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A Study of Commercial Motor Vehicle Electronics-Based Rear and Side Object Detection Systems Prepared in Response to: Section 6057: P.L. 102-240 December 18, 1991 Intermodal Surface Transportation Efficiency Act of 1991

PREFACE

The National Highway Traffic Safety Administration (NHTSA) has prepared this report in response to Section 6057 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, Public Law 102-240, dated December 18, 1991, which reads as follows:

> "The Secretary shall conduct a study to evaluate technology which is designed for installation on a commercial motor vehicle to provide the individual operating the vehicle with a warning if a turn, lane change, or other intended movement of the vehicle by an operator will place the vehicle in the path of an adjacent object or vehicle."

This report focuses on two types of electronics-based object detection and warning systems for commercial vehicle 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 help drivers avoid backing their vehicles into parked cars, pedestrians, loading docks, or other objects. The tight ***side*** sensing systems are intended primarily as supplements to outside rearview mirror systems to help drivers detect adjacent vehicles or pedestrians when making lane change, merging, or turning maneuvers.

This report describes the agency's initial evaluation of the performance of object detection and warning systems. Analyses of crash statistics were performed to identify the scope of the safety problem such systems address. Several commercially available or working prototype devices were obtained to assess their performance and their interface for presenting information on detected objects to drivers. Data were collected to quantify, the range of performance capabilities of current technology devices. The devices were tested as "black boxes." The testing varied the input (i.e., object to be detected) and measured the output (i.e., when the warning occurred). Discussions were held with several truck drivers experienced with one of these systems. The results of these evaluations are documented in this report and discussed in terms of the desirable improvements that should be incorporated in these devices in order to realize their full potential for preventing crashes.

The work described in this report is part of the broader NHTSA program for research on Intelligent Vehicle Highway Systems (IVHS). The agency's IVHS mission is to facilitate safety-effective commercialization of IVHS products and systems, and to evaluate such products and systems from a safety perspective (NHTSA, 1992). This requires research into the science of crash avoidance to provide a foundation for the engineering and design of safety-enhancing products. Under this broad R&D program, NHTSA will assess the readiness of technology for application to crash avoidance, establish safety targets and performance guidelines for crash avoidance technology, evaluate the performance of such systems, work with industry to demonstrate the most promising ones, and facilitate their deployment in the marketplace.

Several large NHTSA R&D programs will facilitate industry's efforts to develop effective and safe object detection systems. Most notably, a large four-year research program, just initiated, will develop performance guidelines for rear-zone and side-zone object detection systems. This program will gather data on the effectiveness, reliability, costs, and practicability of such systems, and will specify the performance required to ensure safety-effective applications.

In addition, other NHTSA research programs will provide experimental capabilities necessary to advance future crash avoidance research. These capabilities include the National Advanced Driving Simulator (NADS), the Portable Driver Performance Data Acquisition System (DASCAR), and the Vehicle Motion Environment (VME) measurement system. The NADS will provide a high-fidelity facility for simulating crash situations and countermeasures without endangering subjects. DASCAR will be a human factors instrumentation system for installation on regular vehicles. The system will be portable, unobtrusive, and inconspicuous, and thus will obtain data on driver performance and behavior in actual traffic situations--for example, with and without the aid of a warning system. The VME system will automatically record data on the locations and relative motions of vehicles in traffic. VME data will establish the parameters of both normal and unsafe vehicle motions on roadways. Countermeasures such as collision warning systems may be superimposed on VME records analytically to determine their probable effects on safety.

Thus, as this nascent technology for alerting drivers to potential collisions advances in sophistication over the coming years, NHTSA will have the research capabilities to ensure its development as a safe and effective crash countermeasure.

BACKGROUND

Problem Size

In 1991, there were an estimated 330,000 police-reported crashes involving medium and heavy trucks (GVWR> 10,000 lbs.) (General Estimate System, 1991, 1992 crash data were not available at the time the report was written). The majority of these (60 percent) involved combination-unit trucks (for the most part, tractor-semitrailer combinations). Medium/heavy truck crashes resulted in 4,849 fatalities, 659 of which were occupants of heavy trucks, 3,764 were occupants of other vehicles involved in collisions with medium and heavy trucks, and 426 were pedestrians (FARS, 1991). These crashes resulted in another 113,000 persons being injured. On average, combination-unit trucks compile more than four times the per-vehicle mileage of single-unit trucks, and thus have a far greater exposure to crash risk. For example, in 1991, combination-unit trucks accounted for 27percent of medium/heavy truck registrations but 59 percent (198,000) of truck crash involvements and 75 percent of fatal truck crash involvements. For this reason, the focus of this research report, and the NHTSA heavy truck safety research program in general, is on combination-unit heavy trucks.

Crashes involving backing, turning or lane change/merging maneuvers accounted for 19.1 percent of the total number (198,000) of combination-unit truck crash involvements in 1991. These crashes 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.

Primarily because of their high mileage exposure, combination-unit trucks are much more likely to be involved in turning/backing/lane change/merge crashes over the course of their operational lives than are single-unit trucks or other vehicle types. Thus, the per-vehicle payoffs from crash avoidance countermeasures are likely to be much greater for these vehicles.

