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Recommendations for Evaluating & Implementing Proximity Warning Systems on Surface Mining Equipment

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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Public Health Service
Centers for Disease Control and Prevention
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Abbreviations

AMT	Advanced Mining Technology
FCC	Federal Communications Commission
FEL	Front-end Loader
FMCW	Frequency Modulated Continuous Wave
FOV	Field of View
ft	Feet
GHz	Gigahertz
GPS	Global Positioning System
HASARD	Hazardous Area Signaling and Ranging Device
IP	Internet Protocol
KHz	Kilohertz
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LF	Low Frequency
m	Meter
MHz	Megahertz
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
PDOP	Positional Dilution of Precision
RF	Radio Frequency
SA	Selective Availability
SAE	Society of Automotive Engineers
UK	United Kingdom
UWB	Ultra-wideband

Abstract

Researchers at the National Institute for Occupational Safety and Health, Spokane Research Laboratory, studied technology and methods that could reduce accidents involving surface mining equipment that collides with other vehicles or workers, or drives over an unseen road edge. These accidents are partially attributed to the lack of full visibility around these large pieces of equipment. Blind areas can be extensive and this report presents plots of blind areas for five pieces of surface mining equipment. Several technologies designed for detecting obstacles in blind areas and providing a warning to the operator were evaluated on off-highway dump trucks. These proximity warning systems included radar, sonar, GPS, radio transceiver tags, and combinations of radar and cameras. A summary of test results is presented in this report, along with guidance on effective proximity warning technology, installation and maintenance considerations, and recommendations for effective implementation. This study found several commercially available systems that could effectively warn an equipment operator of an impending collision. Several new technologies also show promise for reducing these accidents. In most applications, it is recommended that sensor-based systems be combined with video cameras to provide important alarming functions along with an actual view of the blind area.

Acknowledgments

This study could not have been conducted without the assistance and expertise of the engineers, technicians, and managers at Phelps Dodge, Inc. The helpfulness, dedication, and professionalism of the following individuals are greatly appreciated: Jim Hanson, Mac McCauley, Mark Bartlett, Vivien Hui, and Jessica Morgan. The following NIOSH personnel are also gratefully acknowledged for their contributions to the project: Richard Rains, Mike Jones, Ted Lowe, Ron Backer, and Chelsea Woodward.

1 Introduction

Accidents involving surface mining equipment that collide with another vehicle, run over a pedestrian worker, or back over an embankment or other object are a major concern for mine workers and managers, regulators, insurance companies, and safety researchers. These accidents occur in spite of rules that require audible back-up alarms on mobile equipment (Code of Federal Regulations, 1999; Laroche, 2006). There are many factors that must be considered when looking at the cause of these accidents; including training issues, equipment design, equipment and job site operating procedures, worker fatigue, and equipment blind areas. Because the ultimate responsibility for the safe operation of equipment usually falls on the operator, there has been considerable interest in providing better information to the operator regarding obstacles and workers near the equipment. One method to improve situational awareness incorporates the use of sensors to detect nearby obstacles and workers and provide a warning alarm to the operator. These devices are referred to as collision or proximity warning systems.

In 1998, the Mine Safety and Health Administration (MSHA) proposed a rule change that would have required the installation of video cameras and proximity warning systems on surface mining haulage equipment to alert operators to objects and workers in their blind areas (MSHA, 1998). At that time, only camera systems were available and proven to work on surface mining equipment and concerns were raised by industry regarding the use of sensor-based monitoring systems. To better understand these concerns, researchers at the National Institute for Occupational Safety and Health (NIOSH) talked with mine safety personnel, equipment manufacturers, and engineers at MSHA. These stakeholders indicated that the main factors in the reluctance to implement proximity warning systems on heavy equipment included 1) a lack of field testing and research to determine the effectiveness of the systems, 2) poor reliability due to possibly high false alarm rates, and 3) poor reliability and high maintenance requirements due to the harsh environment in mines. Based on these discussions, NIOSH researchers decided that proximity warning systems needed further development and testing before they would be widely embraced by industry.

