Evaluation of Devices to Prevent Construction Equipment Backing Incidents

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ABSTRACT

Blind areas around construction equipment are a major contributing factor in incidents involving a piece of equipment striking a worker. In highway construction, these types of incidents result in an average of 22 deaths a year in the United States. The Spokane Research Laboratory of the National Institute for Occupational Safety and Health, in cooperation with the Washington State Department of Transportation, is evaluating methods to decrease these incidents. One such method uses devices that assist equipment operators in monitoring blind areas around the equipment to prevent collisions with workers or other objects. Several camera and sensor systems are available for this application. These systems were evaluated on various trucks used in road construction and maintenance. Tests were conducted on sanding trucks during the winter months, which allowed researchers to investigate the effectiveness and limitations of various technologies under the most extreme conditions. Tests were also conducted on dump trucks and utility vehicles during the warmer months to study the effectiveness of the systems in highway work zones. Results showed that many difficulties arise when using camera and sensor systems in cold, snowy climates. And, while the operation of these systems is more reliable during the warmer months, challenges still exist in using them on equipment in congested work areas.

INTRODUCTION

The Spokane Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) is cooperating with the Washington State Department of Transportation (WSDOT) in an evaluation of technologies that assist drivers in monitoring blind areas around construction equipment. One such technology consists of cameras that provide a view of the blind area; another features sensor-based collision warning systems that warn the driver if an object or person is nearby.

Road construction workers must work very close to moving equipment. According to Pratt et al. (2001), the majority of fatalities that occur in highway construction work zones in the United States involve a worker being struck by construction equipment or another type of vehicle. In fact, a worker in the construction industry is just as likely to be struck by a piece of construction equipment inside the work zone as by passing traffic. Also, half the fatalities involving construction equipment occur while the equipment is backing. Accidents involving WSDOT equipment often involve some type of truck backing into a worker or another vehicle. This and the blind areas associated with construction equipment contribute to making road construction a dangerous occupation.

For this reason, a study was initiated to evaluate methods of monitoring blind areas around trucks used in road construction and maintenance. Several camera and sensor systems are available for this application, and understanding the difficulties in implementing these systems on trucks used in all types of weather is important. Tests were conducted on sanding trucks and utility vehicles during the winter months, which allowed researchers to investigate the effectiveness and limitations of various technologies under the most extreme conditions. Other tests were conducted on dump trucks and utility vehicles during the warmer months to study the effectiveness of the systems in highway work zones.

NIOSH researchers' experience with camera systems and collision warning systems on mining equipment helped narrow the list of technologies to be evaluated (Ruff, 2001). Systems were selected on the basis of their ability to sense obstacles through snow and rain, to handle the tough environment of highway construction, and to meet minimum standards regarding mounting position and detection range. All systems went through an initial test to determine if they could be mounted on a particular piece of equipment and function according to minimum specifications. These included—

- Low probability of a false alarm in a clear, flat area (parking lot).
- Reliable detection of a person in a zone starting immediately behind the truck, extending at least 2.7 m (9 ft) behind the truck, and covering the width of the truck.
- Apparent ability of the system to handle harsh conditions.
- Ease of mounting and configuring a system on a vehicle.

For more details on these tests, see Ruff (2003). If a system operated satisfactorily in initial tests, then tests were conducted for several months while the equipment was used in actual road construction and maintenance activities.

TEST PROCEDURE

The following systems were chosen for long-term tests on WSDOT dump trucks, utility vehicles, and plowing trucks: Preco's Standard Preview radar system, Sonar Safety System's Hindsight 20/20 sonar system, and Intec Video System's Car Vision camera system. Other systems were also evaluated in an earlier phase of testing as described in Ruff (2003), but the most thorough evaluations were conducted on these three systems.

Systems selected for long-term tests were permanently mounted on a WSDOT truck according to the manufacturer's suggestions. In some instances, the mounting position of the system had to be changed due to the particular configuration of the truck. Long-term tests in the winter were conducted on a tandem-axle sanding/plowing truck (figure 1*A*) and a sport utility vehicle (figure 1*B*). Long-term tests during warmer months were conducted on a 7.6-m^3 (10-yd^3) dump truck (figure 1*C*), the sport utility vehicle, and a pickup truck (figure 1*D*). Test duration was 2 months or more in actual work situations. Jobs during the summer months usually involved asphalt patching operations or road material hauling. Jobs during winter involved sanding and plowing operations.