The total direct monetary loss associated with combination-unit truck turning/backing/lane change/merge crashes is estimated to be $250.8 million for 1991, or $156 for each of 1.61 million registered trucks. This monetary estimate includes all damage and injuries resulting from the crash; that is, it includes all vehicles, not just the combination-unit truck. It includes estimates for property damage, medical, emergency service, work place, travel delay, legal, and administrative costs, and compensable pain, but does not incorporate a value placed on “pain and suffering” or lost quality of life resulting from crash injuries.

By extrapolating the estimate of $156 per vehicle per year over the entire life of heavy trucks (14.7 years on average; Miaou, 1990), and then applying an annual discount rate of 4 percent (to account for the fact that future costs have less “value” than current costs), the monetary value of target crashes for each new combination-unit truck produced is calculated to be approximately $1,724. From a monetary cost-benefit standpoint, a hypothetical device that could prevent all of a vehicle’s “at fault” target crash involvements would thus be worth up to $1,724 added to the cost of the new vehicle. A device (or combination of devices) that would reduce a vehicle's "at fault" crash experience by 50 percent would be worth $862 (i.e., 0.50 x $1,724). If it were only 10 percent effective, the device would be worth $172. This means that a device costing $862 or less (including maintenance costs) would pay for itself over the life of the vehicle if it were 50 percent effective in preventing target crashes. This is a conservative figure because many relatively minor crashes or crashes in off road, loading dock areas are not police-reported crashes and thus not counted in the FARS or GES databases.

Damage Location

Table 1 indicates the distribution of turning/backing/lane change/merge crashes for combination unit trucks: 28 percent of all target crashes involved right turning trucks, 37 percent occurred on the right side of the vehicle (associated with lane change merges from the left to the right), 11 percent involved collisions on the left side of the vehicle (associated with lane change/merges from the right to the left), and 24 percent involved backing maneuvers. In terms of crash consequences, right side involvements also account for the majority of the fatalities (44 percent), injuries (60 percent), and costs (44 percent) associated with these crashes.

Since the vehicle maneuvers associated with the side and rear crash types under consideration are distinctly different, it is appropriate to consider these crash types separately. Angle/sideswipe, lane change/merge crashes (crashes involving the sides of the truck, hereafter referred to as AS/LCM crashes) are much more frequent on the right side of the truck (77.6 percent), compared to the left side (22.4 percent). In the case of right side AS/LCM crashes, the majority (53.7 percent) involve collisions into the side of the tractor, 35.3 percent involve collisions into the side of the trailer, while the rest (II. 0 percent) involve collisions in which parts of both the tractor and trailer were involved. Similar patterns are seen for left side AS/LCM crashes.

The findings relative to the impact zones for combination-unit truck AS/LCM crashes are interesting from a number of viewpoints. First, in the case of lane change/merge right side crashes, the data confirm that the impact point is most frequently in the area immediately adjacent to the side of tractors - the area where truck drivers have the most difficulty detecting the presence of other vehicles. However, a significant portion of these types of crashes occur 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 truck's conventional outside rearview mirrors (i.e., the "clearly trailer" cases). These findings point not only to the limitations of conventional mirror systems, but also the fact that drivers sometimes fail to use their mirrors properly or misinterpret the visual information presented.

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, Right Turn, & Encroachment Backing 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	4,200	30,000
Costs (Million dollars)	$37.2 M	$109.8 M	$36.1 M	$67.7M	$250.8 M	$3,962.8 M
Estimated Crash-Caused delay (in Million Vehicle Hours)	3.3 M	12.2 M	1.5 M	3.3M	20.3 M	86.6 M

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 (<5mph) vehicle. They do not include "crossing path" backing crashes where a backing vehicle is struck by a moving (>5mph) vehicle, as might occur when a vehicle backing out of a driveway is struck by crossing traffic.

These statistical findings are corroborated by studies of crash causal factors in passenger vehicle backing/lane change/merge crashes (Treat et al., 1979; Tijerina et al., 1993; Chovan et al., 1993). They show that drivers fail to notice the other vehicle, pedestrian, or object because of inattention, distraction, or misperception. The statistical and causal data indicate the substantial potential benefits that could be derived from improved driver awareness of critical objects to the sides and rear.

Crash Countermeasures

The statistical analyses of crashes indicate that commercial vehicles are involved in a substantial number of crashes when turning, lane changing, and backing. In some of these crashes, the drivers were likely not aware of the nearby object either because the driver was not attentive to the road or because the object was not visible in the mirror or through direct viewing out the windows. Several types of devices could help drivers in these situations.

Improved mirrors and increased direct viewing from the truck cab could increase the areas near a truck in which nearby vehicles, other objects, or pedestrians could be visible to the driver. Mirror improvements include adding mirrors that are focused on the right front area of the tractor or increasing the convexity of the mirror to increase the field of view. Mirrors are relatively inexpensive but can cause some drivers problems because of the increased effort needed to monitor more mirrors or observe minified images in highly convex mirrors. Mirrors also have a very limited field of view directly behind a tractor-semitrailer combination.

To help truck drivers see to the rear when backing, several manufacturers offer video systems. The video camera is located at the top rear of the trailer. In addition to the camera, some systems include a microphone and speaker to pick up voices. The monitor is located in the cab so the driver can view the rearward scene. Because these devices are detection, not warning systems, one system was obtained to determine the view provided the driver. The field of view was found to extend approximately 12 meters back from the rear of the trailer and 5 meters to the left and right of the trailer center. The image quality of the rear scene in the monitor was good. Video systems can help the attentive driver see objects in the rear. The drawbacks of these systems are their comparatively high costs, reduced performance in low light, and need to have durable electrical connections between the rear camera and the cab monitor.

