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HARDWARE EVALUATION OF HEAVY TRUCK SIDE AND REAR OBJECT DETECTION SYSTEMS

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ABSTRACT

This paper focuses on two types of electronics-based object detection systems for heavy truck applications: those sensing the presence of objects to the rear of the vehicle, and those sensing the presence of objects on the right side of the vehicle. The rearward sensing systems are intended to aid drivers when backing their vehicles, typically at very low "crawl" speeds. Six rear object detection systems that were commercially available at the time that this study was initiated were evaluated. The right side looking systems are intended primarily as supplements to side view mirror systems and as an aid for detecting the presence of adjacent vehicles when making lane changes or merging maneuvers. Four side systems, two commercially available systems and two prototypes, were evaluated.

Three types of evaluation were performed for both the rear and right side object detection systems including hardware performance measurement, a human factors assessment of driver/system interfaces, and an assessment of driver subjective reactions to two systems. The hardware performance measurement consisted of determining the field of view of each system's sensors and, for the right side object detection systems only, determining the frequency of inappropriate alarms and missed vehicles while driving a combination-unit truck equipped with these systems on public roads. The evaluation of driver interfaces was performed using a human factors checklist that was developed specifically for this research and was based upon accepted human factors guidelines for the design of warnings. The last type of evaluation, which gathered subjects reactions to two systems, involved two focus group sessions conducted with drivers of a fleet of tractor-semitrailers that used one rear and one right side object detection system.

An additional type of evaluation was performed which addressed the issue of human performance with side object detection systems. In this evaluation, subjects drove a test vehicle equipped with various right side object detection systems. This evaluation is described in the companion paper "Human Performance Evaluation of Heavy Truck Side Object Detection Systems," [1][1].

The results of these tests and evaluations indicate that object detection system technology is still in the early stages of its development. Drivers of heavy trucks appreciate the value of these aids, but improvements in the technology are needed before the full potential of these systems for preventing crashes can be realized. Manufacturers should focus on improving system reliability and sensor performance and the human factors aspects of the control and display interface.

THIS PAPER DESCRIBES AN EVALUATION OF TWO TYPES of electronics-based object detection systems that have recently been marketed for heavy truck applications: those which sense the presence of objects located to the rear of the vehicle (referred to as Rear Object Detection Systems, or RODS), and those which sense the presence of objects on the right side of the vehicle (referred to as Side Object Detection Systems, or SODS).

The rearward sensing systems are intended to aid drivers when backing their vehicles, typically at very low speeds, so they do not damage parked cars or other fixed objects, strike pedestrians, or impact loading docks at too high of a speed. Six rear systems that were commercially available at the time this study was initiated were evaluated.

The right side looking systems are intended primarily as supplements to outside rear-view mirror systems and as an aid for detecting adjacent vehicles when making lane change or merging maneuvers. Lane changes, especially those to the right, often present difficult challenges for drivers of heavy trucks, particularly in dense traffic situations. Four of these systems, two commercially available systems and two prototypes, were evaluated.

Numbers in parenthesis represent references at the end of this paper.

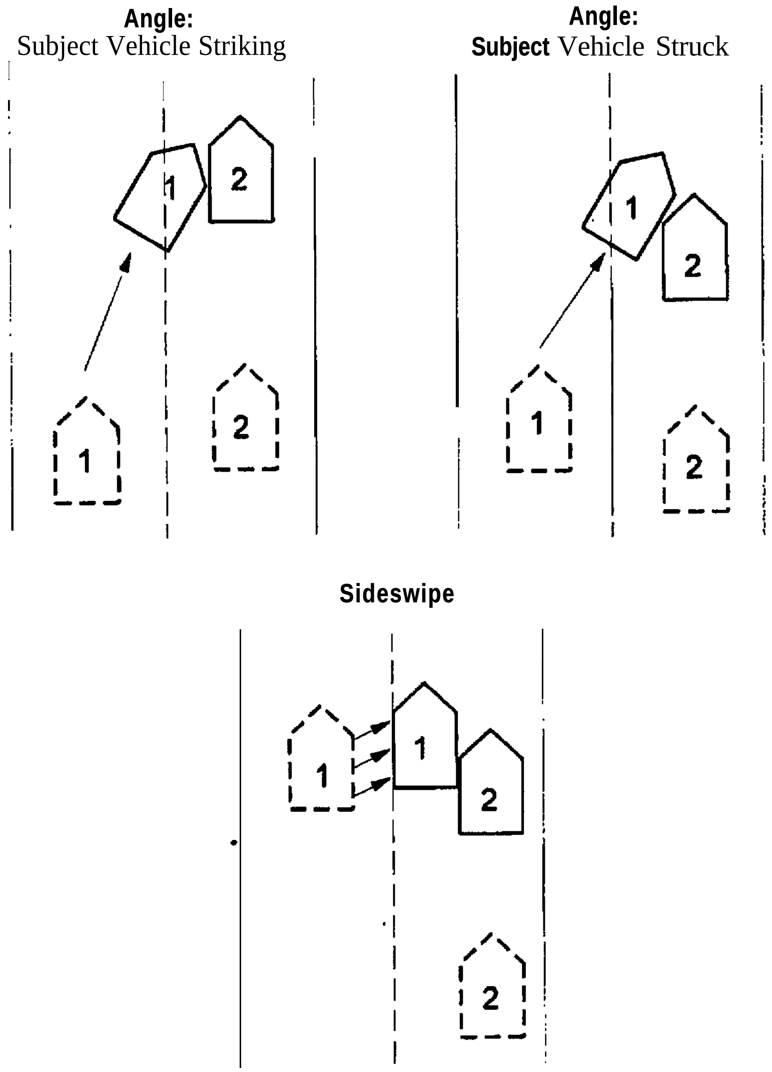
HEAVY TRUCK BACKING AND LANE CHANGE/ MERGE CRASHES

Data from the National Accident Sampling System (NASS) General Estimates System (GES), shows that in 1991 an estimated 330,000 police-reported crashes involving medium and heavy trucks (gross vehicle weight rating greater than 10,000 lbs.) were reported [2,3]. Of these, an estimated 190,000 crashes involved combination-unit trucks. The Fatal Accident Reporting System (FARS), reported that in 1991 medium and heavy truck crashes resulted in 4.849 fatalities, of which 659 were occupants of heavy trucks, 3,764 were occupants of other vehicles involved in collisions with medium and heavy trucks, and 426 were pedestrians.

Combination-unit truck crashes involving backing, turning or lane changing/merging maneuvers accounted for 19.1 percent of the total number of combination-unit truck crash involvements in 1991. These crashes also accounted for approximately 1 .0 percent of all the fatalities, 10.8 percent of the injuries, and 6.3 percent of the costs attributable to combination-unit truck crashes that year.

Lane change/merge (LCM) crashes are divided into two categories consisting of angle/sideswipe and rear-end LCM collisions. According to [4], angle/sideswipe LCM (AS/LCM) collisions are the crash type most amenable to prevention through the use of object detection and warning systems. Figure 1 illustrates possible accident scenarios for the AS/LCM collision category.

A further breakdown of these crashes is presented in Table 1 which indicates the distribution of AS/LCM and backing crashes for combination-unit trucks. Crash statistics are listed by individual crash type. Crashes are categorized according to incidence and resultant degree of injury to persons involved.


Angle:
Subject Vehicle Striking

Angle:
Subject Vehicle Struck

Sideswipe

Figure 1. Angle/sideswipe lane change/merge crash configurations (1 = subject vehicle; 2 = target vehicle)

TABLE 1. Combination-Unit Trucks Involved in Angle/Sideswipe, Lane Change/Merge, or Backing Crashes

	Angle/Sideswipe Lane Change/Merge (AS/LCM) Crashes		**Encroachment* Backing Crashes**	**Right Turn Crashes**	**AS/LCM, Righ Turn, & Encroachment Back Total**	**All Combination-Unit Trucks Involved in Crashes**
	Left Side Impacts	**Right Side Impacts**				
Number of Vehicles Involved in Crashes (GES)	4,000	13,600	8,600	10,200	36,400	**198,000**
By Horizontal Impact Location						
Clearly Tractor	2,200	7,300				
Clearly Trailer	1,500	4,800				
Some of Both **(Tractor and Trailer)**	300	1,500				
Fatalities/Injuries						
Fatalities (FARS)	3	16	9	8	36	3,642
Incapacitating Injuries (GES)	200	500	0	100	800	14,000
Non-incapacitating Injuries (GES)	500	1,000	0	300	1,800	19,000
Possible Injuries (GES)	400	2,600	100	1,100	3,100	30,000
Costs (Million dollars)	$37.2	$109.8	$36.1	$67.7	$183.1	$3,962.8

Source: 1991 GES/FARS. Horizontal impact location data derived by applying truck damage location percentages from 1982-86 National Accident Sampling System (NASS) to the 1991 GES problem size.

Note(*): "Encroachment" backing crashes are those where a vehicle backs into an object, pedestrian, pedalcyclist, stopped vehicle, or slow-moving (<5 mph) vehicle. They do not include "crossing path" backing crashes where a backing vehicle is struck by a moving (>5 mph) vehicle, as might occur when a vehicle backing out of a driveway is struck by crossing traffic.

Combination-unit truck AS/LCM crashes are further classified by side and horizontal location of impact. These data show that AS/LCM crashes occur much more frequently on the right side of the tractor (77.6 percent), compared to the left side (22.4 percent). In addition, in the case of right side AS/LCM crashes, the majority (53.7 percent) were collisions with the side of the tractor, 35.3 percent were collisions with the side of the trailer, while the remaining 11 .0 percent were collisions in which parts of both the tractor and the trailer were impacted.

It is significant that for AS/LCM crashes involving combination-unit trucks, the impact point is most frequently the right side of the tractor. This area coincides with the area where truck drivers have the most difficulty detecting the presence of other vehicles. These data point to the right side blind spot which exists in heavy trucks as a contributing factor in AS/LCM crashes.

However, a substantial portion of these crashes occurred at impact locations on the truck where the possibility existed that the driver had an opportunity to detect the presence of the other vehicle through the use of the conventional outside rear-view mirrors (i.e., the clearly trailer cases). These findings suggest not only the limitations of conventional mirrors systems, but also indicate that drivers sometimes fail to use their mirrors properly or misinterpret the visual information presented.

Figure 2 compares 1991 AS/LCM crash involvements for different types of vehicles. This shows that many more passenger vehicles (208,000) were the subject, or accident-initiating vehicle, than were combination-unit trucks (18,000) or single-unit trucks (6,000). However, crash involvements as the subject vehicle AS/LCM accidents constituted a larger percentage of all crashes for combination-unit trucks (9.2 percent) than for single-unit trucks (4.3 percent) and passenger vehicles (3.5 percent). In addition, as shown in Figure 3, based on vehicle miles of travel, ,combigation-unit trucks had the highest AS/LCM crash involvement rate (18.1 per 100 million vehicle miles traveled) as the subject vehicle, compared to 10.7 for passenger vehicles, and 10.4 for single-unit trucks. Combination-unit trucks also exhibited the highest number of angle/sideswipe LCM crash involvements per vehicle (as the subject vehicle) at 10.9 per 1,000, versus 1.3 per 1,000 single-unit trucks, and 1.2 per 1,000 passenger vehicles.

Estimates based on extrapolating 199 1 statistics predict that the expected number of LCM crash involvements during a combination-unit truck's lifetime is 0.1608. As shown in Figure 4, this value is ten times the value for passenger vehicles (0.0153) and eight times the value for single-unit trucks (0.0193). These statistics demonstrate that although AS/LCM crashes with a passenger car as the subject vehicle are far more numerous than AS/LCM crashes in which a truck is the subject vehicle, combination-unit trucks have a higher incidence rate and are far more likely to be involved in an AS/LCM crash over the vehicle's operational life than are passenger vehicles or single-unit trucks.

Further examination of AS/LCM crashes found that combination-unit trucks, as the subject vehicle, were damaged much more frequently on the right side than the left side. For comparison, passenger vehicles have nearly equal incidence of impact on the left and right sides of the vehicle. Figure 5 illustrates these statistics showing that for combination-unit trucks 63 percent of AS/LCM collisions had the initial point of impact on the right side while only 18.5 percent of the initial impacts were on the left. For passenger vehicles, 38.9 percent of the initial impacts were on the right side versus 42.5 percent on the left. It is reasonable that combination-unit trucks are more likely to be involved in left-to-right LCM crashes since the combination-unit trucks' right side blind spot makes it difficult for drivers to see vehicles directly to their right.