To evaluate the systems, a form was available in the cab of the truck so the driver could make daily comments and record the effectiveness of the system. Informal discussions with drivers and direct observation of the system in use also helped researchers understand a system's problems and capabilities. In one set of tests, a data collection system that recorded video from a camera along with Preview radar alarm information was used to

Figure 1.—WSDOT test vehicles. *A*, Sanding/plowing truck; *B*, sport utility vehicle; *C,* dump truck; *D,* pickup truck.

determine the source of alarms and distinguish false from real alarm rates. When the long-term test was completed, the systems were removed from the trucks and inspected for damage or abnormal wear.

TEST RESULTS

SYSTEM 1:

Standard Preview radar system, model SPV2015
Manufacturer: Preco Electronics, Boise, ID.
Approximate cost: $350

System Description: This radar system uses pulsed microwave signal techniques to detect an object in the radar beam. It consists of a radar antenna and processing electronics, an alarm display, and cables (figure 2). No motion of the object or vehicle is needed for detection. The alarm display indicates distance in 1-m increments using a series of LED's. An audible alarm that changes in frequency as the distance to an object changes is generated. The radar system is designed to monitor the rear blind area and is activated when the vehicle is in reverse. This model has no user-adjustable settings.

Figure 2.—Preco's Preview radar system

Figure 3.—Preview radar antenna mounted on hitch plate.

Test Results-Dump Truck: Tests were conducted on a tandem-axle dump truck (figure 1*C*). Several positions for the radar antenna were tried; the best results were obtained when the antenna was mounted on the hitch plate at a height of 89 cm (35 in) and slightly off-center (figure 3). The antenna could not be mounted closer to the center of the truck because the system may detect the hitch, causing false alarms, or be crushed when the truck is backed up to a trailer tongue. The alarm display was mounted on top of the dashboard in the cab.

The solid line in figure 4 shows the detection area for a person standing behind the truck. The zone was verified by moving the truck slowly in reverse toward a person, with no significant differences. This detection zone was adequate and extended to 4.6 m (15 ft). The dashed line shows the detection area for the same person in a crouching position (on one knee and bent at the waist). The detection zone for a crouching person was smaller in width than for a standing person. This caused some concern because of the potential for someone to be crouching and working behind the truck.

The radar system was tested through the spring on this truck. Several discussions with drivers indicated that the radar system was well accepted. The radar produced few false alarms and operated reliably, even with a few millimeters of mud caked on some places on the antenna. Drivers stated that the radar alarms prompted them to reverse with caution and recheck mirrors. They did comment that nuisance alarms from nearby equipment or berms were frequent in congested work areas. Nuisance alarms are caused from objects which the operator is already aware of, e.g., a piece of equipment, or objects that pose no danger, e.g., foliage.

While anecdotal data such as driver comments are useful in determining if a system is effective and accepted by users, researchers wanted to obtain quantitative data also. For example, it is difficult to quantify false alarms without having some knowledge of exactly what is behind the vehicle when they occur. Many times the system is correctly detecting a pot hole, a rock, or some other object that the driver does not consider a hazard. For this reason, a video recorder that accepted sensor inputs was used to record time-stamped video from a rear-mounted camera, along with radar alarms. (More discussion on the camera system can be found later in this report.) In some of the tests, the camera view was also made available to the driver on a video monitor in the cab. Consequently, many of the driver comments concerned the combination of radar and camera systems. The main conclusion drawn from the feedback was that the radar system was very useful in prompting operators to look at the video monitor when an alarm sounded.

The camera also allowed the driver to check the source of any alarms, which greatly reduced the inconvenience of getting out of the cab to verify whether the area was clear. The combination of the two systems offered many advantages over using either system by itself.