Fiber optic systems consist of three basis components: 1) an external lens; 2) a flexible fiberoptic bundle to transmit the lens image inside the vehicle; and 3) a viewing screen to display the image to the driver. They can be pointed to the sides or rear to pick up current blind spot areas. They are relatively costly and need special installation effort. At this time in their development stage, their major limitation is the relatively low quality of the image presented to the driver. Furthermore, they have not been tested to determine the ability of drivers to effectively use them when changing lanes and backing. Fiber optic systems also require that the driver be attentive to the display.

Electronic object detection and warning systems can provide the inattentive driver with an alert of nearby objects and for alert drivers they can supplement mirror systems to detect vehicles in “blind spots” on the sides or rear of the truck. The effectiveness of these systems in aiding drivers depends on how well they satisfy the following technological and human factors concerns:

1. Do the devices detect all relevant objects and not detect irrelevant ones?

2. Do drivers detect and understand the warning?

3. Does the warning facilitate appropriate and timely driver actions to avoid a crash?

4. Will drivers use the devices or ignore them?

These questions formed the basis for several evaluations of the range of capabilities and characteristics of commercially available or operational prototype object detection systems. Two types of technologies were examined in this study--ultrasonic and radar. Products incorporating infrared and optical pattern recognition of critical objects were not sufficiently developed to be included in this assessment.

Rear Zone Object Detection and Warning Systems

Introduction

The rear zone object detection and warning systems were primarily designed to aid drivers while they are slowly backing the truck towards stationary or slowly moving objects (e.g., pedestrians, loading docks, other vehicles).

Three types of evaluations were performed. One measured the distance at which objects were initially detected by the device. Another assessed the human factors aspects of the auditory and visible display used to convey the warning to the driver. The final evaluation was based on a focus group interview with several drivers experienced with using one particular system.

Description of Systems

Five commercially available rear object detection and warning systems were tested on a tractor-semitrailer. The systems are shown in Table 2. These were all the known systems available as of January 1993. The table lists the sensor technologies, the number of sensors, and the locations at which the sensors were mounted during this testing. All systems used ultrasonic sensors. They differ primarily in the type of warning display and in the number and location of their sensors; the sensors themselves are all quite similar.

Table 2 – Object Detection Technologies Employed by the Backing Systems

System	Sensor Technology	Number of Sensors	Location of Sensors During Testing
Armatron Echovision	Ultrasonic	2 Transmitters & 2 Receivers	Transmitters 0.762m right of center of trailer, receivers 0.762m to left. One transmitter/receiver is 1.143m above ground, the other is 4.014m above ground.
Safety Technology Safety Sensor	Ultrasonic	1 Transmitter & 2 Receivers	The transmitter is at the center of trailer, with receivers 0.457m to the right and to the left. All are 0.889, above ground.
Dynatech Scan II	Ultrasonic	2 Transmitter/ Receiver Pairs	One pair is 0.965m to right of center of the trailer, the other is 0.965m to the left. Both are 0.851m above the ground.
EBI Hindsight 20/20	Ultrasonic	2 Transmitter/ Receiver Pairs	One pair is 0.432m to right of center of trailer, the other is 0.432m to the left. Both are 1.067m above the ground.
Technodyne Protex CV 2000	Ultrasonic	1 Transmitter/ Receiver Pair	Center of trailer, 1.067m above the ground.

Measurement of Object Detection Zones

An important measure of device effectiveness is the distances and locations at which it senses objects. For example, effectiveness is reduced if objects are detected only when they are so close to the sensor that drivers do not have time to take appropriate avoidance actions. To evaluate this aspect of performance, the detection zones for several types of objects were measured for all five devices. The basic procedure was to place a test obstacle behind the trailer and slowly move the object or trailer until the auditory or visual alarm activated. The object location with respect to the trailer was then noted. The objects used were a flat 0.30 meter square piece of cardboard, a large garage overhead door, a full-size van directly behind the trailer, a full-size van laterally offset from the trailer center line, and a pedestrian.

The shortest and longest detection zones measured for the cardboard target are shown in Figure 1. These zones cover most, but not all of the area immediately behind the trailer. The detection zone, however, did not extend beyond the sides of the trailer. The maximum rearward distance ranged from about 2.2 meters to 3.6 meters.

The range of distances at which the five different devices first detected the overhead garage door and van are shown in **Figure 2.** These distances are generally less than the cardboard detection distances.

Pedestrian detection was evaluated by measuring whether or not the devices detected a pedestrian walking slowly along a line parallel to the back of the semitrailer. For each device, the pedestrian started from a point outside the detection zone (as previously measured to a cardboard target) on one side of the semitrailer, and 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. The percentage of times that the pedestrian was detected ranged from 20 percent to 100 percent. Only one of the five systems detected the pedestrian' 100 percent of the time.

The results of the detection range measurements illustrate several aspects of device performance. The devices have a limited range of about 2 to 4 meters for detecting objects. The limited range helps prevent the devices from sounding an alarm at non critical objects far away from the backing vehicle. Because the range does not extend beyond the sides of the trailer, the devices will be less helpful to drivers in preventing backup crashes to objects that are moving into the path of the backing vehicle. The detection range varies from device to device and depends on the reflective characteristics of the object. Also, some devices were observed to exhibit day to day variability in detection performance. Because of this variability in object detection capability, drivers can not solely rely on device warnings to determine where objects are located. Thus, these devices supplement but do not substitute for the driver's need to be attentive when backing.