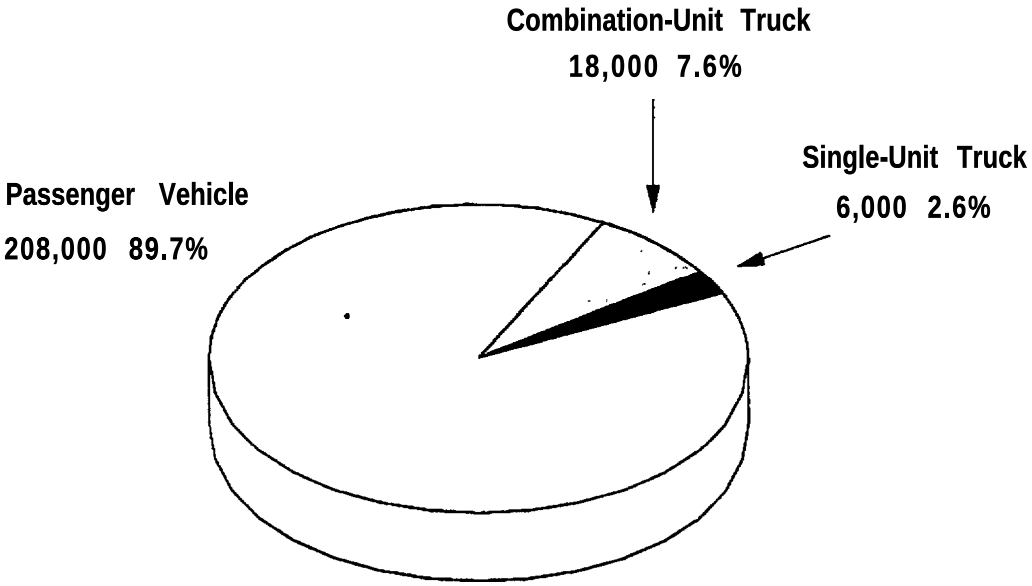


Figure 2. Angle/sideswipe LCM crash involvements (as subject vehicle) by vehicle type

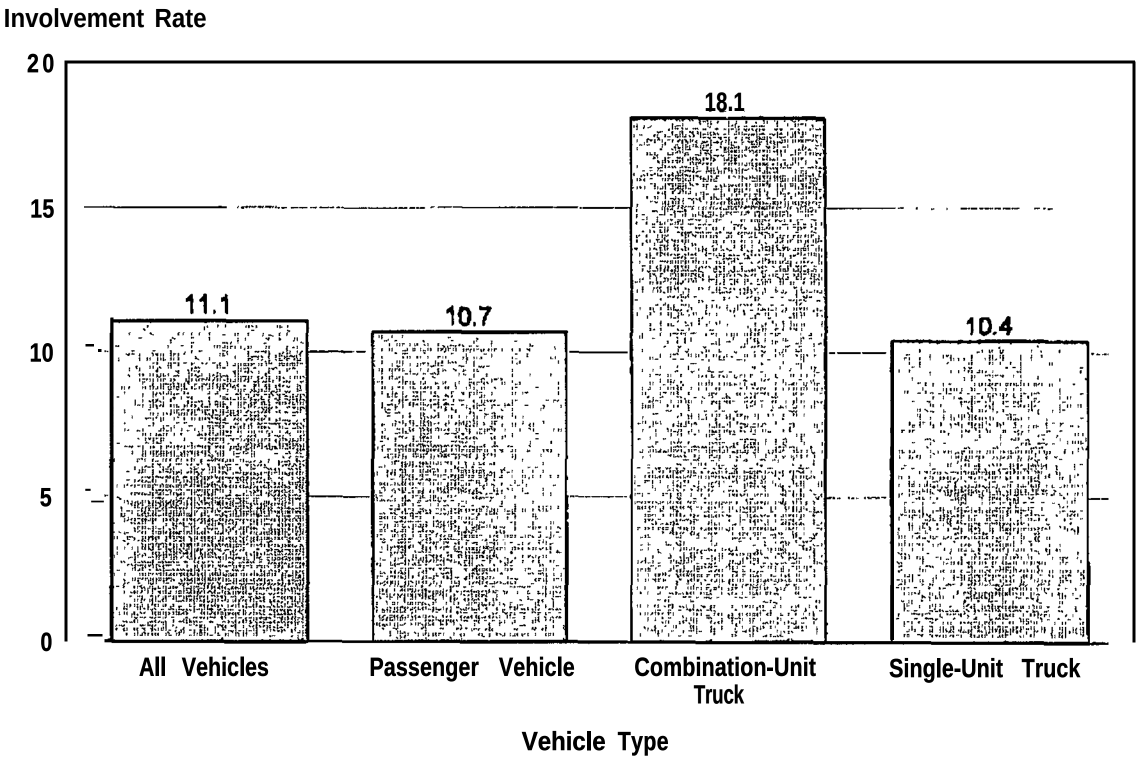


Figure 3. Angle/sideswipe LCM crash involvement rate (per 100 million vehicle miles traveled) by vehicle type

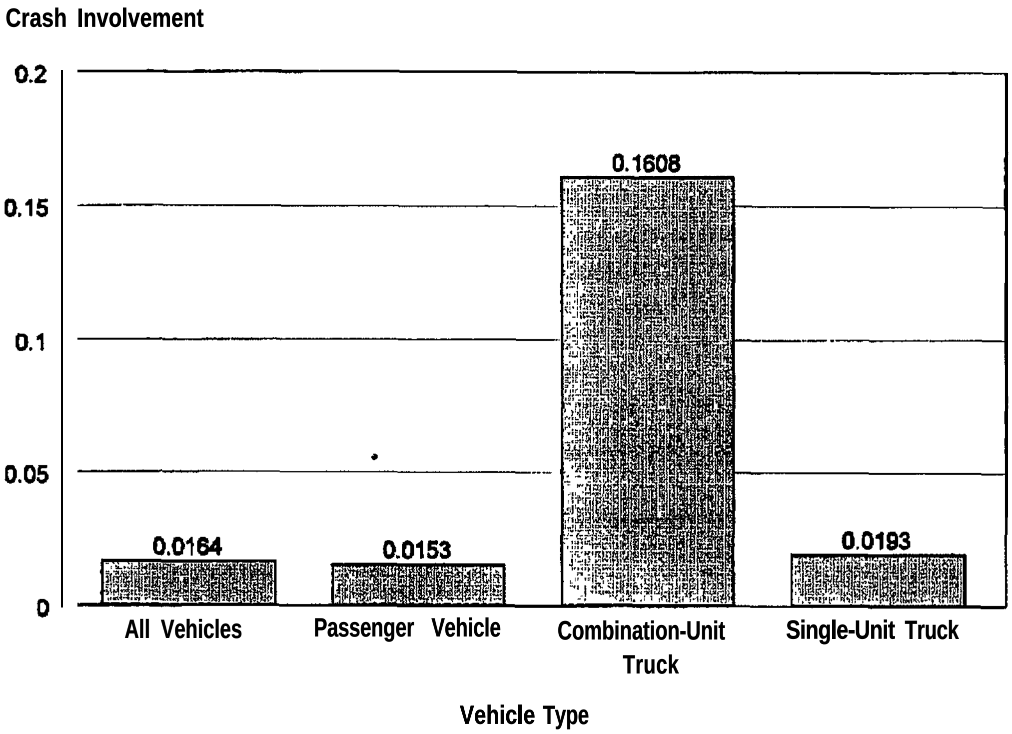


Figure 4. Expected number of angle/sideswipe LCM crash involvements over vehicle operational life by vehicle type

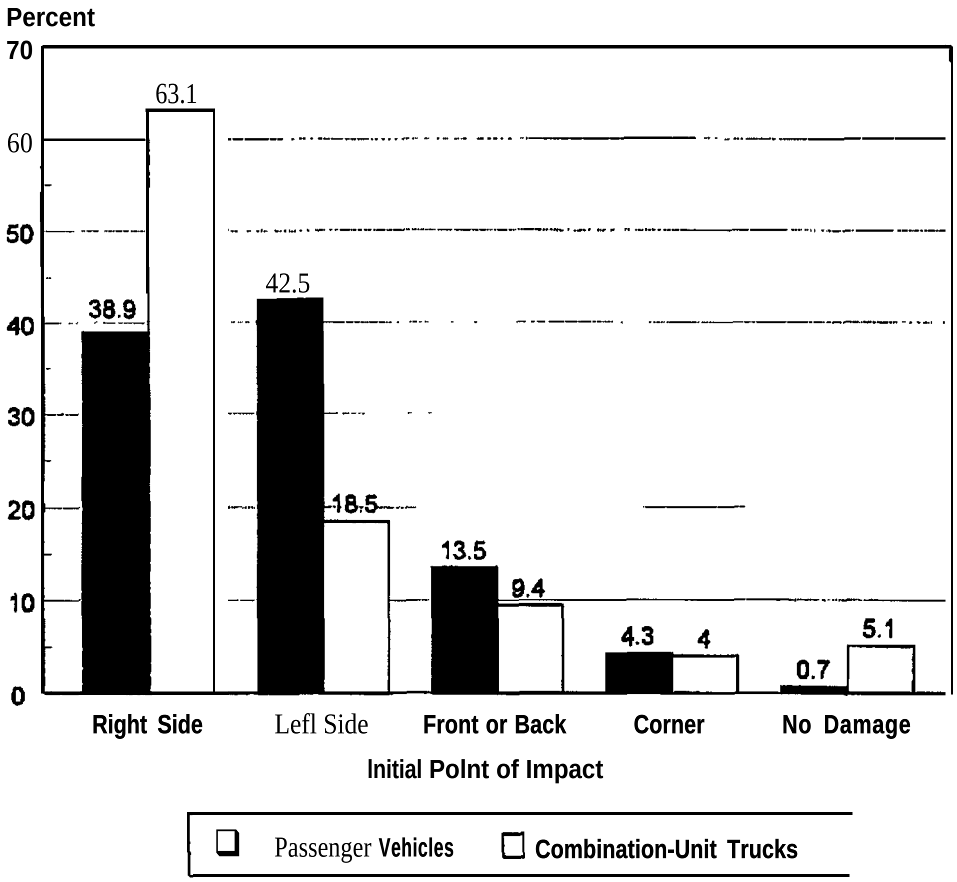


Figure 5. Initial point of impact distribution for LCM crashes

EVALUATION OF REAR OBJECT DETECTION SYSTEMS

For the RODS, three types of performance evaluations were conducted. The first evaluation characterized the physical performance characteristics of the sensor hardware used by each system to detect obstacles behind the vehicle. The second evaluation assessed the appropriateness of the interface used to convey the information acquired by the sensor(s) to the driver by means of a checklist based upon accepted human factors guidelines. The third evaluation, which was performed for only one rear system, was a focus group conducted to learn the opinions of drivers with experience using this particular warning device.

The RODS studied were primarily designed to aid drivers while backing a vehicle toward a stationary or slowly moving obstacle. They are not intended to help in preventing collisions in which the backing vehicle is struck by a rapidly moving vehicle coming from either the left or right side, or "on-road" rear end collisions (i.e., ones where neither vehicle is backing).

All known RODS which were commercially available at the time of this study (a total of six) were purchased and tested on a tractor-semitrailer. The systems tested are shown in Table 2 along with a letter code which is used to refer to each system in the remainder of this paper.