Figure 5 shows an example of a video obtained from the camera and radar combination. Note that a "W" appears on screen whenever the radar system alarms. Since the radar detection zone is entirely contained within the camera's field of view (FOV), any object that causes an alarm can be seen in the video. This allows researchers to determine when alarms occur and what causes them. In this case, the radar system correctly detected the nearby equipment and workers.

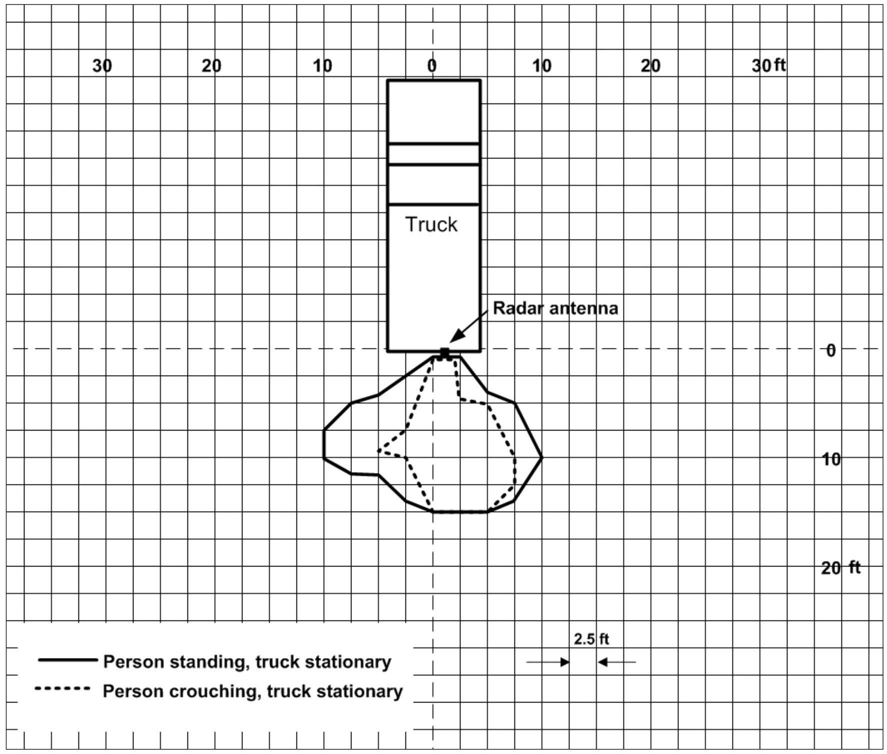

Figure 4.—Detection zone for a person and Preview radar system on dump truck.

The first video was collected during a sand hauling operation, and 6 hours of footage was recorded to tape. Very little backing occurred during this work. Only one radar alarm was recorded, and the video showed that the walls of the maintenance shop were correctly detected as the truck backed out of the shop. The truck did back up to a dump point four times in the video footage; however, a wheeled loader had pushed the sand over the edge after each dump, and the small sand pile remaining was not detected by the radar.

The next video was collected during an asphalt paving operation, and another 6 hours of footage was collected.

Figure 5.—Screen shot of video from rear camera view. Note that the "W" indicates a radar alarm.

In this footage, eight backing events and four radar alarms were generated during these events. Two of the alarms correctly warned of nearby objects or workers. The other two alarms were from the detection of tall weeds behind the truck. There were no instances where the radar missed detecting an object or person. At the time of writing this report, more video footage was being collected so more meaningful conclusions could be drawn.

Test Results-Sanding/Plow Truck: Tests of the radar system through the winter were conducted on a sanding truck (figure 1*A*) to determine the system's effectiveness in harsh weather conditions. Radar mounting was the same as described above for the dump truck. Only driver interviews and a researcher's direct observation were used to obtain feedback on the system's operation.

Driver comments were generally favorable for wintertime use of the radar. The build-up of snow and ice on the back of these trucks can be extensive during snowy conditions, and this was a major concern (Ruff, 2003). However, the driver of the truck did not complain of any false alarms and indicated that snow was not sticking to the radar antenna. Road grime did build up on the antenna, but did not cause alarms. The truck was sprayed with water at the end of each shift, and this may have prevented a significant amount of grime or snow from building up and causing false alarms. The driver did state that the radar system prompted him to recheck mirrors and reverse with extra caution.