To this end, NIOSH started a research project in 2000 with three goals. The first goal included testing commercially available proximity warning systems on equipment used at mining operations. The second goal involved developing new technology or modifying existing systems to address the specific needs of this industry. The final research goal focused on making recommendations regarding testing and implementing this technology on surface mining dump trucks and other equipment. Partnerships were established with MSHA, Caterpillar, Inc., Phelps Dodge, Inc., and several proximity warning system developers to assist in this research. This report summarizes this NIOSH study that ended in 2006 and provides recommendations for implementing proximity warning systems on surface mining equipment based on tests at mining operations.

2 Problem

To better understand the extent of the problem, researchers studied fatal accidents that occurred at US surface mining operations and defined the blind areas around five large and commonly used pieces of surface mining equipment. This helped identify equipment that has a high risk of being involved in collisions and the areas near this equipment that should be monitored for obstacles or workers.

2.1 Recent Accidents

Fatalities at US surface mines that are at least partially related to the equipment operator's inability to see certain areas near the machine are displayed in table 1. Researchers collected this data from the MSHA fatality reports published between January 2000 through the first half of 2006 (MSHA, 2006). Equipment types with the highest number of fatal accidents were dump trucks (38%) followed by front-end loaders (33%). Distribution of accidents by mine type was fairly even among surface coal (29%), sand and gravel (29%), and stone operations (38%). There were no such fatalities in surface metal mines during the study period. The majority of accidents involved obstacles or workers in the rear blind area of reversing equipment (67%).

Table 1. Fatal accidents in surface mines partially attributed to blind areas around equipment.

Year	Description	Mine type	Equipment involved	Area where accident occurred
2000	Scraper backed over victim who was walking behind it.	Sand/gravel	Scraper	Rear blind area
2000	Front-end loader backed over victim who was working under the loader.	Stone	Front-end loader (FEL)	Underneath machine
2000	Coal truck backed over victim who was walking behind it.	Coal	Dump truck	Rear blind area
2000	Haul truck drove over victim who was walking in front of it.	Surface - mill	Dump truck	Front blind area
2000	Haul truck driver killed when truck backed over the edge of a dump point.	Coal	Dump truck	Rear blind area
2002	Front-end loader drove over victim who was walking in front it.	Stone	FEL	Front blind area
2002	Dump truck backed over victim who was standing behind it.	Stone	Dump truck	Rear blind are

Table 1 *continued*. Fatal accidents in surface mines partially attributed to blind areas around equipment.

Year	Description	Mine type	Equipment involved	Area where accident occurred
2002	Front-end loader backed over victim who was walking behind it.	Sand/gravel	FEL	Rear blind area
2002	Haul truck driver killed when truck backed over the edge of a dump point.	Coal	Dump truck	Rear blind area
2002	Front-end loader operator killed when it backed over a drop-off.	Sand/gravel	FEL	Rear blind area
2003	Haul truck drove over a van which was parked in front of the truck, two passengers killed.	Coal	Dump truck	Front blind area
2003	Front-end loader backed over victim who was walking behind it.	Sand/gravel	FEL	Rear blind area
2003	Front-end loader backed over a pickup truck, killing driver.	Stone	FEL	Rear blind area
2003	Haul truck driver killed when truck backed over the edge of a dump point.	Coal	Dump truck	Rear blind area
2003	Dozer operator killed when the dozer backed over the edge of a highwall.	Coal	Dozer	Rear blind area
2005	Worker run over while repositioning stacking conveyor.	Sand/gravel	Conveyor	Near wheels
2005	Scraper operator killed when machine drove over edge.	Sand/gravel	Scraper	Front and side blind areas
2005	Haul truck driver killed when truck backed over the edge of a dump point.	Stone	Dump truck	Rear blind area
2006	Worker run over by FEL on the surface of an underground mine.	Stone	FEL	Front blind area
2006	Dozer operator killed when the dozer backed over the edge of a highwall.	Stone	Dozer	Rear blind area
2006	Worker run over by reversing skid-steer loader.	Stone	Skid-steer loader	Rear blind area