TABLE 2. Rear Object Detection Systems Evaluated

System	Key
Sony Rearvision	A
Safety Technology Safety Sensor	C
Dynatech Scan II	D
EBI Hindsight 20/20	E
Armatron Echovision	G
Technodvne Protex CV 2000	J

TABLE 3. Rear Object Detection System Sensor Technologies

System	Sensor Technology	Number of Sensors	Location of Sensors During Testing
A	Video camera with microphone	1 black and white video camera	Center of trailer, 4. I2 m above ground.
C	Ultrasonic	2 transmitters and 2 receivers	Transmitter at center of trailer, with receivers 0.46 m to the right and to the left, 0.89 m above ground.
D	Ultrasonic	2 transmitters and 2 receivers	One pair 0.97 m to tight of center of trailer, the other 0.97 m to left, both 0.85 m above ground.
E	Ultrasonic	2 transmitters and 2 receivers	One pair 0.43 m to tight of center of trailer, the other 0.43 to left, both I .07 m above ground.
G	Ultrasonic	2 transmitters and 2 receivers	Transmitters 0.76 m right of center of trailer, receivers 0.76 m to left. One transmitter/receiver at 1.14 m above ground, the other at 4.0 I m above ground
J	Ultrasonic	2 transmitters and 2 receivers	Center of trailer, 1.07 m above ground

Table 3 lists the object detection technologies employed by each RODS, the number of sensors, and the locations at which the sensors were mounted during this testing. The RODS studied use two different sensor technologies. One system uses a video camera (System A) while the other five have ultrasonic sensors (Systems C through J). The five ultrasonic systems differ primarily in their driver interfaces and in the number and location of their ultrasonic sensors; the sensors themselves are all quite similar. Figure 6 shows where the sensors for each system tested were mounted on the rear of the semitrailer. The placement of sensors was in accordance with manufacturer suggestions, when given, to provide adequate object detection coverage of areas of interest.

There is a fundamental difference in function between the video camera system and the ultrasonic sensor systems. The video camera system allows drivers to see more than is possible when using conventional "West Coast" mirror systems commonly installed on heavy trucks. However, it does not provide drivers with any type of warning that an obstacle is present. The systems which use ultrasonic sensors warn drivers when an obstacle is present through an auditory and/or visual warning signal, but do not provide drivers with additional visual information about the environment behind the truck.

SENSOR EVALUATION OF THE REAR OBJECT DETECTION SYSTEMS - The sensor evaluation performed for the video camera system (System A) differed from that performed for the ultrasonic systems (Systems C through J). For the video camera system the sensor evaluation consisted only of determining the camera's field of view, which is shown In Figure 7. As this figure shows, the video camera's field-of-view covers, except for a narrow strip immediately behind the rear of the trailer, the entire area immediately behind the vehicle. The field of view substantially exceeded the zone, also depicted in Figure 7, over which field-of-view measurements were made. Although precise measurements were not made, the camera's field of view extended approximately 12 meters outward from the rear of the trailer and 5 meters to the left and right of the center of the trailer. This field of view covered more than the area that a driver needs to see while backing.

In addition to the video camera, System A also included a microphone and speaker. While no attempt was made to measure the area over which sound could be picked up by this microphone, experience with the system found that voices could be heard in a large area behind the trailer.

For the ultrasonic systems, multiple sensor evaluations were performed. Measurements were made of the area over which a nonmoving system's sensors could detect a 0.30 meter square of flat cardboard which was held parallel to the back of the semitrailer. The center of the cardboard square was at the same height as the sensor. A flat cardboard square was used since a flat object presents a highly reflective target for an ultrasonic sensor. Using this target was expected to provide a "best case" or largest field-of-view measurement for these systems. Figure 8 depicts the largest and smallest detection zones measured using the flat cardboard square for Systems C through J. These detection zones covered most, but not all, of the area immediately behind the vehicle. Therefore, while these sensors usually alert the driver to the presence of an obstacle immediately behind the vehicle, it is possible for an obstacle (particularly a small one such as a pedestrian) to be behind the vehicle in a location where these sensors cannot detect it.

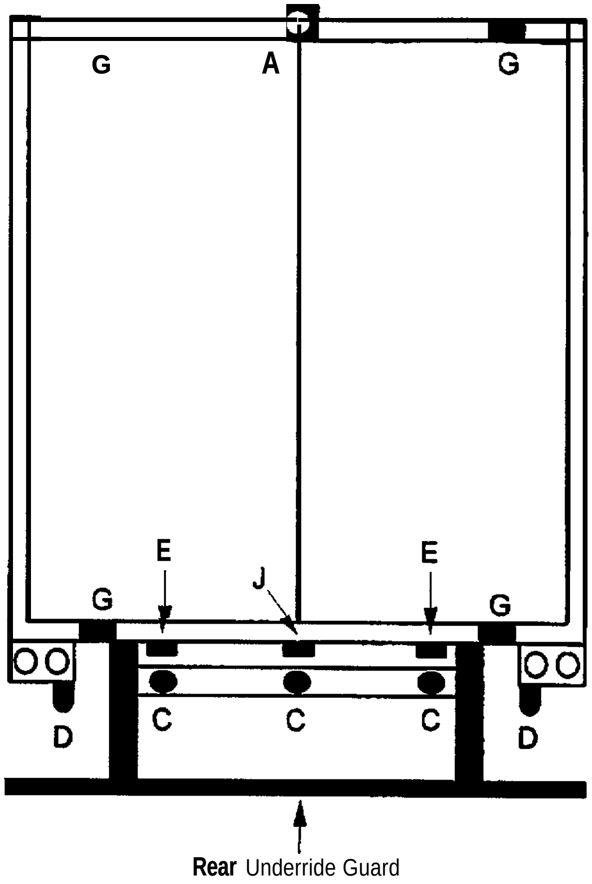


Figure 6. Location of backing system sensors on rear of semitrailer

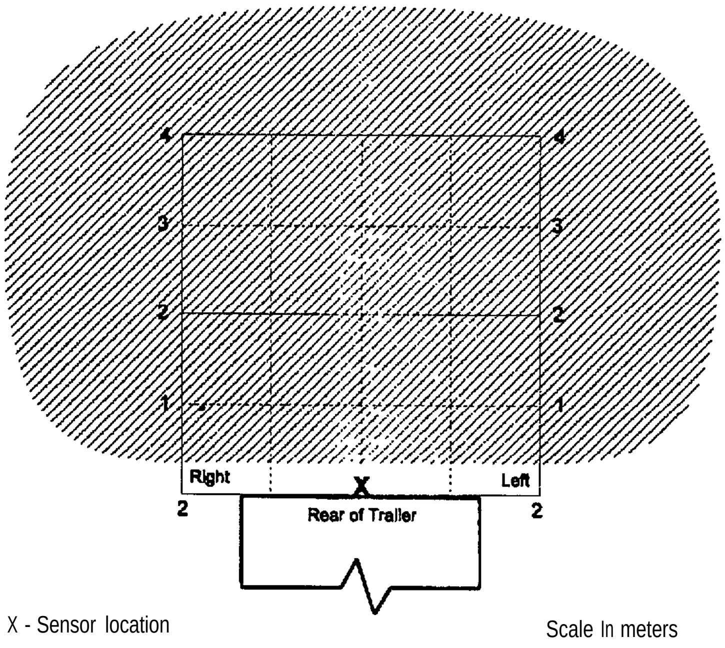


Figure 7. Top View - Field of View of System A (shaded area is that which is visible to the driver via the in-cab display)

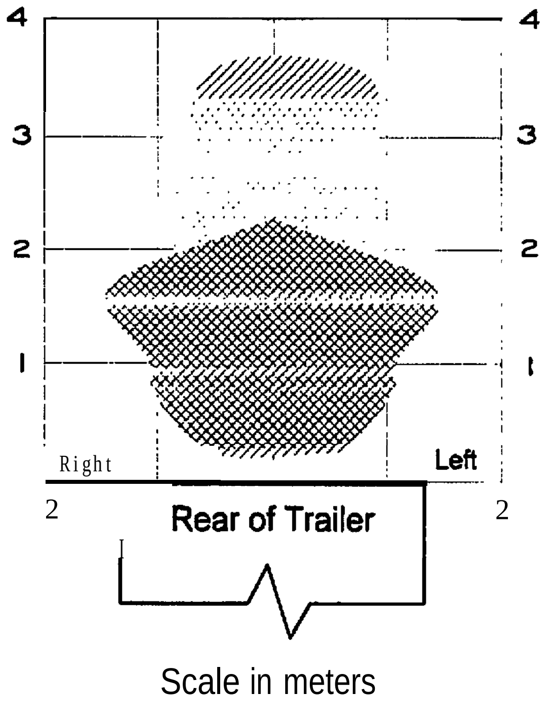


Figure 8. Shortest and longest RODS detection zones for cardboard target

Measurements were also made of the distance at which each system's sensors could detect a large (3.66 meters wide by 4.27 meters high) door parallel to the back of the semitrailer as the vehicle was slowly backed toward the door (the vehicle speed was less than 5 mph). The door used was a standard garage overhead door (big enough to allow heavy trucks through) which is flat with breaks that allow hinged sections to fold as the door opens. Figure 9 summarizes results from these measurements. Note that this figure shows the distance at which different warning levels are activated for each ultrasonic system except System C. Different warning levels are not shown for System C since this system has 10 different warning levels that correspond to the range (in feet) from the rear of the semitrailer to the detected obstacle.

Measurements were also made of the distance at which each system's sensors first detected a full-size van as the tractor-semitrailer was slowly (at a speed of less than 5 mph) backed toward the van. The tests were conducted with the van laterally centered behind the semitrailer and with the van offset such that the center line of the van is directly behind either the left or right edge of the semitrailer. Figure 9 also summarizes results from these measurements.

A determination was made of the percentage of times a pedestrian walking behind the semitrailer was detected. For these tests, the pedestrian walked generally along a line parallel with the back of the trailer at a distance from the back of the trailer which was within the detection zone of the system. The path of the pedestrian started from a point outside the detection zone on one side of the semitrailer. The pedestrian then walked across the detection zone to a point outside the detection zone on the opposite side of the semitrailer. Multiple passes were made from alternating directions. During this testing the pedestrian was moving slightly slower than normal walking speed. Table 4 summarizes results from these measurements. Note that all of the results shown in Table 4 are for one, particular, pedestrian; the results may differ when other people walk behind the semitrailer. No considerations for clothing type or body size of the pedestrian subject were made.

TABLE 4. Percentage of Time that Ultrasonic Rear Object Detection Systems Detected Pedestrians Walking Slowly Through the Detection Zone, Parallel to the Rear of the Semitrailer

System	Percent of Time Pedestrian Detected
C	57%
D	54%
E	92%
G	90%
J	39%

The performance of the RODS sensors appeared to vary from day to day. To obtain a measure of this variability. the pedestrian detection experiment was performed on multiple days for Systems E and G. All tests were performed in good weather conditions. Table 5, which summarizes the results of this testing, shows that the performance of the ultrasonic sensors