Midway through the winter, the radar system malfunctioned. The cause was determined to be corrosion of the wires that provided power to the sensor system. Power for the radar used the same reverse signal that powered the backup alarm. Open lug terminals on the backup alarm corroded from the de-icing solution applied on the road by the truck. This is a common problem with any exposed wiring on these trucks. The terminals were cleaned and the wiring was re-terminated, which fixed the problem.

SYSTEM 2:

Intec camera system
Distributor: Intec, Laguna Hills, CA
Approximate cost: $1100

System Description: The Intec camera system consists of a small camera the size of a 5-cm (2-in) cube (model CVC210XL), an 11.4-cm (4.5-in) video monitor (model CVM450LPP), and cables (figure 6).

Test Results-Dump Truck: Initially the camera was mounted on the right side of the dump box, above the rear taillights that are integrated into the box (figure 7). Tests showed that this was an acceptable mounting position and provided an acceptable FOV for the driver. However, a crouching person near the back of the truck might not be in view because of the camera's high position. It might also be of more benefit to mount the camera on the left side of the box, pointing to the right, so that the larger blind spot to the right would be covered more adequately.

Because the dump box is removed and replaced with a sand hopper, WSDOT and NIOSH researchers wanted to find a mounting position that would be undisturbed during the box switching process. An alternative camera mounting position near the hitch is shown in figure 8. This may not be an adequate position for all truck types, especially if the camera is in the path of material as it flows out of the tailgate or if the FOV is blocked by structures on the truck. The monitor was mounted in the cab on the center pedestal between the seats. This allowed the driver to check the monitor without too much head movement after checking the right side mirror. Other monitor positions are acceptable, and feedback from the driver is required to find the preferred position. Figure 9 shows the FOV of the camera with the view extending to the horizon.

Figure 6.—Intec camera system

Figure 7.—Initial mounting position for Intec camera on dump box.

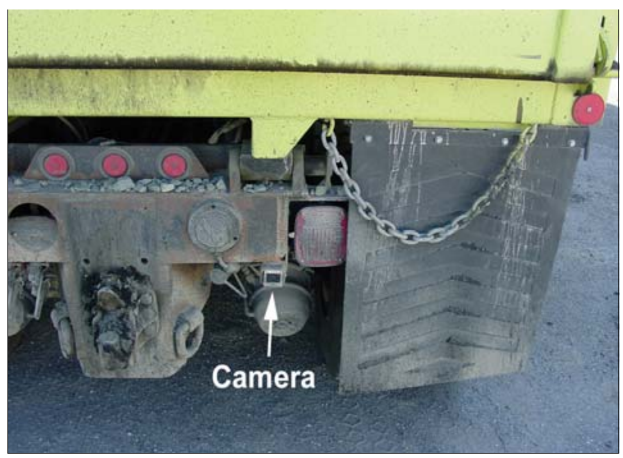

Figure 8.—Intec camera mounted near hitch.

The camera system was tested during spring and summer months with positive comments from the drivers. The camera has the advantage of providing an actual view of the blind area, and drivers relied on it to help them posi-

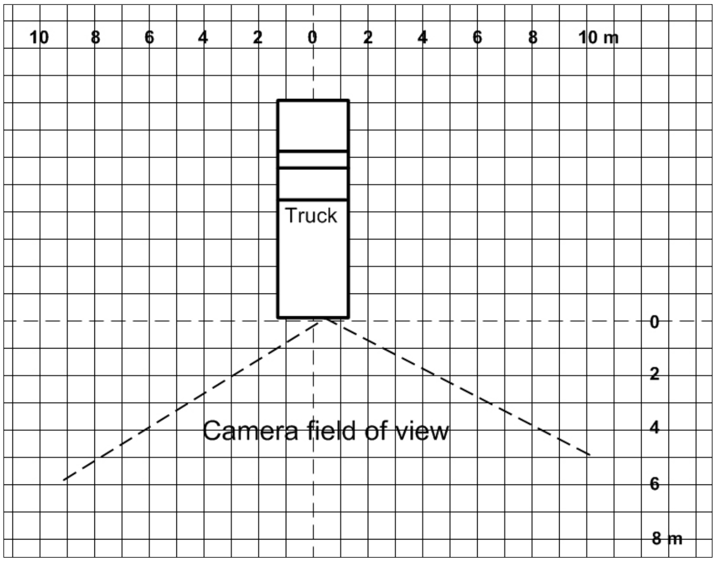

Figure 9.—Field of view for camera mounted near hitch. (Note: dimensions are in meters.)