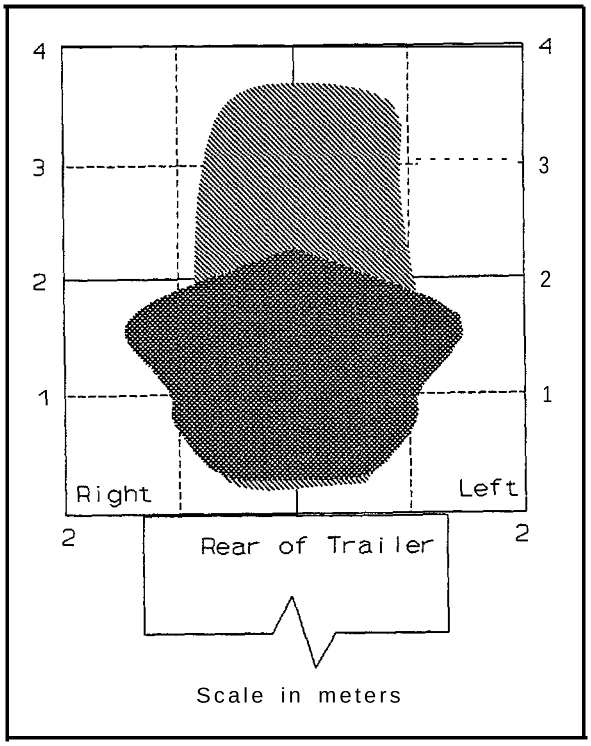

Figure 1 Shortest and Longest Detection Zones to Cardboard Target Covered by Rear Object Detection Systems

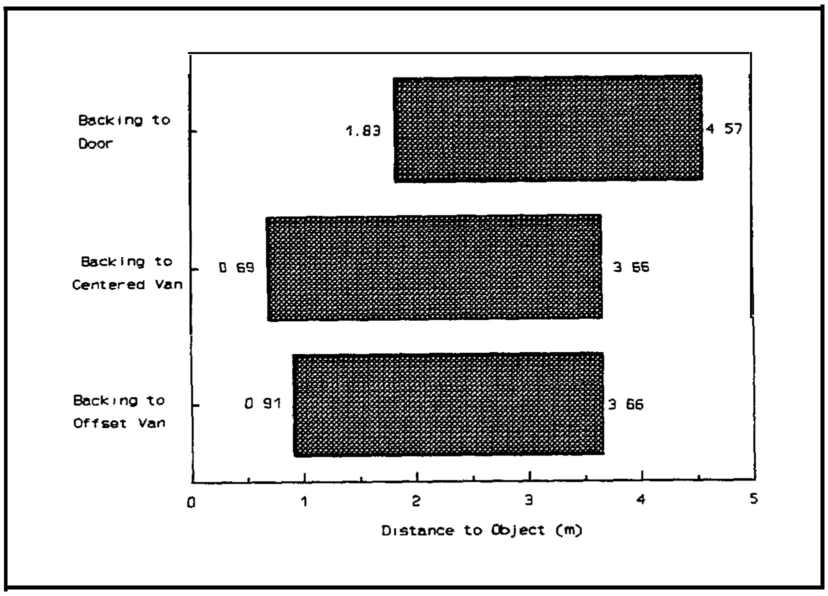

Figure 2 The Range of Maximum Detection Distances to Three Different Objects Provided by Five Rear Object Detection Systems

Evaluation of Auditory and Visual Warning Displays

Another component of device effectiveness is its ability to convey sensor information on object detection so drivers arc alerted in tune to take appropriate actions. Each device had a different approach to conveying this information, which is summarized in **Table 3.** Some devices used auditory alarms and warning lights; some auditory alarms only. Some had displays of actual distance to objects; some had yellow lights for far distances and red lights for close distances.

A human factors checklist was developed to evaluate the various auditory and visual displays of information provided by the devices. The checklist was a systematic tool for subjectively rating the extent to which basic human factors principles of good design were employed and where improvements might be desirable to enhance driver performance. Two raters, a human factors engineer and a test driver, examined the displays while the object detection devices were in operation on a test truck and evaluated the displays in terms of the following design issues:

Overall Design--the overall concept of the interface design. Some of the issues in this category were whether the driver can adjust display brightness, whether the system indicates sensor or logic failures, and what the system displays when no objects are detected.

Conspicuity--how well each system captured the driver's attention. This category included such issues as appropriateness of warning light colors, whether the lights can be seen in day and night, and whether the auditory warnings can be easily heard.

Annoyance Factors--the extent to which the alarm operation might be annoying and cause the driver to be distracted or turn off the device. Some of the items rated included whether the. controls are easily reachable, whether the visual warnings produce glare under low light driving conditions, and whether the auditory warnings are excessively loud or piercing.

Documentation--the quality of the instructions provided with the system. Examples of this category included whether the documentation completely explains use of all of the controls, 'whether the documentation explains/identifies conditions under which system performance will be degraded, and whether the documentation explains that the system is a driving aid, not a replacement for the mirrors.