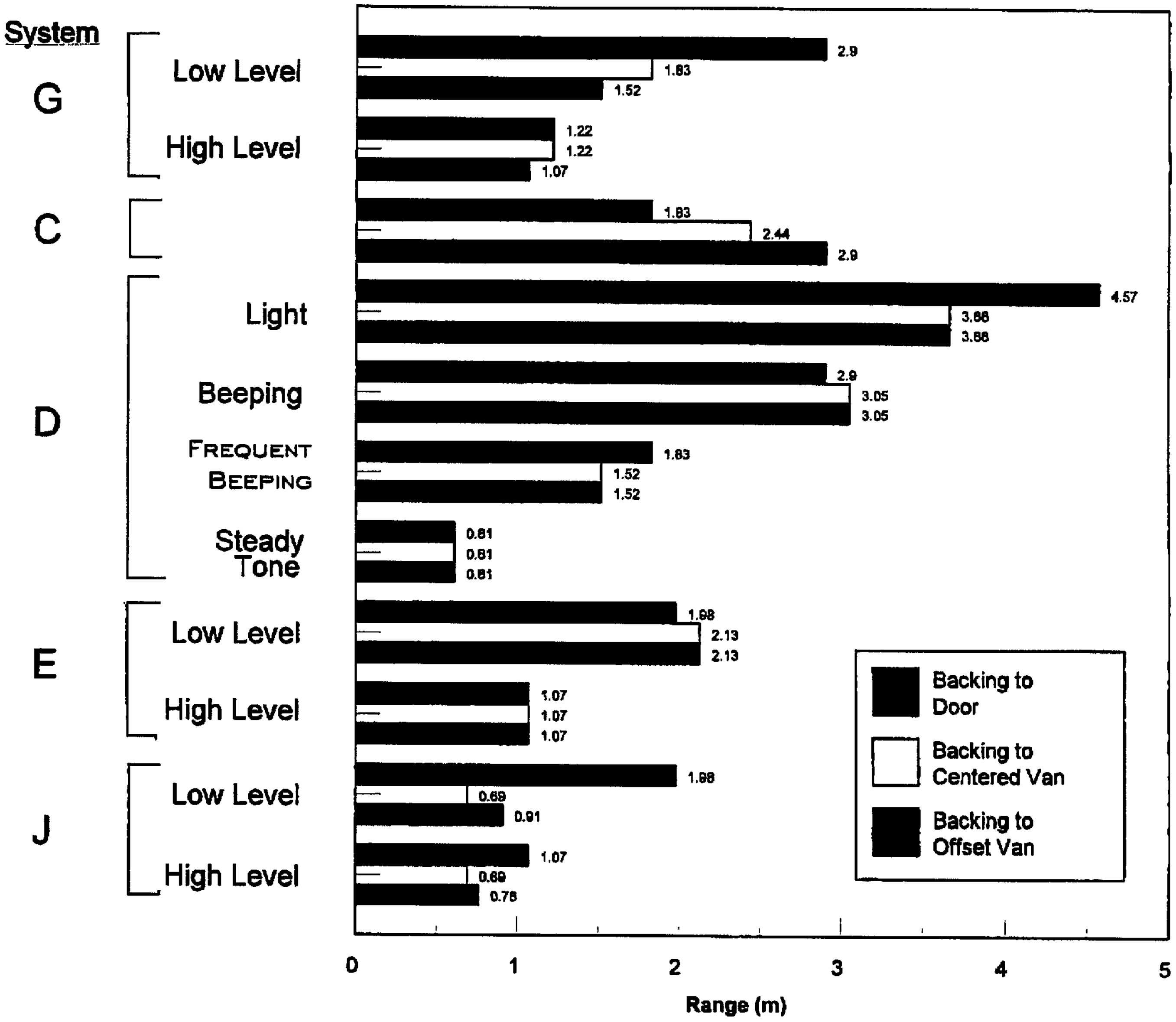


Figure 9. Range at which rear object detection systems detected overhead door and a vehicle while backing

TABLE 5. Day-to-Day Variability in Pedestrian Detection for Two RODS

System	Range	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
E	1.0 m	100%	100%	100%	100%	100%	100%	No Test
E	2.0 m	100%	100%	100%	0%	100%	100%	No Test
E	3.0 m	0%	0%	50%	0%	45%	0%	No Test
G	1.0 m	100%	100%	100%	84%	80%	100%	100%
G	2.0 m	100%	85%	76%	68%	85%	83%	95%
G	3.0 m	33%	0%	0%	0%	0%	0%	0%

used by these two RODS varied from day to day. Note that the detection percentages shown in Table 4 do not include data for any range greater than 3.0 meters, which was beyond the detection zones for these systems, using the cardboard square, the garage door, or the van. However, on some days the sensors had a longer range and were able to detect pedestrians at this range. The reasons for these increases in range are not known.

Table 5 also shows day-to-day variability in the detection of pedestrians at the shorter ranges of 1.0 and 2.0 meters. As would be expected, there is less variability at 1.0 meter than at 2.0 meters. The reasons for this variability are not known.

System C informs the driver, in one-foot increments, of the range to the nearest obstacle detected. System D has a similar capability except that the range increments displayed are 0.1 foot if the object is within 10 feet. Evaluations of these two systems showed that the maximum error in the displayed distance was less than one foot for both systems.

All ultrasonic systems except System D detected the cardboard square at a longer range than that at which they detected the garage door. Since the cardboard square and the door both present the sensor with flat, highly reflective surfaces, the differences **in** detection range between these two obstacles possibly **occur** because the cardboard square measurements were made with the vehicle stationary while the door measurements were made with the vehicle moving. Other tests with ultrasonic sensors have shown differences in the static and dynamic fields of view. Another possible reason for these differences is that these two sets of measurements were made on different days.

Table 5 shows that these ultrasonic sensors do exhibit day to-day performance variability when detecting pedestrians; this is also expected to occur for objects other than pedestrians.

The van was expected to be a less reflective obstacle than was the flat door since the van has rounded surfaces which are not necessarily parallel to the back of the semitrailer. The testing showed that the earliest detection for three of the five systems was at a greater distance when backing toward the door than when backing toward the van. For the other two systems, this pattern was reversed. This indicates that the door was not a significantly more reflective target than the van. The observed differences in detection range between the door and the van may also be due to the day-to-day performance variability of the ultrasonic sensors.

Comparing the detection range for the laterally offset van to that for the laterally centered van, two of the ultrasonic sensors detected the offset van at a longer range, one sensor detected the centered van at a longer range, and two sensors detected both the offset and centered van at the same range. There is no obvious explanation for these differences; they are thought to be due to sensor variability.

HUMAN FACTORS EVALUATION OF REAR OBJECT DETECTION SYSTEM DISPLAYS - Due to the fundamental difference in function between the video camera system and the systems with ultrasonic sensors, the method (direct observation) used to perform the human factors evaluation of the driver interface for System A differed from the driver interface evaluation method used for Systems C through J (a human factors checklist).

The driver interface for System A was a 12.7 cm diagonal, black and white, television monitor. Two lines drawn on the face of the monitor indicated to the driver the portion of the camera field of view that is directly behind the semitrailer. Push-button controls were provided for power and day/night mode. Knob controls were provided for brightness, contrast, and volume.

The monitor was mounted extending downward from the roof of the cab at the center of the front windshield (i.e., about where the rearview mirror is located in a passenger car}. The monitor was approximately 0.75 meters from the driver's eyes and provided an adequate view of the images presented on the screen. With the volume setting properly adjusted, sounds from behind the semitrailer could also be heard by the driver.

Since televisions are very common, the driver interface for System A should be easily understood by drivers. Drivers should need little instruction on how to use the system's controls. However, due to the location of the video monitor, drivers cannot watch both the monitor and the side view mirrors at the same time. This may not be a problem, however, since viewing both the mirrors and the monitor simultaneously may not be necessary during low speed backing maneuvers.

For Systems C through J, a human factors checklist was developed and used to evaluate the driver interfaces. This procedure, which is described in greater detail in [5], employed a detailed rating form for evaluating each system in terms of the extent to which its design features might enhance or degrade driver performance.

Two persons were involved in completing the human factors checklist for each system: a human factors engineer and a test driver experienced in driving heavy vehicles. The same two individuals performed the human factors evaluation of all of the driver interfaces.

The checklist that was developed included a total of I32 questions plus descriptive information. This checklist was based upon accepted human factors guidelines and design principles for the display of warning information. Some of the questions were answered using a '1 to 5 rating scale' (with 5 being the highest possible score and 1 the lowest) while others required only "yes" or "no" answers. To score the checklist, the values from the 1 to 5 rating scale questions were used directly. For yes/no questions, each desirable answer was awarded five points while each less-than-desirable answer was given zero points. Values from groups of related questions were then averaged together and these averages used to rate the driver interfaces.

The human factors checklist questions were divided into six groups of related questions. Tables 6 through I 1 indicate the issues covered by each group of questions. Table 12 shows the numerical rating determined for each system by issue. An Overall Rating is also shown Table 12; this was calculated for each system by computing an average of the six preceding ratings. These ratings were not intended to designate a "best" and "worst" system, but rather to provide a means for the comparison of systems through a relative rating scale. This system used a scale of 0 to 100 to score the systems according to how well they met the specifications of the categories mentioned.

Three systems (Systems C, D and G) generated both auditory and visual warnings. The other two systems (Systems E and J) generated auditory warnings only. While severely hearing impaired individuals cannot obtain a Commercial Drivers License (CDL) without first obtaining a waiver, persons with up to 40 dB of hearing loss can obtain a CDL. Auditory only warnings are probably insufficient for drivers who have close to 40 dB of hearing loss. Sound human factors principles support the use of both auditory and visual warnings whenever possible; however, the importance of having both types of warnings for these systems is unclear at this time.

While the system interfaces evaluated were adequate, none of them was close to an ideal interface. The major drawback of the two systems that provided only auditory warnings has been discussed above. The three systems that provided visual warnings all suffered from a common, major problem. Since manufacturers generally gave no specific indication of where to mount the driver displays, due to space considerations and the size and shape of the displays, they were mounted on the center of the dashboard, slightly to the right of the driver's normal straight-ahead line of sight. This site was chosen because it was a central location close to the driver and provided a convenient mounting surface. Thus, the driver cannot easily look at both the warning display and the left or right side view mirrors at the same time. Since these RODS are intended to serve only as supplements, not replacements, for the side view mirrors, this problem makes these systems substantially harder to use.

TABLE 6. Issues Covered by the Overall Design Group of Questions

- Recommended location of the object detection system driver interface
- Number of warning levels
- What the system displays when no objects are detected
- Whether the driver can adjust the brightness of visual warning displays
- Whether the driver can adjust loudness of auditory warnings
- Whether the driver can adjust sensitivity of system's sensors
- Whether the driver can manually override unnecessary warnings
- How the system is turned on/enabled
- What controls the system has
- Whether the controls are within reach of the driver
- Whether the design and placement of controls prevents accidental activation by the driver
- Whether the status of variable control options are noticeable at all times
- Whether the system has a self-test mechanism
- Whether the system indicates sensor, logic, visual display or auditory warning failures

TABLE 7. Issues Covered by the Conspicuity Group of Questions

- Colors of warning, system on, system failure, and control lights
- Whether warning lights and control labels are protected from glare
- Whether warning lights and control labels can be easily seen/read during both day and night driving
- Whether the driver display is located appropriately within the driver's field of view
- Whether visual warning displays and the side view mirror can be seen at the same time
- Whether the visual warnings can be seen by the driver using peripheral vision
- Whether the higher level visual warning is brighter than all other visual displays
- Whether lower level visual warnings are readily distinguishable from higher level visual warnings
- Whether visual warning indicatesthe distance to an obstacle
- Whether the characteristics of auditory warnings are appropriate
- Whether lower level auditory warnings are readily distinguishable from higher level auditory warning
- Whether auditory warnings indicate the distance to an obstacle
- Whether all control functions on the display are clearly labeled
- Whether illumination of controls and labels is provided for night driving
- Whether all status displays can be easily read by the driver
- Whether status displays are readily distinguishable from warning displays'

TABLE 8. Issues Covered by the Annoyance Factors Group of Questions

- Whether the visual warnings are annoying, distracting or startling to the driver
- Whether the visual warnings produce glare under night or in conditions of low ambient light
- Whether the auditory warnings are annoying, distracting or startling to the driver
- Whether the auditory warnings are excessively loud or piercing
- Whether the status displays are annoying, distracting or startling to the driver

TABLE 9. Issues Covered by the Documentation Group of Questions

- Whether the documentation is concise and easy to understand
- Whether the documentation completely explains the use of all controls
- Whether the documentation explains/identifies conditions under which system performance may be degraded
- Whether the documentation explains/identifies maintenance requirements
- Whether the documentation explains that the system is a driving aid or supplement, not a replacement for the side view mirrors

TABLE 10. Issues Covered by the Comprehension Group of Questions

- Whether the functions and consequences of control manipulation are easily understood
- Whether control motion expectancies have been considered in the design of controls
- Whether the system provides an obvious indication of when it is operational and when it is not
- Whether the meanings of warnings are obvious to novice users
- Whether the meaning of warnings and status displays can be understood without referring to the documentation
- Whether sudden changes in distance to a detected obstacle are clearly communicated to the driver

TABLE 11. Issues Covered by the Personal Judgement Group of Questions

- Whether the documentation is adequate/sufficient
- whether the controls and status displays provided are adequate/sufficient
- Whether the high and low level warnings provided are adequate/sufficient
- Whether the high and low level warnings are provided in a timely manner
- Whether the system provides the driver with a greater probability of perceiving adjacent obstacles

Note – This group of questions ranks the subjective impressions of the interface by a human factors specialist and an experienced test driver. While all of the checklist rankings are, to some extent, based on subjective assessments, attempts were made to make the rankings as objective as possible.

