subtask (Figure 4). Because the driver backed a trailer through the S-curve, the barrels were set to allow greater tolerance in backing.

Group 1 Test Order

Reviewing, two C/VIS enhancements were tested in Group 1: the Backing/Bobtailing enhancement (using the Volvo tractor), and the Trailer Wide-angle Multipurpose Enhancement (using the Peterbilt tractor with trailer). It was deemed desirable to test both enhancements using Task A, the Highway Driving scenario, and Task B, the Low Speed Backing scenario.

The test ordering for Group 1 was counterbalanced as shown in Table 2. The Task A tests were counterbalanced in terms of baseline and C/VIS runs, and in terms of Task A and Task B. Similarly, the Task B tests were counterbalanced in terms of baseline and C/VIS runs, and in terms of Task A and Task B. In addition, for every younger driver there was an older driver with exactly the same order of presentation.

It is important to note that all drivers drove the Peterbilt tractor with trailer first. Thereafter, they drove the Volvo tractor in the bobtailing mode. This procedure was used so that direct comparisons could be made between the Group 1 results and the Group 2 results in regard to tests using the Peterbilt tractor with trailer. By having drivers drive the Peterbilt tractor with trailer first, the amount of practice for Groups 1 and 2 in regard to the Peterbilt tractor with trailer was essentially the same.

The counterbalancing scheme shown in Table 2 for the four conditions was repeated: the first replication used the Peterbilt with trailer (for the trailer wide angle multipurpose C/VIS tests), and the second used the Volvo tractor (for the backing/bobtailing rear view C/VIS tests). The comparisons between Groups 1 and 2 were as follows: the trailer wide-angle multipurpose rear enhancement could be compared to the left and right merge/re-merge enhancements in terms of highway performance and the trailer wide-angle multipurpose rear enhancement could be compared to the (regular) trailer rear look-down enhancement in terms of backing performance.

Table 2. Presentation orders for Group 1.

Subject Number	Age	Presentation Order			
		First	Second	Third	Fourth
1	Y	Task A, Baseline	Task A, C/VIS	Task B, Baseline	Task B, C/VIS
2	O	Task A, Baseline	Task A, C/VIS	Task B, Baseline	Task B, C/VIS
3	Y	Task A, C/VIS	Task A, Baseline	Task B, C/VIS	Task B, Baseline
4	O	Task A, C/VIS	Task A, Baseline	Task B, C/VIS	Task B, Baseline
5	Y	Task B, Baseline	Task B, C/VIS	Task A, Baseline	Task A, C/VIS
6	O	Task B, Baseline	Task B, C/VIS	Task A, Baseline	Task A, C/VIS
7	Y	Task B, C/VIS	Task B, Baseline	Task A, C/VIS	Task A, Baseline
8	O	Task B, C/VIS	Task B, Baseline	Task A, C/VIS	Task A, Baseline

Group 2: Tests

Left and Right Merge/Re-Merge Enhancements

The left and right merge/re-merge enhancements included cameras located approximately 5 ft, 10 in (1.78 m) above the roadway, looking across the back of the trailer. The right merge camera was located at the outer left edge of the trailer and was aimed into the right adjacent lane. Similarly, the left merge camera was located at the outer right edge of the trailer and was aimed into the left adjacent lane. The fields of view were 55 degrees, with the edge of the image showing the edge of the trailer. Accordingly, the driver could glance into the monitor and determine the degree of clearance (if any) with vehicles in the adjacent lane prior to performing the merge maneuver. The size 2 monitors were located on the left and right headers, more or less in line with the outside rear view mirrors. Thus the driver was able to time-share between the mirrors and the corresponding monitor.

The test scenario for these enhancements included highway driving only; that is, Task A, because the enhancements were not intended for use in backing and parking tasks. In other words, Task B was not performed for the left and right merge/re-merge enhancements. The first set of subtasks involved having the confederate vehicle approach from the rear in the adjacent left lane and the adjacent right lane. Data taking then involved clearance/overlap decisions. The confederate vehicle maneuvered longitudinally alongside the trailer. When requested by the experimenter, the driver indicated whether there was clearance between the back of the trailer and the confederate vehicle as well as the amount of clearance or overlap in feet. The second set of tasks involved actual merges to the left and right, while the confederate vehicle maintained speed. In this case the driver had to increase speed and merge when he or she felt it was appropriate to do so. These tasks provided measures that indicated any changes in performance associated with the C/VIS as compared with baseline. Position data were gathered from the DGPSs installed on the tractor-trailer and on the confederate automobile. The two enhancement camera videos were used as backup in determining clearances and estimating distances.

Trailer Rear Look-down Enhancement

The trailer rear look-down enhancement had the camera at the rear top center of the trailer 13 ft, 4 in (4.06 m) above the road surface. The camera had a 60 degree horizontal field of view. It was aimed so that the bottom edge of the image included the rear edge (bumper) of the trailer, thereby allowing drivers to judge distance to objects behind the trailer. The monitor was size 1 and was located at the center dash.