Comprehension--how easy it is for drivers to understand the warnings and controls. Examples of this category included whether the functions and consequences of moving the controls are easily understood, whether the appropriate direction of movement of a control is used for increasing the controlled parameter, and whether the meaning of warnings is obvious to novice users.

Personal Judgement--the overall subjective impressions of the interface. Answers to questions in this category were based solely upon the two raters' personal assessments of each interface. These assessments included whether the high and low level warnings provided are timely and whether the system reduces the overall effort of driving.

Table 3 Display Characteristics of Rear Object Detection System

System	Type of Warning	Warning Levels	Display Location	Description
Armatron Echovision	Visual/Audio	2	Center of Dash	38 mm x 102 mm box with red and green lights to indicate presence of object
Safety Technology Safety Sensor	Visual/Audio Apply Brakes	10	Center of Dash	64 mm x 152 mm box with red and green lights to indicate distance
Dynatech Scan II	Visual/Audio	3*	Center of Dash	64 mm x 64 mm box with digital readout of distance with LED indicating location
EBI Hindsight 20/20	Audio	2	On Dash	40 mm x 40 mm speaker
Technodyne Protex CV 2000	Audio	2	On Dash	45 mm diem speaker

*** The Visual Display is in 0.1 foot increments, 3 audible alarm levels**

The results of the human factors evaluation indicated that all the system interfaces could be improved. The lowest scores were in "overall design" and "conspicuity." One example of a design factor needing improvement was the location of the visual display. Each of the systems with visual warning displays were mounted on the dashboard, slightly to the right of where the driver's head/eye position would normally be during driving. Thus, drivers could not easily look at both the warning display and the left or right side mirrors at the same time. Since these systems are intended to serve only as supplements, not replacements, for the rearview mirrors, drivers will find them an effort to use because of the need to constantly shift their attention between the mirrors and the display. Some displays had low intensity lights, which were not adjustable, and thus difficult to see in bright daylight. Another system was rated low in the "annoyance" factor because its auditory warning had a disturbingly high frequency and intensity. While an alarm needs to be attention getting, if it is annoyingly loud, drivers may turn it off.

Driver Opinions of Real World Device Performance

To gain a better understanding of real world performance of rear obstacle detection and warning systems, focus group interviews were conducted with six professional truck drivers having experience with one of these systems. The fleet employing these drivers was chosen because it had used both backing and side warning systems on their vehicles. The drivers, who operated over congested urban roads as well as freeways, had about 6 months experience with the warning device. They drove tractors with 8.2- and 13.7- meter semitrailers.

The drivers found the warning system very useful. This may have been because these drivers frequently have to negotiate long and narrow driveways and ramps while backing. Also, they sometimes back up to loading docks which are 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. They were helped by the digital distance readout in these types of situations. 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 were moving 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 get into the back of the semitrailer while the vehicle was stationary.

Focus group participants also identified several device shortcomings. The one manager present in the focus group mentioned that the system is not easy to install. The drivers were especially critical of the reliability of the system's components. Several drivers reported sensor failures. One computer failure was mentioned. A common problem was that the contacts and wiring in the connection between the semitrailer and tractor became severed or tom while turning or backing. Another complaint was that the rear sensors were not mounted on the most rearward part of the semitrailer. This forced drivers to correct the value displayed on the digital readout for the portion of the trailer behind the sensors. This was especially a problem when backing up after lowering a loading ramp. Also, some drivers were bothered because the numbers on the digital, distance indicator would fluctuate when the vehicle was stationary.

All things considered, the drivers were positive about the potential of a rear object detection system. As one of them stated, "Anything that can help to improve safety is welcomed." This endorsement is especially impressive in light of the reliability problems that the drivers reported having with the system. These types of real world observations are important for understanding device benefits and shortcomings. Further information from more drivers using different systems under a wider array of roadway and traffic conditions is desirable to supplement this preliminary assessment. However, even this small sample confirms the results of the detection zone measurements that these devices can cover rear blind spots that are not always visible to a driver using mirrors or direct viewing. But because of reliability problems and sensor limitations, the devices are supplements, not substitutes, for mirrors and direct viewing. Most of the instructions do not explicitly state that the device is only intended as a mirror supplement.

Right Side Object Detection and Warning Systems

Introduction

This section presents results of several evaluations of systems that detect and warn of vehicles, pedestrians, or objects along the right side of trucks. These systems may warn drivers of obstacles that are not visible in mirrors or windows and may alert the inattentive driver of a nearby danger.

The same types of evaluations used for the rear object detection and warning systems were conducted on several right side object detection and warning systems. In addition, tests were conducted to measure how well the systems detected vehicles on a 9O-minute drive over city streets and urban freeways.

Description of Right Side Object Detection and Warning Systems

Two commercially available and two operational prototype systems were tested on a tractor-semitrailer. These four systems were, at the time of the study, all of the known and available lane changing and merging systems designed for use on heavy articulated vehicles. **Table** 4 describes the systems evaluated. The capabilities of the prototype systems are not necessarily indicative of the performance that might be available on possible future commercial systems.