TABLE 12. Ratings of the Ultrasonic Rear Object Detection System Interfaces Based on the Human Factors Checklist Assessment

System	Overall Design	Conspicuity	Annoyance Factors	Documentation	Comprehension	Personal Judgement	Overall Score
C	20.6	**45.8**	52.2	34.2	68.4	75.4	**49.4**
D	**48.2**	47.6	57.4	**51.4**	83.4	55.4	57.2
E	16.6	33	85	54.2	34	55.4	46.6
G	15.6	29.4	72.2	60.0	33.4	58.4	44.8
J	16.6	38.8	85	65.8	34	49.2	48.4

FOCUS GROUP EVALUATION OF A REAR OBJECT DETECTION SYSTEM - To gain a better understanding of professional truck drivers' reactions to near obstacle warning systems, two focus group sessions were conducted with drivers from a selected fleet who operate'vehicles equipped with these devices. The two groups consisted of three drivers plus a manager in one group and three drivers in the other group. Due to the difficulties of arranging a focus group, the focus group evaluation was only performed for one of the RODS (System D) and one of the SODS (System U). However, many of the results obtained should carry over to other RODS and SODS.

The particular fleet chosen was selected because it used both RODS and SODS on its vehicles and because its drivers returned to the terminal each night allowing the opportunity for group discussions. The fleet was part of a multinational manufacturer and distributor of medical supplies. The facility that participated is based in the northeast United States, with warehouses and truck routes over a three state region. The company makes daily deliveries of supplies and equipment to hospitals and clinics, many of which are in congested urban areas. The vehicles driven by the focus group drivers were tractors with 8.2 and 13.7 meter semitrailers.

While a driver normally has the same tractor on a regular basis, they may get a different semitrailer every day because of the delivery load for the day (e.g. heavy or tight) and the availability of equipment. He or she typically drives from 150 to 300 miles a day over familiar roads.

The management of this fleet has taken a keen interest in truck safety matters. For example, the cabs of most fleet vehicles were equipped with an on-board computer which monitors vehicle speed. If a tractor-semitrailer equipped with this computer exceeded 55 mph, the computer would register the speed and produce an audible warning for the driver. This meant that this fleet's vehicles were usually operated at or below the legal speed limit. As a result, in most high speed highway situations, this fleet's trucks were driven in the rightmost lane.

The majority of the tractor cabs in this fleet were equipped with a 203 millimeter diameter shallow convex mirror mounted on the right front fender. This, in the opinion of the focus group subjects, provides the driver with an excellent view down the right side of the tractor and semitrailer, especially when the mirror is properly aligned.

In early 1993 the company began a pilot test of Systems D and U. Ten tractors and ten semitrailers were equipped with these systems. For System D (the RODS), two sensors were placed on the rear of each semitrailer facing backwards and mounted in line with the rear under-ride guards. The system interfaces were mounted on the instrument panel, essentially in front of the passenger seat but angled toward the driver. It should be noted that because of the logistics of this fleet, a tractor with a system interface was not always hooked up to a sensor equipped trailer. As a result, the RODS were not operational at all times.

The drivers were introduced to the obstacle detection systems in a common briefing. They were then asked to use the systems for the next six months. Initially, at least for a period of three weeks, they were asked weekly to complete an in-house evaluation form on the obstacle detection systems. New drivers hired after this introduction period received no special training or orientation regarding the obstacle detection systems.

The drivers interviewed reported little difficulty learning to use the obstacle detection systems. They quickly discovered when and under what conditions the auditory alarm would sound or a visual warning be given. They learned to turn down the alarm to be appropriate to the noise levels of the cab, and to be tolerant of the frequent instances of inappropriate warnings.

The focus group drivers described the rear object detection warning system as very useful. They valued its capabilities. This may have been because, as part of their work, the drivers in this fleet frequently have to negotiate long and narrow driveways and ramps while backing. Also, they often find that the loading dock to which they are trying to align is under cover and in shadow or in darkness while the cab/driver is in direct sunlight. This makes it hard to judge distances behind the semitrailer and to anticipate the point at which they will make contact with the loading dock. The digital distance readout from System D was deemed valuable in this situation.

One driver complaint was that the rear ultrasonic sensors were not mounted on the extreme rear edge of the semitrailer. This forced drivers to correct the value displayed on the digital readout for the portion of the vehicle behind the sensors This was especially a problem when backing up after lowering a loading ramp.

More than one driver reported that the system alerted them to pedestrians or other vehicles which were in the way. This includes being warned of other vehicles that might move carelessly or aggressively to usurp the driver's place in line or assigned dock. In one unusual case, the system allowed a driver to detect someone illegally trying to enter the rear of the semitrailer while the vehicle was stationary.

Focus group participants discussed several shortcomings of System D. The one manager present in the focus group mentioned that the system is not easy to install. The drivers were especially critical of the poor reliability of the system's components. Without providing specifics, more than one driver reported sensor failures, perhaps due to moisture. Also troubling was the way the distance readout would fluctuate when the vehicle was stationary. A computer failure was also mentioned.

A common problem was the sensor cabling between the tractor and semitrailer. Both the nature of the contacts and the wiring used caused the connection to become tom or severed while turning or backing.

All things considered, the drivers interviewed were fairly positive about the potential of RODS such as System D. As one driver stated, "Anything that can help to improve safety is welcomed." This endorsement was especially impressive in light of the reliability problems that drivers reported having with the system.

MIRROR SYSTEMS AND BACKING - Since RODS are intended as a supplement to existing mirrors, an understanding of the advantages and drawbacks of using mirror systems while backing commercial vehicles is necessary in order to judge the usefulness of these systems. There are two types of mirror systems currently in use; motorized and nonmotorized plane side view mirrors. Nonmotorized plane side view mirrors are the traditional technology used for backing articulated vehicles. The principal advantages of plane side view mirrors are:

1. They provide drivers with a clear view of any obstructions and hazards that may be within the mirror's field of view.
2. Minimal driver training is required to learn to use this type of mirror. The meaning of images in the mirror is intuitively obvious to drivers.
3. A driver can easily determine whether or not a mirror is functional by looking at it (although it is more difficult to determine whether a mirror is properly aligned).
4. They are relatively inexpensive.

The principal limitations of plane side view mirrors are:

I. They have a relatively restricted field of view. This is particularly an issue for right side view mirrors because there is a greater distance from the driver's eyes to the right mirror than to the left mirror. As a result, movements of the driver's head cause less change in the mirror angle of incidence for the right mirror than for the left mirror, allowing less area to be seen. This limitation is partially addressable through the use of motorized right side view mirrors which can be adjusted from the operators seat. Convex side view mirrors are difficult to use for backing. Depth distortion, due to mirror minification, makes it difficult to determine how close obstacles actually are to the rear of the trailer.
2. No matter how the side view mirrors are aligned, there is an area immediately behind the rear of the vehicle that cannot be placed in either mirror's field of view, due to blockage of the line of sight by the vehicle. As a result, when backing a vehicle by using only the plane side view mirrors, the vehicle is always entering a blind spot.

In summary, while motorized and non-motorized plane side view mirrors have substantial advantages, they also have limitations that are inherent to this technology.

CONCLUSIONS ABOUT REAR OBJECT DETECTION SYSTEMS - Compared to vehicles equipped with only motorized or nonmotorized plane side view mirrors, both rear mounted video cameras and ultrasonic-based RODS may have the potential to improve safety and reduce accidents while backing.

A rear mounted video camera (with microphone) greatly improves a driver's ability to see and hear what is behind the vehicle. The field of view of the camera evaluated in this program is adequate for most backing situations. The information acquired by the camera is transmitted to the driver in an easily understood form.

Since this technology primarily increases the area a driver can see, it is very easy for the driver to determine whether or not the video camera is working. This increases driver confidence in the obstacle detection technology.

The principle limitations associated with rear mounted video camera technology are:

1. **Hardware reliability --** The video camera system evaluated during this project was reasonably rugged; no video camera failures were experienced during this limited time/duration program. Longer time period durability tests would be necessary to more adequately assess the in-service durability of this type of equipment, although no problems were encountered during the study. Based on past difficulties associated with implementing reliable antilock braking systems of heavy trucks, some additional "ruggedization" of the video cameras may be necessary. The more immediate hardware reliability concern is the electrical connection between the semitrailer and the tractor. The focus group drivers identified this as a major problem for System D; it is also expected to be a problem for rear mounted video camera technology. The general problem of passing electrical signals between a tractor and a semitrailer is being addressed in other NHTSA sponsored research.
2. **Lighting behind the vehicle --** The video camera must have adequate light to produce discemable images. If the area behind the vehicle is too dark, the camera may be of little help to the driver (although the microphone may still be helpful in this situation).
3. As is the case with mirrors, the video camera does not warn the driver of obstacles or hazards. It only shows the driver an image of the area behind the vehicle (and allows

the driver to hear sounds from this area); it is the responsibility of the driver to determine whether or not any obstacles or hazards are present.

RODS based on ultrasonic sensors also improve a driver's ability to detect the presence of obstacles behind a vehicle. The field of view of the ultrasonic sensors evaluated in this project is generally adequate for most backing situations. The information acquired by the sensors is transmitted to the driver in an easily understood form.

The principle limitations associated with ultrasonic-based RODS are:

1. **Sensor reliability** -- Substantial variability in the obstacle detection performance of an ultrasonic sensor was noted during the current research. This agrees with the observation of the focus group drivers that the distance readout would fluctuate when the vehicle was stationary relative to an obstacle. One reason for variability in obstacle detection performance by ultrasonic sensors appears to be changes in ambient conditions. During the current research, changes in ultrasonic sensor performance were noted due to changes in temperature, humidity, wind speed, wind direction, and falling rain. Discussions with other people who have used these sensors indicate that fog, falling snow, and ice on the sensors also affect sensor performance.
2. **Hardware reliability** -- Several sensor failures occurred during this research program, even though the program involved only a limited amount of driving and was performed over a fairly short time period. Several of the ultrasonic sensors studied do not appear to be ready for regular use by truck fleets; ruggedization work will be required to make them ready for regular service. As was the case with the video system, the electrical connection between the semitrailer and the tractor will likely be a source of problems. The focus group drivers identified this as a continuing problem for System D; it is also expected to be a problem for the other RODS.
3. **Driver confidence** -- There is no easy way for drivers to be sure that the ultrasonic RODS are actually working. When combined with the reliability problems that have been noted, drivers are reluctant to trust these systems enough to really gain benefits from them. Even if the reliability problems are resolved in the future, a substantial amount of driver training will be required to develop driver confidence in such systems.

In conclusion, both rear mounted video cameras and RODS based on ultrasonic sensors may have the potential to improve safety and reduce accidents while backing. However, until some of the limitations noted above are resolved, obtaining safety benefits may be hindered.

EVALUATION OF SIDE OBJECT DETECTION SYSTEMS

For the SODS, five main types of performance evaluations were performed. The first type focused on the sensor hardware used by each system to detect obstacles along the right side of the vehicle. The second was an evaluation of "over the road" ability of the systems to correctly identify adjacent vehicles. The third assessed the appropriateness of the interface used to convey warning information to the driver. The fourth type of evaluation was a focus group with drivers who had used a system in their fleet. As was the case for the RODS, the focus group was conducted for only one SODS. The final type of evaluation consisted of an on-road human performance experiment involving eight subjects who drove a tractor-semitrailer equipped with two right SODS, Systems R and U.

Four commercially available or prototype SODS designed to aid a truck driver by detecting objects along the right side of the vehicle during lane changing and merging were purchased and tested on a tractor-semitrailer. These four systems were, at the time of the study, all of the known SODS designed for use on combination-unit trucks. Table 13 shows the SODS evaluated and a key which will be used to identify the systems for the remainder of the discussion.

It is important to note that System N and System R are prototypes and not commercially available systems. The performance of their sensors and the design of their driver interfaces are not necessarily indicative of the performance or interfaces that might be offered by these companies on future, commercially available SODS.