This enhancement was intended for backing and parking only. Therefore, tests were limited to backing and parking subtasks (Task B). First, drivers parked in front of a parked car, with instructions to park five feet (1.52 m) away from the parked car. Thereafter, they approached the artificial loading dock, with instructions to stop 1 ft (0.305 m) from the dock. Measurements were made of final position relative to the loading dock and distance the dock had been pushed if it was struck. Lastly, drivers backed through the S-curve. Barrels were set so that the S-curve maneuver could be accomplished with the correct technique.

Group 2 Test Order

Both Task A (for the merge/re-merge enhancements) and Task B (for the trailer rear look-down enhancement) in this group had baseline runs, each involving the tractor-trailer without enhancements. However, the baselines differed from one another. Thus, the situation except for the C/VISs being tested was identical to the Group 1 tests. Consequently, the counterbalancing scheme shown in Table 2 could be used for the Group 2 tests. The only differences were the driver numbers, which ranged from 9 to 16, and the fact that the counterbalancing scheme did not need to be repeated (as it was in the Group 1 tests).

Group 3: Tests

Convex Mirror Surrogates

The Group 3 tests consisted of the use of surrogates. Under the "Convex C/VIS" condition, the convex mirrors were replaced with surrogates. The cameras were placed on the outer edges of the front fenders and had 45 degree fields of view. The monitors were size 2 and were located at the A-pillars. (The preliminary tests indicated that drivers liked this surrogate and felt it was actually superior to the convex mirrors themselves.) The scenarios for these tests are discussed later in this section.

Convex Mirror Surrogates Combined with West Coast (Flat) Mirror Surrogates

Under the "Combined C/VIS" condition, 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. (The reasoning, as explained earlier, is that the convex mirror surrogates perform well and should be used if any surrogates are used.)

For the Combined C/VIS condition the convex mirror surrogates were the same as in the Convex C/VIS condition. 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 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. The stacked monitors were mounted in front of the A-pillars. This location was decided upon, as explained earlier, because it minimized blind spots and was close in angle to the actual mirrors.

The size 3 monitors (for the west coast mirror surrogates) 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 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 flat roadway. Note that 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 field of view, both of which were carefully calibrated prior to data gathering.

The cameras were located on the front fenders. The convex mirror cameras had fields of view of 45 degrees. The west-coast mirror surrogate cameras had fields of view creating the same image size in width as the corresponding mirrors themselves, when viewed from the driver's position. As earlier analyses indicated, this meant that the passenger side field of view was narrower than the driver's side field of view.

The cameras were each carefully aimed so that when the vehicle was being driven in a straight line the edge of the trailer could be seen in the image. Since the fields of view differed for the convex mirror surrogate camera and for the west-coast mirror surrogate, the aim points were quite different.

Special camera mounts had to be used. The mounts were cubes of mild steel having substantial mass. The cubes helped to reduce high frequency vibration in the west-coast mirror surrogate cameras, which were susceptible because they had narrow fields of view. The cubes were mounted on a cross bar that went diagonally down from the cubes to the frame of the tractor, where the crossbar was bolted to the frame. It was found that there was simply too much vibration in the fenders themselves to mount the west-coast mirror surrogates directly to the fenders. It should be mentioned that although the mounts worked adequately, additional improvements in mounting intended to minimize vibration effects should be considered in future applications.

Scenario for Tasks A and B

The two conditions used identical scenarios and had a common baseline. Consequently, the situation was somewhat different from the Group 1 and Group 2 tests. In fact, since there was only one baseline in these tests, there were essentially three runs associated with the Group 3 tests, all of which had identical scenarios.

The scenario included both highway and backing tasks (both Tasks A and B). The highway driving portion (Task A) was performed as described earlier and included both the clearance/overlap subtask and the passing subtask. Drivers are often required to perform these using their side mirrors. Therefore, it was considered important to test the surrogates for this capability. The DGPSs installed on the trailer and on the confederate vehicle provided distance information that could be used to determine such aspects as clearance at merge and uniformity of distance at merge. The left and right merge/re-merge enhancement cameras at the back of the trailer (for the Group 2 tests) and corresponding recorded video (not viewed by the driver) were used as

backup in case of DGPS dropout.

For the backing subtasks, the routines depicted in Figures 2 through 4 were again used. First, drivers parked in front of a parked car (Figure 2), with instructions to park five feet (1.52 m) away from the parked car. Thereafter, they approached the artificial loading dock, with instructions to stop 1 ft (0.305 m) from the dock (Figure 3). Lastly, drivers backed through the S-curve. Barrels were set so that the S-curve maneuver could be accomplished with the correct technique (Figure 4). Because the driver backed a trailer through the S-curve, the barrels were set to allow greater tolerance in backing.

It should be noted once again that during the surrogate tests the corresponding mirrors were covered so they could not be used. For the convex mirror surrogate runs the convex side mirrors were covered, and for the convex mirror surrogates combined with the west coast mirror surrogates all of the side mirrors were covered.