tion the truck and check for obstacles. Some debris built up on the camera lens, especially in wet weather. This usually did not significantly obstruct the camera view, and cleaning the lens at the end of each shift was sufficient. At the end of the test, the camera, monitor, and cables were inspected, and no unusual wear or corrosion were seen.

One disadvantage to camera systems is that they do not provide an alarm if an obstacle is present. If the driver forgets to check the monitor before backing the truck, a potential collision may go unnoticed. For this reason, tests were later conducted with the Preco radar system and camera on the same truck as mentioned in the previous section. Driver comments indicated that the combination of systems was more effective than either system by itself. However, if only one system could be used, the camera system was preferred over radar because of numerous radar alarms in congested work areas.

Test Results-Sanding/Plow Truck: In the fall, the dump box on this truck was replaced with a sand hopper, and a snow plow was mounted to the front. Because the camera and cabling were mounted on the chassis, they remained in the same position as in the dump truck tests.

Tests of the camera system during the winter showed that the camera view was quickly obscured by snow or road grime after traveling just a few miles down the road. Earlier tests showed that this was true for higher camera mounting positions also. For this reason, a lens washing system was devised by Intec, Inc., and sent to NIOSH for testing. The prototype system consisted of a nozzle that mounted just above the camera that allowed the driver to blast compressed air and washing fluid on the camera lens (figure 10). NIOSH researchers were only able to test the washing system on road grime build-up and it worked well. However, tests need to be conducted for snow and ice build-up. During cold and snowy conditions, several centimeters of snow and ice can accumulate on the back of the truck, and it was not determined if the washing system would work in these conditions. More tests are planned.

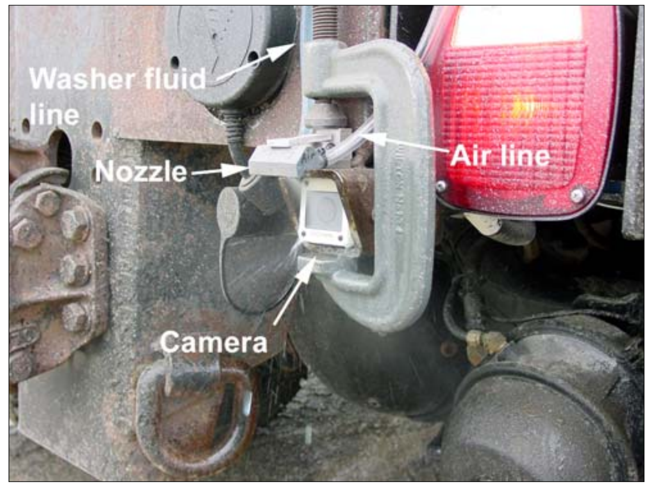

Figure 10.—Prototype lens cleaning system.

During the winter tests, one camera failure was experienced. A short circuit occurred in the internal components of the camera head and was repaired by Intec. Cable connections were somewhat corroded due to the de-icing chemicals and salt used on the roadways. The corrosion was slight and did not cause any system malfunctions during the course of the tests.

SYSTEM 3:

Hindsight 20/20 ultrasonic sensor system, model HS300
Distributor: Sonar Safety Systems, Santa Fe Springs, CA
Approximate cost: $400

System Description: This sonar-based system works by transmitting high-frequency sound waves and detecting reflections of these waves from objects within the sound beam. The maximum range of this system was specified as 2.7 m (9 ft). It consisted of two sensors with rubber enclosures, an alarm display with LED's and an audible alarm that changes frequency depending on distance to the detected object, a cable junction box, and cables (figure 11).