Table 4 Sensor Technologies and Locations for the Lane Change/Merge Systems

System	sensor Technology	System Status	Number of sensors	Location of Sensors During testing
Armatron Echovision	Ultrasonic	Commercially Available	1 Transmitter/ Receiver Pair	On tractor cab, 3.6m aft of front of cab, 1 .Om above ground
Dynatech Scan II	Ultrasonic	Commercially Available	2 Transmitter/ Receiver Pairs	One pair on tractor cab, 3.8m aft of front of cab, 0.8m above ground. Second pair longitudinally centered on trailer, 0.9m above ground.
O'Conner RVI	Relative Velocity Radar	Prototype System	2 Transmitter/ Receiver Pairs	One pair measures ground speed. The second pair is on the aide of the tractor cab, 2.lm aft of the front of the cab, 0.8m above ground, aimed back along the trailer.
Safety First Radar	Position Radar	Prototype System	3 Transmitter/ Receiver Pairs	One pair on tractor cab, 3.2m aft of front of cab, 0.9m above ground. Other two pairs are on trailer, one 5.8m from front of trailer and the other 1.8m from rear of trailer. Roth of these are 0.9m above the ground.

The right side obstacle detection systems use two different sensor technologies: ultrasonic and radar. The two ultrasonic systems differ primarily in their driver interfaces and in the number and location of their ultrasonic sensors; the sensors themselves are quite similar. Of the two radar systems, one determines when to warn the driver by measuring the distance to an obstacle. The other radar system provides drivers with information on the relative velocity of a passing vehicle within the sensor field of view.

Measurements of Detection Zones

The areas in which vehicles were detected by the different systems were measured to show their potential for alerting drivers and preventing crashes. All four systems were evaluated by determining the detection zones for each sensor on a test track and by measuring the number of inappropriate alarms and undetected vehicles in actual traffic.

On the test track the zones were determined both quasi-statically and dynamically. 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.

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 vehicle's locations relative to a sensor at the times when the driver display first indicated it had sensed the target vehicle and when it stopped indicating the presence of the vehicle.

The passenger car detection zones for two right side object detection systems are shown in **Figure 3.** The figure is a schematic depiction of the right half of a tractor-semitrailer. The sparse, diagonal hatching in this figure shows the area over which a driver can detect an object with a height of 1.180 meters using either the right-side mirror system (consisting of a plane mirror and a 373-millimeter radius of curvature shallow convex mirror) or direct observation through the windows of the tractor cab. (The height of 1.180 meters corresponds to the height of the roof of a small car.) The area that is not covered by this sparse hatching is the area that is not visible either directly or indirectly, i.e., the so-called "blind spot."

The dense hatching shows the detection fields of each of the sensors of two, right-side object detection systems. The square hatching is an ultrasonic system; the diagonal hatching is a radar system. The fields were determined by locating the midpoint of a very slowly moving car when the vehicle was first detected by each sensor and when the sensor stopped detecting the vehicle. Note that the ultrasonic system uses only one sensor to detect adjacent vehicles while the radar system has three.