Group 3 Test Order

Counterbalancing for the Group 3 tests involved a single baseline and two tests with surrogates, which were given the temporary names Convex C/VIS and Combined C/VIS as previously described. Counterbalancing was achieved by having the baseline run precede the two C/VIS runs for half the drivers, and follow the C/VIS runs for the other half. In addition, the two C/VIS runs were counterbalanced. These considerations have been incorporated in the counterbalancing scheme shown in Table 3. Using eight drivers, there were four orders for younger drivers (17, 19, 21, and 23) and four identical orders for older drivers (18, 20, 22, and 24). In two of the four runs for each age group, the baseline preceded the surrogate runs, and in the other two runs the baseline followed the surrogate runs. Similarly, the two types of surrogate runs were counterbalanced.

Table 3. Presentation orders for Group 3.

Subject Number	Age Group	Presentation Order		
		First	**Second**	**Third**
17	Y	Baseline	Convex C/VIS	Combined C/VIS
18	O	Baseline	Convex C/VIS	Combined C/VIS
19	Y	Convex C/VIS	Combined C/VIS	Baseline
20	O	Convex C/VIS	Combined C/VIS	Baseline
21	Y	Baseline	Combined C/VIS	Convex C/VIS
22	O	Baseline	Combined C/VIS	Convex C/VIS
23	Y	Combined C/VIS	Convex C/VIS	Baseline
24	O	Combined C/VIS	Convex C/VIS	Baseline

It should be noted that the counterbalancing scheme shown in Table 3 does not account for the ordering of Task A (highway driving) and Task B (backing), both of which were performed by every driver in every condition. It was only possible to perform a partial counterbalance for the Task A/Task B ordering. This was accomplished by having drivers 17 through 20 perform Task A first and Task B second, and by having drivers 21 through 24 perform Task B first and Task A second.

EXPERIMENTAL DESIGN

Independent Variables

The experiments are quite similar in design, particularly for the first two groups of tests. The four corresponding enhancements associated with these two groups were analyzed separately. The independent variables were 2 age groups (between, with 4 drivers in each age group) by 2 C/VIS conditions (within, present vs. absent).

For Group 3, the data for the three conditions were analyzed together. Thus, the independent variables were 2 age groups (between, with 4 drivers in each age group) by 3 C/VIS conditions (within, absent vs. convex C/VIS vs. combined C/VIS).

Dependent Variables

Dependent variables fell into two major groups: highway driving variables and backing and parking variables. For highway driving, the following were used where appropriate:

- Distance between the back end of trailer and the confederate vehicle at the initiation of merge.
- Variability (most likely, the variance) of distance at the initiation of merge.
- Number of correct responses to the clearance queries.
- Highway driving-related individual ratings.

For the backing and parking subtasks, the following were used where appropriate:

- Number of cones struck in the S-curve maneuver.
- Time to complete the S-curve maneuver.
- S-curve maneuver-related difficulty rating.
- Loading dock (or cone barrier for the Volvo tractor) error in final position.
- Loading dock push distance (or distance cones are moved/pushed for the Volvo tractor).
- Time to complete the loading dock (or backing to cones) maneuver.
- Loading dock-related (cone backing-related) difficulty rating.
- Error in final parked position.
- Push distance of parked vehicle.
- Time to complete parking subtask.
- Parking subtask-related individual rating.

Statistical Tests

Parametric and nonparametric statistical tests were used. As is usually the case, parametric tests were run wherever appropriate and nonparametric tests were used for the remainder of the measures. There were a few cases where parametric tests were considered tenuous. Under these circumstances, both parametric and nonparametric tests were used. In all cases, the main objective of the tests was to determine any reliable differences between baseline and the corresponding C/VIS related conditions. Such differences show reliable changes in performance or opinion for the corresponding C/VISs when compared to baseline. Additional aspects of the tests were intended to show which variables exhibited differences and also whether age group had an effect on the drivers' performance and opinions.

Rating Scales

Drivers were administered multiple 9 point rating scales with 5 descriptor levels. These ratings were intended to provide information on the degree of difficulty in performing the various maneuvers and in determining the degree of acceptance of the various C/VISs tested. The performance-related scales were designed so that they could be applied to either baseline or C/VIS runs. Other scales were used for the C/VISs only to determine the degree of acceptance.

As mentioned the Group 1A tests used the Volvo tractor in the uncoupled mode. The loading dock subtask was replaced by the cone-barrier subtask for Group 1-A, and the rating scale wording correspondingly was changed. Also, the ratings generally correspond to "tasks" except for the rear view rating. The word "tasks" is used for the drivers because they did not know that they were part of a larger group of experiments. Thus, "tasks" in the ratings corresponds to "subtasks" in this documentation of the experiment.

CONCLUSIONS

This research provides the foundation for developing camera based indirect viewing systems used in the operation of heavy trucks. Resultant performance specifications that are compatible with driver requirements for operating a heavy truck will be used to form the basis for the design of a future all-weather indirect viewing system. An improvement in driver awareness of traffic conditions around the truck is expected to result in safer heavy vehicle operations.

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