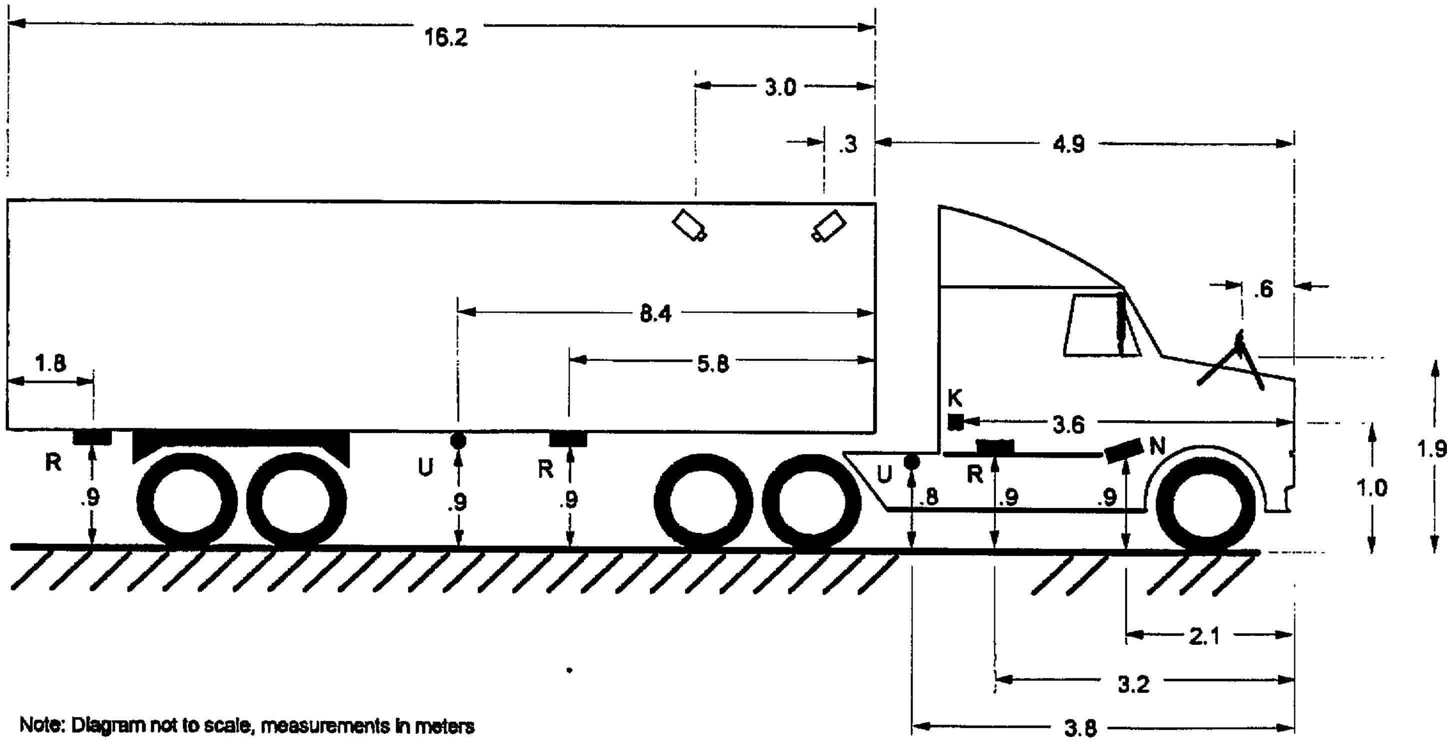
Table 14 lists the object detection technologies employed by each SODS, the number of sensors, and the locations at which the sensors were mounted during this testing. The SODS studied used two different sensor technologies: ultrasonic and radar. The two ultrasonic systems differed primarily in their driver interfaces and in number and location of their ultrasonic sensors; the sensors themselves are quite similar. Of the two radar systems, one determined when to warn the driver by measuring the distance to an obstacle. The other radar system generated warnings based on the relative velocity of an obstacle within the sensor field of view. Figure 10 shows where the sensors for each SODS tested were mounted on the side of the tractor and semitrailer for this testing. The placement of these sensors was in general accordance with manufacturer suggestions, when given, to provide adequate coverage of areas of interest.

TABLE 13. Side Object Detection Systems Evaluated

System	Key
Arrnatron Echovision	K
Prototype, relative velocity radar	N
Prototype, position radar	R
Dynatech Scan II	U

TABLE 14. Sensor Technologies and Locations for the Lane Change/Merge Systems

System	Sensor Technology	Commercially Available?	Number of Sensors	Location of Sensors During Testing
K	Ultrasonic	Yes	1 Transmitter/ Receiver Pair	On tractor cab, 3.6 m aft of front of cab, 1.0 m above ground
N	Relative Velocity/ Doppler Radar	No, Prototype	2 Transmitter/ Receiver Pairs	One pair measures ground speed. The second pair is on the side of the tractor cab, 2.1 m aft of the front of the cab, 0.8 m above ground, aimed back along trailer.
R	Position Radar	No, Prototype	3 Transmitter/ Receiver Pairs	One pair on tractor cab, 3.2 m aft of front of cab, 0.9 m above ground. Other two pairs are on trailer, one 5.8 m from front of trailer and the other 1.8 m from rear of trailer. Both of these are 0.9 m above ground.
U	Ultrasonic	Yes	2 Transmitter/ Receiver Pairs	One pair on tractor cab, 3.8 m aft of front of cab, 0.8 m above ground. Second pair longitudinally centered on trailer, 0.9 m above ground.



Note: Diagram not to scale, measurements in meters

Figure 10. Location of Side Object Detection System Sensors on Side of Tractor and Semitrailer

SENSOR EVALUATION OF SIDE OBJECT DETECTION SYSTEMS - The SODS sensors were evaluated by determining the field of view for each sensor. The fields of view were determined both quasi-statically and dynamically at a variety of relative speeds between the tractor-semitrailer equipped with the SODS and a test vehicle. Two test vehicles were used for both types of tests. One was a full-size van and the other was a small passenger car. These two vehicles were chosen for their contrasting body styles in that the van presents fairly large flat areas while the car is lower with smaller, rounded areas. However, essentially identical results were obtained for both test vehicles; therefore only the small passenger car results are reported in this paper.

Quasi-static tests were conducted with the tractor-semitrailer stationary and the test vehicle driven along the right side of the tractor-semitrailer as slowly as possible. Multiple passes were made with the test vehicle at varying lateral distances from the tractor-semitrailer. Measurements were made of the test vehicles' location relative to a sensor at the times when the driver display first indicated it had sensed an obstacle and when it stopped indicating the presence of an obstacle. The fields of view measured in this way for the passenger car are shown in Figures 11 and 12.

Figures 11 and I2 each have a schematic depiction of the right half of a tractor-semitrailer. The sparse diagonal hatching in these figures shows the area over which a driver can visually detect an obstacle with a height of 1.18 meters using the right side view mirror system (consisting of a plane mirror and a 373 millimeter radius of curvature shallow convex mirror.) The dense diagonal hatching shows the area which is visible to the driver by direct observation through the windows of the tractor cab. (The height of 1.18 meters corresponds to the lowest roof height in NHTSA's database, Reference [6], of light vehicle inertial parameters.) The area shown outside the vehicle that has no pattern represents the area that is not visible either directly or indirectly, i.e., the "blind spot." The figures use shaded and crossed line patterns to show the sensor fields of view, or detection zone, of each SODS's sensors. Figure II shows the detection zones as measured for systems K and U. Figure 12 shows the detection zones as measured for systems N and R. These fields of view were determined by locating the midpoint of the slowly moving car when the vehicle was first detected by each sensor and when each sensor stopped detecting the vehicle.

As these figures show, for three of the four systems, there is considerable overlap between the areas covered by the existing right side rear view mirror system and the SODS. Only System K covers just the "blind spot" and nothing else.

The relatively small field of view of System K's sensor occurs, at least in part, because the sensitivity of this sensor may be varied by the user via an internal control. For this testing the sensitivity was set quite low so as to minimize the number of inappropriate alarms generated by the system. Increasing the sensitivity increases the range of this sensor to approximately that of System U's sensor.

Dynamic detection fields were also measured for each SODS. A typical set of dynamic detection fields, the ones for System R measured using the passenger car as the test vehicle, are shown in Figure 13. This data was obtained by having the test vehicle pass the tractor-semitrailer in the lane to the right of the tractor-semitrailer at a number of relative speeds between the two vehicles, (8, 16, and 32 km/h). The tests were conducted with the tractor-semitrailer stationary and with it moving at 32 km/h. The test vehicle moved at the appropriate speed to obtain the desired relative speeds. Measurements were made of the test vehicle's longitudinal position, based upon its center point, relative to the sensor at the moment the system warning light first indicated the presence of the test vehicle (the downward pointing end or bottom of each bar on the graph) and when it stopped indicating the presence of the vehicle (the upward pointing end of each bar). Three measurements were made for each condition and are shown by the three bars.

Comparison of Figure 13 with Figure 12 shows that there are differences between the quasi-static and dynamic fields of view of the SODS. In general, as relative speeds between the vehicles increase, the coverage zones appear to move longitudinally forward, with the effect being most apparent at the highest relative speed tested (32 kph). This is indicative of a short sensor time delay. However, the variability in the sensors makes it impossible to accurately determine the length of this delay.

In addition to the quasi-static and dynamic field of view measurements, observations were made of the sensors/systems measurement capabilities under a variety of operating conditions. Due to the difficulty of simulating a variety of weather conditions or ensuring that actual weather conditions were the same for tests of the different sensors/systems, these observations were somewhat subjective. To some degree, all of the systems produced inappropriate driver warnings, or alarms, in rain or wet road conditions. The ultrasonic systems also showed some sensitivity to dirt on the sensors. All of the systems except System N would, at least sometimes, sensed fixed objects along the side of the road (e.g., guardrail, bridges, road signs, etc.).

A more quantitative evaluation of the number of inappropriate alarms and undetected vehicles for Systems R and U was made during "over the road" driving. The sensor-equipped tractor-semitrailer was driven over a set route, which took approximately 90 minutes to complete. This route was repeated multiple times for both SODS, included both city streets and urban freeways, and was driven at approximately the same time of day for each test run. The SODS were evaluated using the same route to ensure that, as much as possible, objects around the test vehicle (fixed objects along the road, other traffic, etc.) were the same for each system. The route was run seven times for System IJ and eight times for System R.

The number of inappropriate alarms and undetected vehicles for both SODS was determined by counting the number and type of vehicles that passed (or were passed by) on the right side of the tractor-semitrailer and noting the warning system's response. If the system alarm was activated by a sign or guardrail or when no vehicle was nearby, it was classified as "inappropriate." These data were obtained from video cameras which recorded any traffic or objects in the lane to the right of the tractor-semitrailer as well as the warning system display status. The results of this evaluation are shown in Table 15. It

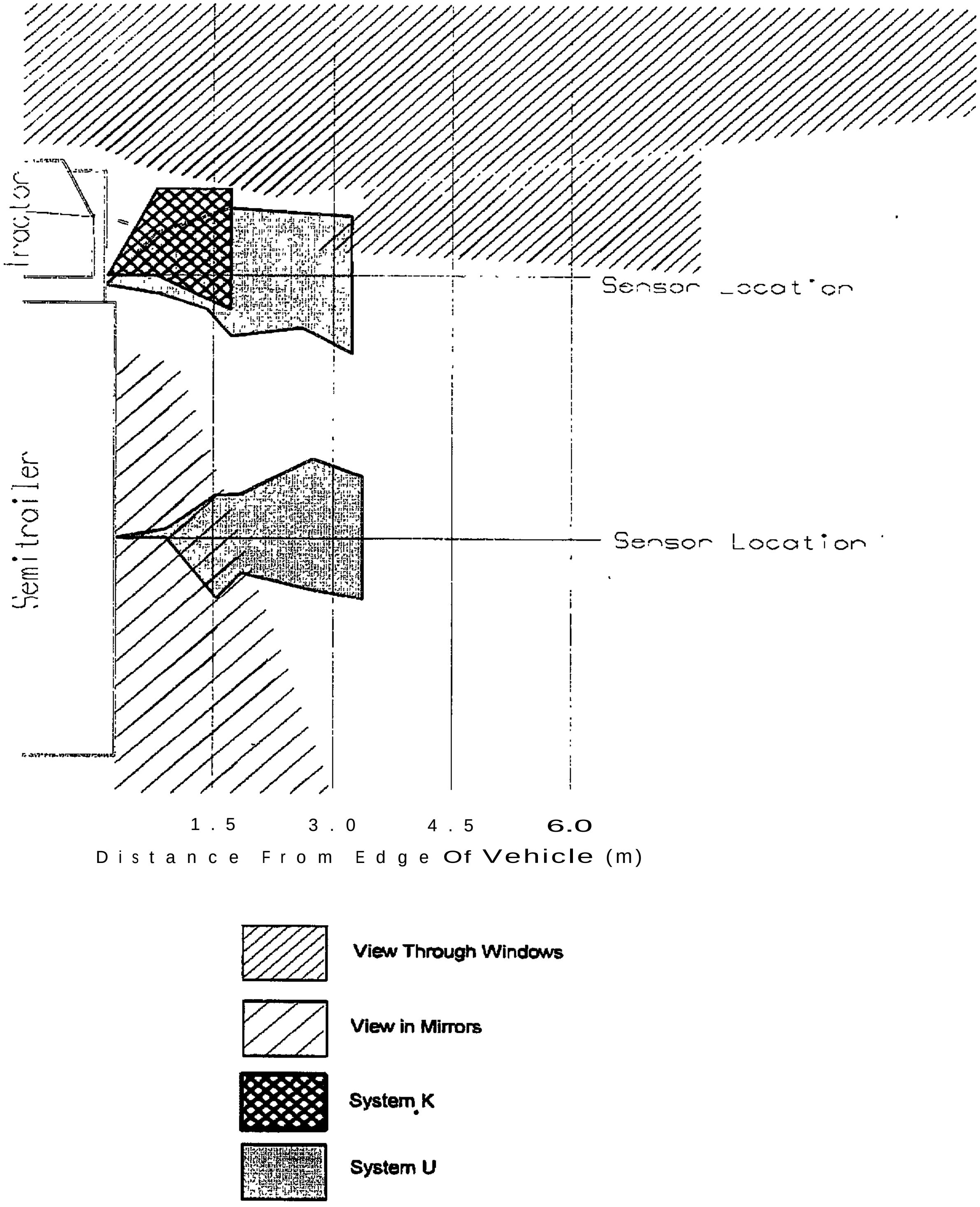


Figure 11. Top view, quasi-static field of view of Systems K and U measured using a small passenger car