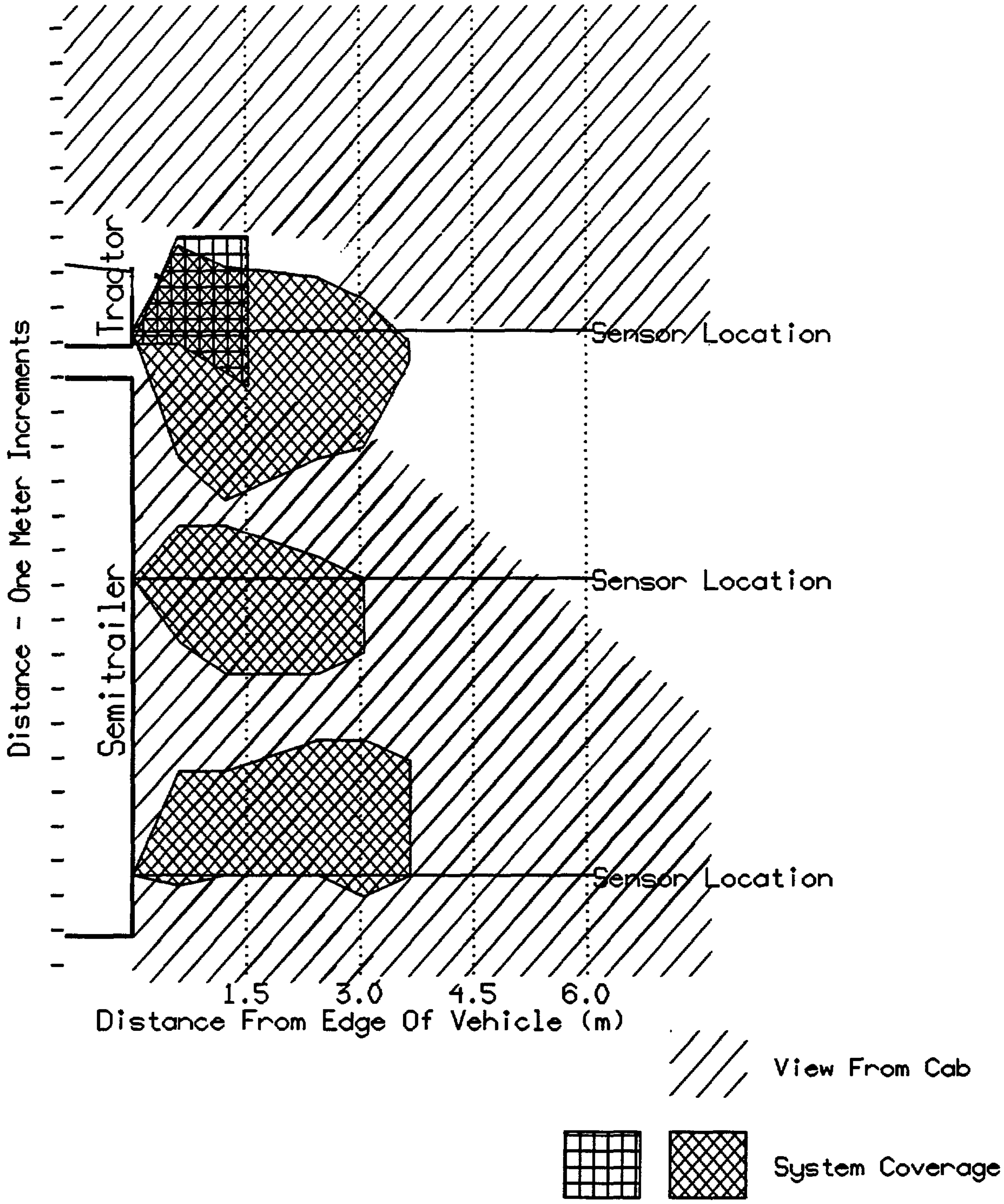

Figure 3 Detection Zones of Two, Right-Side Object Detection Systems and Driver View From the Tractor Cab

This figure shows that the coverage can overlap the existing area visible to drivers as well as the “blind spot” to the immediate right of the tractor.

Dynamic tests were conducted with the test vehicle passing the tractor-semitrailer at three closing speeds (8, 16, and 32 km/hr). In half the trials the truck was stationary and in half it was moving at 32 km/h. Under these conditions, the test vehicle was undetected in a few trials by the ultrasonic sensors. In addition, as the relative velocity increased, the detection zones of all the systems moved longitudinally forward. In some trials, both ultrasonic and radar systems did not detect the passing vehicle until after it had passed the sensors. Also, the point at which both ultrasonic and radar sensors first detected the target vehicle varied by several meters from trial to trial.

To better assess detection performance under more realistic conditions, the test truck equipped with all four systems was driven over a set route which included city streets and urban freeways. A different right-side object detection and warning system was used for each day’s driving. A quantitative evaluation of the number of inappropriate alarms and undetected targets for each system was obtained during a 90-minute portion of the test route, which included several different types of roads. For each day’s test on that portion of the route, data were obtained on the number of vehicles that passed or were passed by the tractor-semitrailer and on the waming 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. All four systems were evaluated using the same section of the route to help ensure that roadway and traffic conditions were similar for each system.

The overall percentage of undetected vehicles ranged from a low of 4 percent to a high of 55 percent. Inappropriate alarms ranged from none over the 90-minute drive to an average of one every 2.6 minutes. None of the systems was without fault in terms of these two metrics of performance. All of the systems had relatively high percentages of missed vehicles in at least one test condition. The percentage of vehicles missed by each system was not consistent between different test days. The system with the more frequent inappropriate alarms had the lowest number of undetected vehicles. This fmding highlights the dilemma designers face relative to the need to have sufficient activation sensitivity to detect all critical objects, while at the same time not wanting the sensitivity so high that it causes an inordinate number of inappropriate activations.

These types of characteristics potentially could limit the usefulness of the devices as warning systems. Drivers using these various systems must go through a process of benchmarking or calibrating the relative coverage zones of the system when they first drive a vehicle equipped with one. Without consistent detection performance at different speeds or with different types of vehicles or from day to day, drivers may have a difficult time using the system. They will not be able to trust the devices to consistently warn of critical objects.

Evaluation of Auditory and Visual Warning Displays

The different warning systems used various approaches to convey object detection information to drivers. Table 5 describes some of the key differences. The human factors checklist described in the section on rear object detection devices was again used to evaluate the displays of the right-side object detection systems. The results of this evaluation found several common deficiencies that could reduce the operational effectiveness of the systems. For example, most of the visual displays were too dim to he seen in bright daylight or were too small for the drivers to easily see while driving. To obtain warning information, drivers would need to make relatively long glances at the displays, resulting in unacceptable distraction from the roadway. Fortunately, these types of deficiencies can be remedied with proper attention to the influence of display design on driver performance and acceptance. For example, the visual display could be located close to or in the rearview mirror to encourage the driver to visually check for nearby vehicles.

Table 5 Display Characteristics of Right Side Systems

System	Type of Warning	Warning Levels	Activated by Turn Signal	Display Location	Description
Armatron Echovision	Visual/Audio	1	Visual (No) Audio (Yes)	Center of Dash and near right A-pillar	38 mm x 101 mm box with red and green lights to indicate presence of object plus red "X" over right side window
Dynatech Scan II	Visual/Audio	Distance to object plus 1 audible alarm level	No	Center of Dash	64 mm x 64 mm box with digital readout of distance with LED indicating location of object
O'Conner RVI	Visual	see description	No	Center of Dash	70 mm x 190 mm box with digital readout of target vehicle relative velocity plus LED indication of when detection occurs
Safety First	Visual/Audio	1	Visual (No) Audio (Yea)	Center of Dash	35 mm x 108 mm box with red lights to indicate location of object

Driver Opinions of Real World Device Performance

As was done for rear object detection systems, focus group interviews were conducted to obtain driver opinions of the performance of right-side object detection systems. The interviews were with the same six drivers who used the rear detection system. The warning system used one ultrasonic sensor mounted on the right side of the tractor cab above the fuel tank. The driver warning display was mounted on the instrument panel, in front of the passenger seat and angled toward the driver.