Test Results-Dump Truck After some experimentation to find a suitable mounting position, the sensors were placed near the taillights on the hitch plate, as shown in figure 12. The sensors were mounted at a height of 76 cm (30 in) with 81 cm (32 in) spacing. Spacing greater

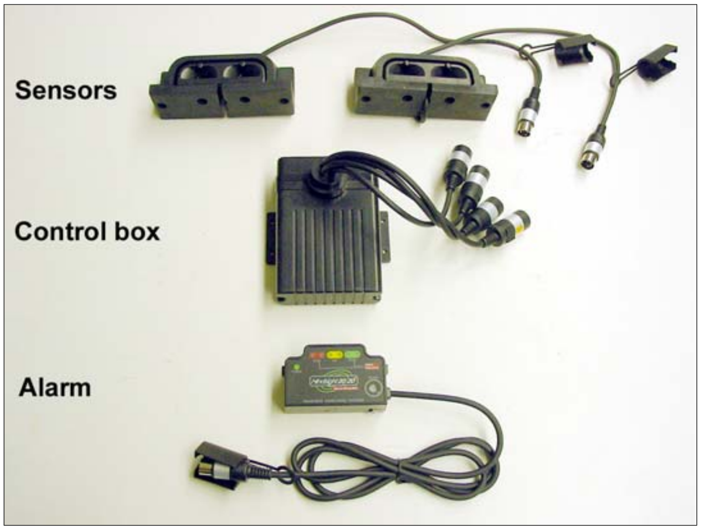

Figure 11.—Hindsight sonar system (two sensors).

Figure 12.—Hindsight system sensors mounted on dump truck.

than this, e.g., on the lower corners of the dump box, resulted in missed detection of a person near the truck between the two sensors. Furthermore, it was desired to mount the sensors in a location that would not be disturbed by the replacement of the dump box with a sand hopper in the winter. The alarm was mounted on the driver's side of the dashboard. The detection zones for a standing and crouching person are shown in figure 13; this system had a detection range of 2.4 m (8 ft).

The system was tested during the summer months on road-patching and material-hauling jobs. No evaluation forms were turned in, but comments from drivers were received through interviews and are summarized below.

- The system was reliable, and false alarms were rare in most situations.

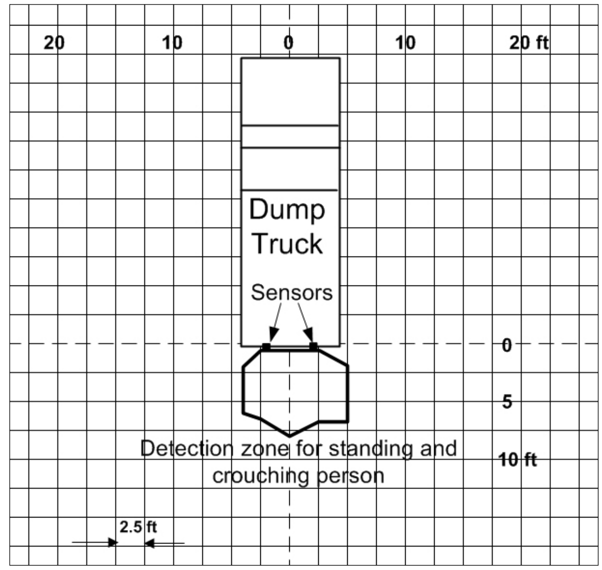

Figure 13.—Detection zone for Hindsight system on dump truck.

- The system produced false alarms when backing through thick airborne dust.
- The system alarmed continuously when a trailer was pulled behind the truck, and there was no way to turn the system off temporarily (without disconnecting it).

Modifications will be needed for this system to function on trucks that pull trailers. This is true for all sensor-based systems that do not require object motion for an alarm. Sonar Safety Systems sells an add-on to the system that detects when a trailer is present by sensing when the trailer light connector is plugged into the truck. If the trailer lights are connected, then the system disables the truck-mounted sensors and switches to sensors on the trailer. This was not tested, but would be an acceptable solution.