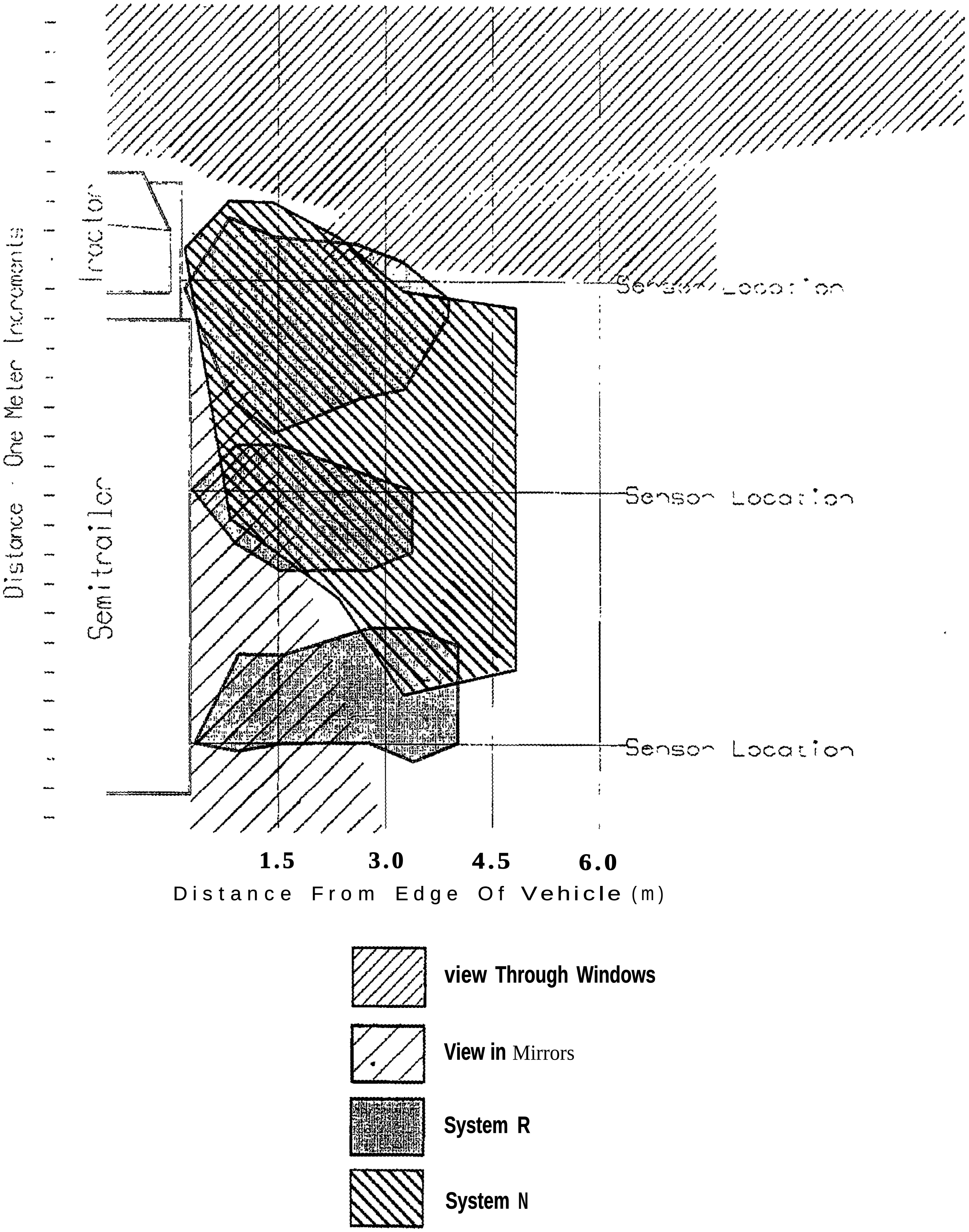


Figure 12. Top view, quasi-static field of view of Systems N and R measured using a small passenger car

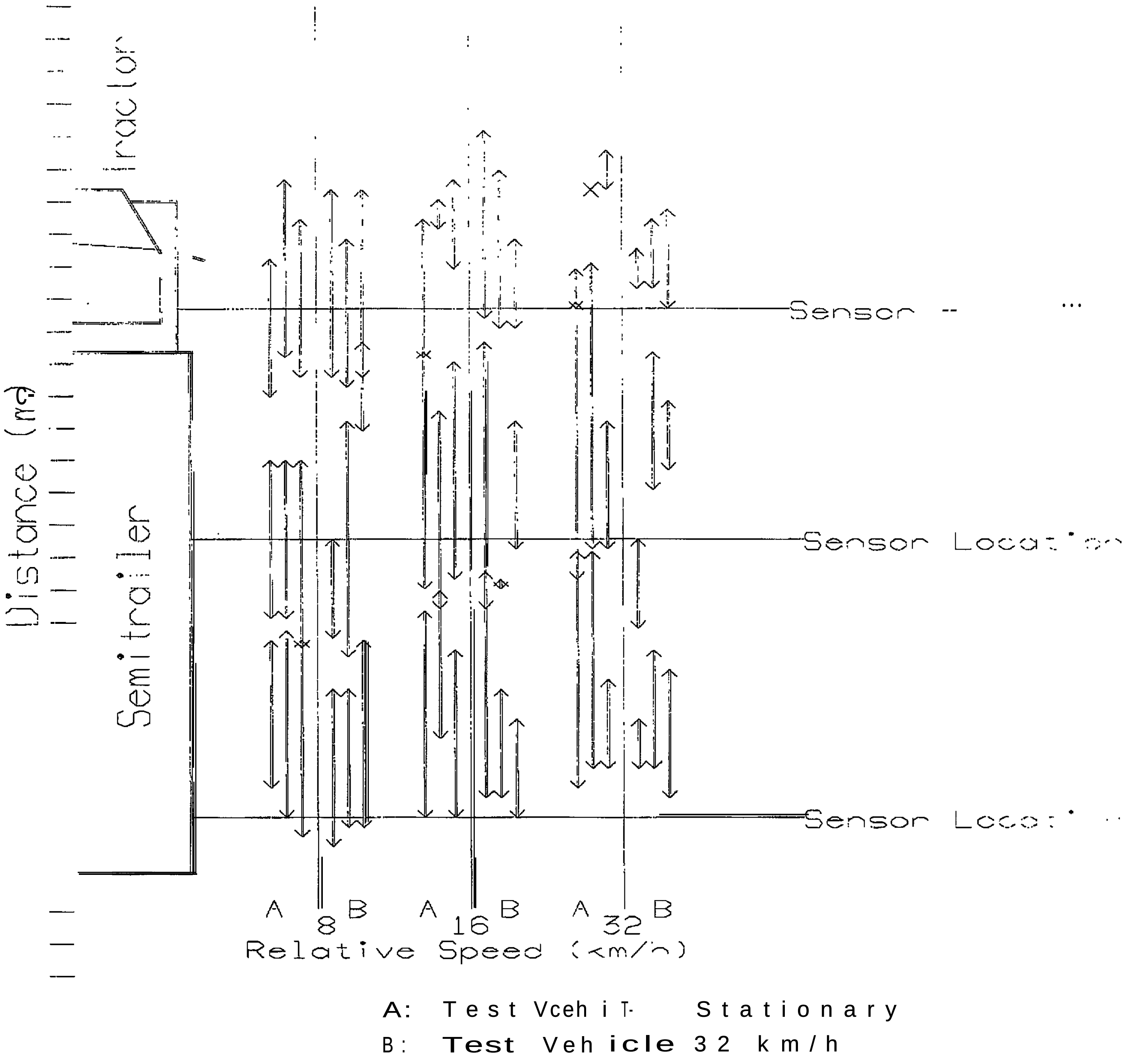


Figure 13. Dynamic measurements of the detection zones of System R, measured using a sm
lines with arrows at either end represent points where the confederate vehicle was detected by

should be noted that for these evaluations, there was no rain and the road was dry.

Table 15 shows, for each SODS, the proportion of vehicles which passed or were passed by the test vehicle that -were not detected by the system, the ratio of inappropriate to appropriate alarms, and the relative frequency of inappropriate activations, i.e., the time between system activations when there was no vehicle in the lane to the right of the test vehicle.

TABLE 15. SODS Performance Metrics

System	% of Vehicles Undetected	Ratio of Inappropriate to Appropriate Alarms	Average Minutes Between Inappropriate Alarms
R	**3.2**	**0.22:**1	15
U	**6.3**	**0.03:**1	**126**

As the table shows, no system was without fault in terms of these metrics of performance. Overall, System R missed fewer vehicles. However, System R also had a somewhat higher frequency of inappropriate alarms than did the other system -- a possible indication that its sensor sensitivity was too high. System U had fewer inappropriate alarms, but more missed vehicles -- a possible indication that its sensors were not sensitive enough. These findings highlight a dilemma which designers face relative to the need to have sufficient sensor sensitivity such as not to miss too many critical objects, while at the same time not wanting the sensitivity level to be so high as to cause an inordinate number of inappropriate activations.

Analysis of the video tapes of these tests did not yield any systematic explanation for the undetected vehicles such as distance from the test vehicle, type or body style of target vehicle. The inappropriate warnings for System R (which had fewer) could generally be traced to solid objects along the road such as guardrail and barriers, signs, and light posts.

HUMAN FACTORS EVALUATION OF SIDE OBJECT DETECTION SYSTEM DISPLAYS - As was done for the RODS, a human factors checklist approach was used to evaluate the display and control designs of Systems K, N, R, and U. The same checklist which was used to evaluate RODS displays was also used to rate each of the SODS driver interfaces.

Table 16 summarizes the ratings from the human factors checklist. Note that two systems, Systems N and R, were prototypes and not commercially available. As a result, their system interfaces may not have been as well designed as they would be if they were fully developed commercial products.

Three systems (Systems K, R, and U) generated both auditory and visual warnings. The other system (System N) produced visual warnings only. Although human factors guidelines suggest that redundancy in warning presentation is beneficial, this checklist did not penalize systems without an auditory warning. Providing both types of warnings should increase the chance that the driver will accurately perceive the information being conveyed through the warning presentation.

Overall, none of the system interfaces were especially well designed from a human factors perspective. Many common deficiencies were noted. For example, most of the visual displays were too dim to be seen in high levels of ambient illumination or were too small to be easily seen by the driver while performing the driving task. As a result, drivers needed to make concentrated looks at the displays in order to perceive the warning. These attentional demands can distract the driver from the roadway and result in lower system acceptability. Fortunately, these types of deficiencies can be remedied with proper attention to the influence of display design on driver performance and acceptance.