2.2 Equipment Blind Areas

In order to fully understand the visibility limitations for various types of surface mining equipment, NIOSH and Steeleworks, Inc., of Denver, Colorado, conducted a study to define the blind areas near five pieces of commonly used machines including a haul truck, a front-end loader, an excavator, a bulldozer, and a motor grader (Steele, 2006). Figures in Appendix A show the blind areas as determined by a similar, but simplified visibility evaluation procedure described by ISO standard 5006 (2006). The first plot for each piece of equipment shows the areas where the operator cannot see the ground. The second plot shows the areas where an operator cannot see a 1.5 m (4.9 ft) tall person. Blind areas are indicated by grey shading. Areas visible using mirrors are indicated by hatched areas.

These blind area plots can be used as a guide to determine the effective placement of monitoring devices. For instance, the most significant blind areas on a haul truck (figs. A1, A2, A3) are to the front, the right side, and to the rear. Cameras or proximity warning sensors should monitor these areas. On a front-end loader (figs. A4, A5, A6) the rear blind area is a concern, but a raised bucket can also cause a significant blind area to the front. Large excavators (figs. A7, A8, A9) have extensive blind areas on the side opposite the cab and to the rear. These machines tram slowly, but the primary concern is an object or person within the swing radius. A tracked dozer (figs. A10, A11, A12) has significant blind areas to the rear and to the front when the blade is raised. Side blind areas are a concern too, because tracked or skid-steer machines can rotate quickly around the machine's center point. A large motor grader (figs. A13, A14, A15) has fairly good visibility if mirrors are used, but the front and rear blind areas are still of concern. Visualizing the extent of the blind areas can be an effective tool in reminding workers of the dangers of approaching equipment while on foot or in a smaller vehicle. Blind areas for many other types of smaller equipment used in mining and construction can be found in Hefner, 2003.

3 Approach

The objective of this study was to determine if off-the-shelf proximity warning systems could be used on mining equipment to monitor blind areas and assist the operator in avoiding collisions. If off-the-shelf technology was determined to be inadequate, researchers would then work with manufacturers to either modify their existing technology or develop new systems specifically meant for the mining application. The first step was to assess the state of proximity warning technology and identify systems that showed potential for surface mining equipment. The next step was to test those systems in a controlled setting with a dump truck to determine which systems should advance to field trials at a surface mine. Tests were primarily conducted using off-highway dump trucks because they were involved in many of the accidents listed in the MSHA reports. In most cases, systems that work on trucks can also be used on other equipment. The final phase of this work involved an evaluation of new technology and off-the-shelf systems on dump trucks during surface mining operations.

3.1 Technology Assessment

At the beginning of this study, many devices were available that could detect an obstacle near a vehicle and provide a warning to the driver. However, the most common applications for this technology were automobiles, recreational vehicles, delivery vans, and other on-highway trucks. Available technologies at the time consisted of radar, sonar, infrared sensors, and tag-based proximity warning systems, but very few systems were designed or marketed for off-highway construction or mining equipment. A brief discussion of the operating principles for these technologies follows.