Sensing dust was a problem with this sonar system according to the drivers, which brought up concerns about false alarms in snow and rain. Drivers did not notice false alarms in rain. The manufacturer did acknowledge the possibility of false alarms in heavy snow. Additional tests are needed to determine what precipitation rates would cause an alarm, if any.

Concerns were also raised regarding the short detection range of the system. A person immediately behind a very slow-moving truck might be detected in time for the driver to react. However, in fast-moving situations, 2.4 m (8 ft) of detection does not give adequate time to respond (Society of Automotive Engineers, 1999).

At the end of the summer, the system was removed and inspected. All components were in good working order.

Test Results-Sanding/Plow Truck In the winter following the summer tests, the dump box was removed from the truck chassis and replaced with a sand hopper. A snow plow was also attached to the front of the truck. In this new configuration, mud flaps attached to the sand hopper platform hung down near the sonar sensors. The flaps caused false alarms on the sonar system. An alternative mounting configuration was not found that would allow the sensors to remain on the hitch plate, so tests were not conducted during the winter months with this system. An alternative mounting site could have been possible, but probably would have required the sensors to be mounted on the sand hopper platform. This was not desired because of the sand hopper is removed seasonally and subsequent reinstallation of the sensors and wiring on the dump truck would be timeconsuming.

Test Results-Utility Vehicles: Tests on two utility vehicles were conducted with the sonar system. These types of vehicles are involved in a high percentage of the backing incidents experienced by WSDOT. A Ford Explorer and a pickup with a large walk-in box were chosen for these tests, which had been in progress for 7 months at the time of writing this report.

A single sensor system (HS100) was mounted on the receiver hitch of the Ford Explorer (figure 1*B*) at a height of 50 cm (20 in) at the center of the vehicle. The alarm display was mounted in the rear cargo area of the cabin and near the upper right corner of the rear window. This was the recommended mounting position and allowed the driver to see the warning lights when looking over the right shoulder while reversing. Power for the system was taken from the reverse lights. The detection area for a person covered the width of the vehicle and extended to 2 m (6.6 ft) from the bumper in a rectangular shape.

Comment forms were received from the driver, and periodic interviews were conducted. Early in the tests, the system did occasionally generate false alarms from detecting the ground, and consistent alarms when backing to a concrete curb approximately 13 cm (5 in) high. To reduce these alarms, the sensor mounting bracket was adjusted so the sensor had an upward angle of 5 degrees. This modification eliminated false alarms and most curb alarms. There is a tradeoff to angling the sensor upward any further because this can cause the system to miss rocks or other objects that need to be avoided.

During the warmer months, the driver stated that the system worked reliably. False alarms were rare. Weeds or tall grass behind the truck did cause alarms, but the driver did not feel this was too much of a nuisance. He stated the system warned him of nearby vehicles several times, which caused him to be more cautious when reversing. The main concern for this driver was that the detection zone was too small to provide adequate warning when reversing at higher speeds or when turning and reversing at the same time. During the winter months, the driver did not see any reduction in sensor performance. He was careful to remove any snow built up on the sensor before driving the vehicle. It is important to note that the driver requested that the system be left on the vehicle after the tests were completed.

On the pickup truck (figure 1*D*), a two-sensor system was tested (HS300). This vehicle was wider than the Ford Explorer and required two sensors for adequate detection. The sensors were mounted near the ends of the rear bumper at a height of 46 cm (18 in) and a spacing of 1 m (39 in), as shown in figure 14. The alarm display was mounted in the cab on the dashboard. The sensor configuration resulted in a detection area for a person that was similar to that in figure 13. It covered the width of the truck and extended 2.5 m (8.2 ft). Early in the tests the system generated false alarms when the truck was moved in reverse in a clear area on asphalt or gravel surfaces. The sensor mounting brackets were modified so the sensors had an upward angle of approximately 5 degrees. This eliminated false alarms on flat ground, but still allowed a 13 cm (5 in) high curb to be detected.