TABLE 16. Ratings of the SODS Interfaces Based on the Human Factors Checklist Assessment

System	**Overall** Design	**Conspicuity**	**Annoyance Factors**	**Documentation**	**Comprehension**	**Personal Judgement**	**Overall Score**
K	**46.2**	**28.8**	**37.4**	**71.4**	**55.0**	**46.2**	**47.5**
N	**28.4**	**23.6**	**20.0**	**5.6**	**43.4**	**40.0**	**26.8**
R	**39.4**	**25.4**	**34.0**	**31.4**	**43.4**	**43.0**	**36.1**
U	**48.2**	**47.6**	**57.4**	**51.4**	**83.4**	**55.4**	**57.2**

FOCUS GROUP EVALUATION OF A SIDE OBJECT DETECTION SYSTEM - As was previously mentioned, focus group sessions were conducted to gain information about the subjective reactions of professional truck drivers experienced in using near object detection systems. The systems addressed in these sessions included both a RODS (System D) and a SODS (System U). Results from the focus group sessions that particularly relate to the SODS follow.

The management of this fleet had taken a keen interest in truck safety matters. For example, the cabs of most of the fleet vehicles were equipped with an on-board computer which monitors vehicle speed. If a tractor-semitrailer equipped with this computer exceeded 55 mph, the computer would register the speed and produce an audible warning for the driver. This meant that the fleet's vehicles were usually operated at or below the legal speed limit. As a result, in most high speed highway situations, the fleet's trucks were driven in the rightmost lane.

The majority of the tractor cabs in this fleet were equipped with a 20.3 millimeter diameter shallow convex mirror mounted on the right front fender. This, in the opinion of the focus group subjects, provided the driver with an excellent view down the right side of the tractor and semitrailer, especially when the mirror is properly aligned.

In early 1993 the company embarked on a pilot test of Systems D (an ultrasonic rear object detection system) and U (an ultrasonic side object detection system). Ten tractors and ten semitrailers were equipped with these systems. For System U, one sensor was mounted on the tractor, specifically on the right side of the cab above the fuel tank. (Note that this is a different configuration of System U than is used elsewhere in this report. For all of this research, except for these focus groups, System U had two ultrasonic sensors. Of these, one was located on the tractor in approximately the same location used by this fleet. However, this fleet did not have the ultrasonic sensor mounted on the semitrailer that was present in the rest of this research.)

The drivers reported little difficulty learning to use the SODS. They quickly discovered when and under what conditions the auditory alarm would sound or a visual warning be given. They learned to turn down the alarm to accommodate the noise levels in the cab and to be tolerant of the frequent instances of inappropriate warnings. Inappropriate warnings were caused by passing trees, telephone poles, construction zones, and bridge abutments. Inappropriate warnings of this type were common because, being restricted to speeds of 55 mph, the vehicles were being driven most often in the right lane. Drivers also learned to mentally adjust the distance value displayed by the system to compensate for the fact that the tractor sensors were not located on the rightmost edge of the tractor.

Drivers reported that they made regular use of System U, but not as a primary way of detecting hazards or potentially unsafe conditions. The systems were treated as a supplement to the driver's well-ingrained habit of scanning the road and mirrors. Most drivers reported they did not attend to the display on a regular basis, but also would not ignore any auditory warning.

Drivers would anticipate the auditory alarm when they saw a vehicle coming up on the right. More importantly, in spite of the frequent inappropriate warnings experienced, they would respond to an auditory alarm by immediately checking the right side mirrors. None would ignore an auditory warning.

SODS have been marketed as useful tools for alerting drivers to adjacent traffic while changing lanes or merging. However, the drivers in this fleet did not see its value under these circumstances. First, as noted, most of the time these drivers were already in the far right lane. Thus, lane changes were not very frequent. On the other hand, with other traffic merging, they reported that either the angle of the traffic coming from the right or its speed rendered the side mounted sensors ineffective. In these instances, the drivers tended to rely on their right side view mirrors or looking out the right side window for clues to potential hazards.

The drivers did find the SODS useful in a variety of circumstances. For example, when they were attempting to merge in congested settings, such as at toll booths or entering tunnels, the right side detectors gave them additional guidance regarding the location of other vehicles jockeying for position. They also found it helpful in negotiating very narrow rights of way, as in construction zones or in urban settings where other vehicles are double parked. Thus, the driver could determine just how close he was to the point of scraping against something. Similarly, the drivers felt that the right side scanning capability allowed them to make cuts to the right or tight right-hand turns around obstacles. In all these situations, the tractor-semitrailer would be moving fairly slowly, with a lot of attention being directed toward the traffic or road ahead.

When stopped at an intersection, drivers did report being warned by the SODS when a pedestrian walked into their mirror's blind spot or, more frequently, when a small or low vehicle crept into this zone, perhaps in anticipation of a change of light and with plans to pull ahead and in front of the truck. In both these situations, the driver might be less alert than while moving. The auditory alarm was reported to be particularly helpful in these situations.

Several limitations of the SODS have already been alluded to (e.g., the frequent inappropriate warnings). The focus group subjects mentioned other limitations as well. The manager mentioned that the system is not easy to install. The drivers were very critical about the poor reliability of the system's components, particularly the lines between the tractor and trailer which connected the driver display and main computer to the sensors. Without providing specifics, more than one driver reported that the sensors would fail, they thought perhaps due to moisture as caused by rain or other source. A computer failure was also mentioned. The drivers were annoyed by the way the distance display would fluctuate, even when their vehicle was stationary relative to an object.

Drivers also criticized the location of the system's display. Placed as it was (on top of the dashboard, essentially in front of the passenger seat but angled toward the driver), the display was frequently difficult to read due to glare combined with the small size and relative dimness of the LEDs. These and other qualities of the visual display required that the driver take his eyes off the road ahead to view the display. This led to a behavior in which the drivers would attend to the visual display only after an auditory alarm occurred. The drivers expressed a preference for

. relocating the system's display to be more directly in front of the driver.

Finally, the drivers were unhappy that the SODS became disengaged when they had the vehicle in reverse gear and were backing up. They felt that, as often as not, it would have been very useful to be able to detect walls and other obstacles on their right side while trying to back or dock in tight quarters.

All things considered, the drivers interviewed were fairly positive about the potential of SODS, like System U, although they were clearly more impressed with the capabilities of the backup warning system, As one of them put it, "Anything that can help to improve safety is welcomed."

One fundamental limitation of the drivers' evaluations is that they did not have a great need for the capabilities provided by a SODS. The drivers reported that, since the right fender-mounted mirror allowed the drivers to see into normal mirror system blind spot areas, they had a pretty good view of the right side of the rig. Also, because of the speed limiter, the drivers tended to stay in the right lane and make few lane changes.

The following points summarize the major points made in the comments of the drivers who participated in the two focus group sessions:

1 For this particular fleet's application, near object detection systems are a useful tool in backing situations, for detecting objects on the right side of their vehicle when stationary, and for merging in congested traffic settings.
2. The SODS was viewed as a supplement to the right side mirrors. Drivers keyed on the auditory alarm and subsequently sought visual confirmation of the object in the mirrors. Most drivers reported that they did not regularly attend to the visual display.
3. Drivers were able to learn to use the systems quickly and without much instruction.
4. There are several problems with the systems, including hardware reliability, false warnings, display legibility, display location, and sensor location. Interestingly, the drivers were not overly bothered by the inappropriate warnings because of the value they placed on information about near object location.
5. Overall, the drivers were receptive to the concept of using electronic systems to improve object detection and, hence, increase the safety of operations.

CONCLUSIONS ABOUT SIDE OBJECT DETECTION SYSTEMS - SODS may provide benefits to drivers by increasing their awareness of vehicles in the lane to the right. Particularly on congested roadways where unexpected events may require quick decisions on whether or not it is safe to change lanes, devices which increase the drivers awareness of the traffic around him/her should aid in making those decisions. However, considering the noticeable incidence of undetected, or missed, vehicles in this testing, **it** appears that improvements to sensor performance are necessary in order to receive significant benefit from these systems,

Hardware evaluations of SODS have shown that while these types of systems could be beneficial, there are significant problems with current systems. The sensors for the systems tested have rather limited fields of view, which may lower their usefulness in rapidly changing traffic. To increase the fields of view, additional sensors may be necessary on the semitrailer.

All of the systems evaluated showed some variability in the day-to-day operational characteristics. The systems also gave a significant numbers of inappropriate alarms or undetected vehicles in on-the-road use. These types of limitations make drivers hesitant to rely on the systems.

Most of the sensors tested have had reliability problems as a result of the vehicle environment, indicating that more ruggedization of the sensors will be necessary. Additionally, since the current evaluations have been conducted in relatively good weather conditions, data are not available as to their performance in other weather conditions. Discussions with users of such systems indicate that weather, including wind, may be a problem, particularly for systems with ultrasonic sensors.

The driver displays also require refinements to make them easier for the drivers to see and interpret. Many of the current displays are too dim and/or small to be seen without visually concentrating on the display, thus requiring drivers to focus their eyes away from the roadway. Also, the location of the display should be chosen to minimize the time the driver is distracted from the road to check the warning system.

Discussions with fleet drivers experienced with one of the systems showed the drivers to be fairly positive about the systems. While there were problems discussed, such as reliability, inappropriate warnings, display legibility, display location, and sensor location, the drivers were receptive to the concept and felt that the system may contribute to improving safety.

In conclusion, while SODS show potential for improving the safety of performing lane changes and merging maneuvers, a number of limitations exist with the current systems. Many of these limitations can be remedied with proper attention to the needs of the driver and improved hardware system design.

SUMMARY AND CONCLUSIONS

In general, the results of these tests and evaluations tend to indicate that near object detection technology is still in the early stages of its development. Commercial truck drivers appreciate the value of RODS and SODS but improvements in the technology are needed before drivers can realize their full potential for preventing crashes. Improvements should focus on improving system reliability and the human factors aspects of the control and display interface.

The overriding fact that has come to light as a result of the test work completed to date is that the devices tested in this project do not appear to perform at a consistently acceptable level of performance. The frequency of inappropriate alarms and/or missed object/vehicle detections among all the systems was sufficiently high to make it clear that drivers would be reluctant to trust the systems. However, viewed in the context of a supplement to the existing rear-view mirror systems. drivers appeared to be positively inclined toward these systems, but not as their primary or sole means of detecting the presence of vehicles or objects around their vehicle.

The object detection zones of the various systems \ aried widely, primarily dependent on whether a given system utilized one sensor/receiver set or multiple sets of sensors/receivers. The performance of these systems was observed to vary from day to day under constant environmental conditions. Environmental changes (e.g., rain or snow) also affected performance. To the extent these variations are large, drivers can lose confidence in the system and be less inclined to rely on it. At a minimum, this requires drivers to continuously "calibrate" or "benchmark" the performance of the device through a trial-and-error approach in order to determine how the system works (Le., what areas its detection zones cover).

The study results highlight that some of the systems display their detection signal outputs to drivers using display formats that are clearly inadequate but amenable to positive corrective changes. Many of the displays violate fundamental human factors engineering display design principles, thereby making it problematic whether drivers can fully utilize the device to which the display is connected. Many of the systems warrant more careful attention to this aspect of the overall system design process.

Based on the limited amount of focus group work performed, in which drivers who have used these devices were asked their opinions about them, drivers appear to like the concept of these systems and are predisposed to use them, if they determine they work correctly and consistently. Nevertheless, they do not appear to be using the devices for lane change/merge maneuvers, rather they use them during low speed maneuvering in tight situations.

Further studies of these systems will address many fundamental questions relative to the use of these devices which could not be answered within the time available to complete this study. Principal among these are:

I. What type of permanent driving behavior changes can be expected with the more wide-spread introduction of devices of this type? Will those behavior changes vary as a function of the driving environment in which the driver finds himself/herself, or will it be constant, notwithstanding operating conditions?
2. Ideally, what type of driving behavior changes are desirable as a result of using these systems?
3. How do drivers cope with inappropriate alarms? What effect do these unnecessary warnings have on drivers' ability to "benchmark" the systems and, therefore, develop confidence in their performance?

On balance, these devices offer significant promise for safety benefits in the future, but improved designs are needed in order for these benefits to be fully realized.

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