The drivers reported little difficulty learning to use the system. They readily learned what situations would activate the auditory and visual warnings and that the device had frequent noncritical warnings caused by such objects as trees, telephone poles, and bridge abutments. These alarms were tolerated by the drivers. Drivers also learned to mentally correct the digital distance readout to compensate for the placement of the sensor inboard of the right most point of the tractor.

The drivers used the system, but not as their primary means for detecting hazards. They considered the device as a supplement to their routine of scanning the road and mirrors. In spite of the frequent noncritical warnings, no driver would ignore the alarm without checking out the window and mirror. They found the device useful when they were attempting to merge in congested settings, such as at toll booths or tunnel entrances. It was also helpful when they were driving through very narrow rights of way, as in construction zones or in urban settings where vehicles were double parked. The drivers also used the system when making tight right turns around obstacles. At intersections, the device helped to warn the drivers when pedestrians were in the truck's right front blind spot or when a small vehicle pulled into this area.

Drivers, in general, did not fmd the device useful for making merging or lane change decisions. When merging, they reported that either the angle or speed of the traffic approaching from the right rendered the sensor ineffective in providing timely or accurate warnings. The drivers did not believe they needed much help from an object detection device during lane changing because their vehicles had a good mirror system, including a fender-mounted mirror which gave them a good view of the right side of the vehicle. Also, because the truck had a 55-mph speed limiter, drivers tended to stay in the right lane and make few lane changes.

Drivers mentioned several additional limitations. The fluctuations of the digital distance display numbers was annoying. The location of the display in front of the passenger seat, its small size, and its low brightness made it difficult to read. This problem caused the drivers to look at the visual display only after they heard an auditory alarm. Sometimes the auditory warning was difficult to distinguish from the speed monitor alarm and hard to hear over the sounds from the engine, wind, and radio. Drivers suggested that the right side warning should not be automatically deactivated when the vehicle is in reverse gear. They thought it would have been useful for detecting walls and other obstacles during backing maneuvers to some loading docks.

SUMMARY AND CONCLUSIONS

This report is the first opportunity the National Highway Traffic Safety Administration has had to examine current technology that provides truck drivers with warnings of objects located behind and to the right side of the vehicle. The number and types of crashes that might be prevented with improved driver awareness of nearby objects were identified. Commercially available and operational prototype devices were obtained for testing. Data were collected to help address questions about the effectiveness and usefulness of this type of technology. The findings relative to these questions are described below:

1. Do the devices detect all relevant objects and not detect irrelevant ones?

The results of the limited amount of testing conducted to date indicate that the devices have difficulty consistently detecting many critical objects under both backing and lane changing scenarios. The side-object detection systems often cannot discriminate between critical and noncritical objects. Rear-object detection systems have a limited area of coverage which helps to reduce irrelevant warnings, but as a result their ability to detect moving pedestrians may be limited. Because of these characteristics, the devices can be supplements, but not replacements for appropriate driver precautions and mirror use when lane changing, backing, or turning.

2. Do drivers detect and understand the warnings?

This question was answered indirectly by conducting a human factors evaluation of the warning display and was also assessed directly from interviews with truck drivers who used one of these systems. The human factors evaluation found that some systems conveyed their detection signal information to drivers using display designs that were not as effective as possible, e.g., lights not easily visible in daylight. The drivers we interviewed corroborated the findings of the human factors evaluation. For example, they mentioned the difficulty of easily hearing the auditory alarm in the presence of various cab noises and the problem of interpreting the digital, distance-to-object sensor which was not calibrated for the actual truck width or length. Fortunately, these’ types of deficiencies can be remedied with proper attention to the influence of display design on driver performance.

3. Does the warning facilitate appropriate and timely driver actions to avoid crashes?

This question was addressed by measuring the detection performance of the devices and from driver interviews. No direct measures of driver turning, lane change, or backing performance were obtained. The test results of both ultrasonic and radar side object detection systems found that the detection zones changed from trial to trial. Both types of systems had some test trials in which the alarm would not activate until after the vehicle passed the sensors. Thus, drivers could not consistently depend on the device to make lane change or merging decisions. The drivers who were interviewed confirmed this problem and mentioned several merging situations where the device did not alert them to encroaching vehicles. For rear-object detection systems, the drivers were helped by the device when backing slowly to a loading dock and for warning of pedestrians. However, the low pedestrian detection rate found for some systems, the limited coverage area of all systems, and the variability of detection performance suggest that drivers cannot solely rely on these systems to back up safely under all situations.

4. Will drivers use the devices or ignore them?

Drivers using one particular device indicated that despite its shortcomings, they used it in certain backing and driving situations and appreciated any help it provided in detecting nearby objects. However, these situations do not appear to be the situations leading to the more significant safety problems associated with the turning, lane change, merging, and backing crashes described in this report.

On balance, obstacle detection and warning devices offer significant promise for safety benefits in the future, but more work is needed to refme their performance and design in order to achieve their potential. The agency plans to further examine these systems as part of its IVHS program, which was mentioned in the Preface. This work will examine such factors as adverse weather performance, detection of different objects, capabilities under more varied traffic situations, and driver usage and acceptance. Some additional testing, including human factors evaluations, is already underway. A more detailed technical report covering this work will be released in the future.

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