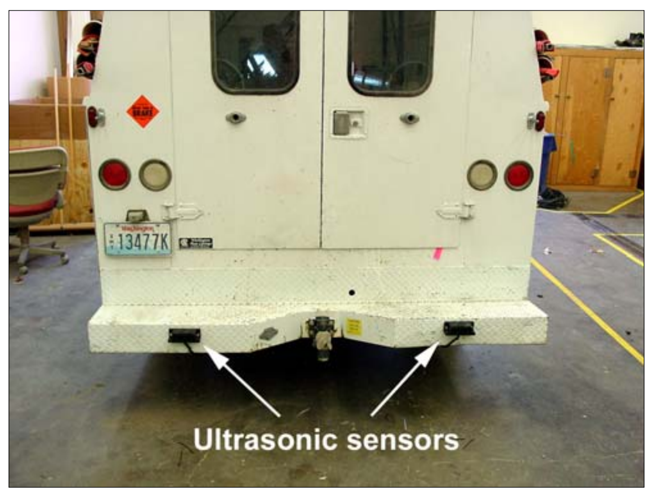

Figure 14.—Hindsight system sensors mounted on pickup.

The system was tested through the spring and summer, and driver comments were obtained through periodic interviews. The driver stated that false alarms were very rare, but nuisance alarms were common. Nuisance alarms were especially frequent on road construction job sites where barriers, cones, and other equipment were commonly near the truck. The driver stated that the nuisance alarms affected his ability to trust the system. The driver did appreciate that the system could warn when a person entered the rear blind spot of the truck, but he stated that this situation was rare and was not experienced during the tests.

This truck was not used during winter months, so no feedback was received for winter use. The driver requested that the system be removed after the testing was completed.

CONCLUSIONS

While many more collision warning and cameras systems are available than were tested here, tests of the above systems did show the challenges associated with implementing these types of systems on trucks used in the winter or in congested highway work zones. The following general observations can be made based on these test results.

- Highway construction zones are typically crowded with equipment and workers on foot. Sensor-based collision warning systems, e.g., radar or sonar, will alarm often in this environment. These alarms will most often be nuisance alarms caused by workers or objects of which the driver is already aware or that are not in danger of being hit. If too many alarms are associated with objects that are not in real danger, all alarms will eventually be ignored. For this reason, camera systems may be more appropriate in this environment.

- The alarm functions of sensor-based systems provide a warning to the driver and are a more positive method of monitoring, while camera systems are a more passive technology, much like mirrors. Using the two systems in combination on the same truck may have many advantages. The camera system provides an actual view of the blind area near the truck and provides a method to check the source of any alarms. At the same time, the sensor provides an alarm that prompts the driver to check the video monitor so that the potential for a collision does not go unnoticed. There would still be a problem with frequent nuisance alarms in highway work zones, but they may be more tolerable if there is a quick method of checking the source of any alarm.

- If sensor-based systems are implemented on a vehicle, some method must be used to eliminate false alarms from mud, dirt, or snow build-up on the sensing portion of the system. This can be done using processing methods that ignore object detection directly in front of the sensor or by using some other means that prevents debris from blocking the sensor's signal.

- Most trucks used in construction are also used to pull trailers. Most sensor-based collision warning systems will sense the trailer and produce an alarm. Some method must be provided to disable the system when a trailer is being pulled or allow quick connection to separate sensors mounted on the trailer.

- Cameras work well during warmer months, and daily cleaning of the lens is usually sufficient. However, on some types of equipment, snow and grime build up on the lens quickly during winter months. Some method of preventing snow, ice, and grime from covering the camera must be employed.

- It is often difficult to find a mounting position for sensors or cameras, especially on dump trucks. Mounting these devices on the side of the dump box was found to be an acceptable solution if the size of the device will allow this. If the dump box is removed seasonally, it may be desirable to mount the sensor or camera in a position where it will not need to be remounted and the wiring rerouted. Mounting near the bumper/hitch area is acceptable, but the increased exposure may shorten the sensor or camera's life and may cause the camera lens to be obscured more quickly.

- Many camera and sensor systems are available for automobiles and on-road trucking. The construction equipment application is more demanding and harsher than standard transportation applications. It is important to choose systems made for and proven on heavy construction equipment.

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