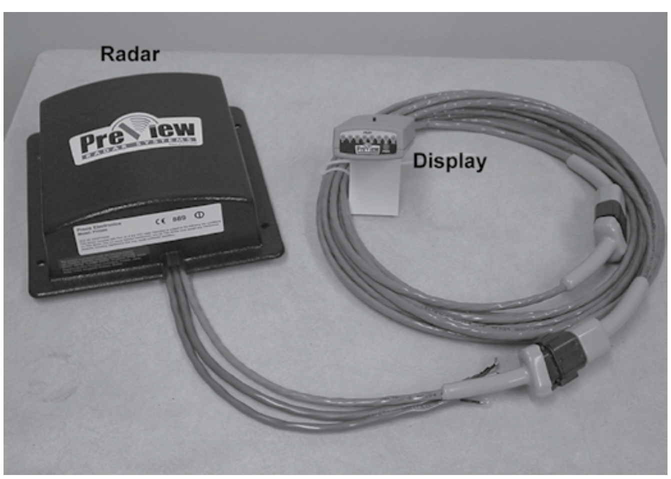

Figure 1. An example of a radar-based proximity warning system (early version of the Preview radar system by Preco Electronics).

3.1.1 Radar

Radar systems (fig. 1) transmit a radio signal from a directional antenna that is mounted on the vehicle. The radio signal is reflected off of objects that are within the transmitted beam and a portion of the reflected energy returns to the receive antenna, which causes an alarm to be generated. Typically these systems operate in the microwave (300 MHz - 40 GHz) portion of the radio spectrum. Doppler radar detects the relative motion of an obstacle, i.e., detection requires either movement of the obstacle or the vehicle. Pulsed or ultra-wideband (UWB) radar detects obstacles by measuring the time of flight of a pulsed signal that is transmitted and then reflected from an object within the radar's beam. Both types of radar are effective for detecting people, other vehicles, large rocks, and buildings. Some obstacles are not good radar reflectors, such as plastics, dry wood, or objects with large flat surfaces that can reflect signals away from the radar antenna. Possible obstacle detection ranges for a radar-based proximity warning system vary from less than a meter to 30 meters or more. To accommodate the wide detection areas typically needed for surface mining equipment, multiple antennas may be required for full coverage. For more information see Skolnik, 1990 and Ruff, 2002. Several radar-based proximity warning systems were available at the beginning of this study and two progressed to field tests at a surface mine.

3.1.2 Sonar

Sonar or ultrasonic sensor systems (fig. 2) transmit pulsed sound waves and detect echoes from nearby objects. The frequency of the sound is above that of human hearing (greater than 20KHz). When this study was started, sonar systems for vehicles had very limited range—typically less than 3 m (10 ft). Multiple sensors were needed to cover the width of a large vehicle. These sensors can be sensitive to particles in the air (dust, snow, and rain) and must be kept fairly clean to avoid any debris buildup on the face of the sensor. Limited preliminary tests were conducted with one sonar system meant for delivery trucks and construction equipment (Ruff, 2001); however, due to the system's range of about 2.4 m (8 ft), the system was not tested in a mining environment. Improvements to these types of sensors are possible and new systems may be available that would be better suited for surface mining applications. For more information see Fink, 1989 and Massa, 1999.

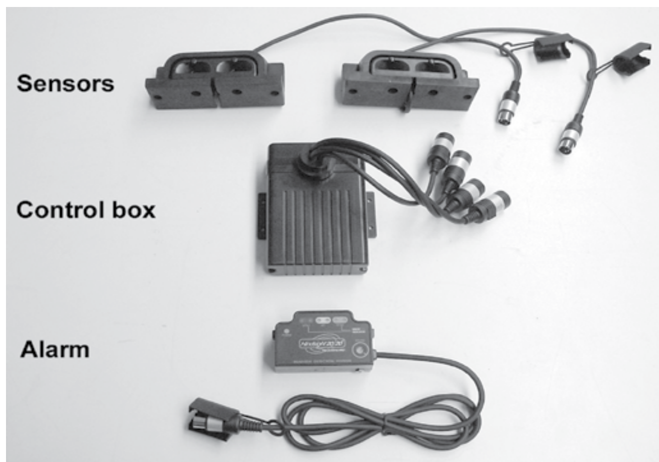

Figure 2. An example of a sonar or ultrasonic sensor-based proximity warning system (Hindsight 20-20 by Sonar Safety Systems).

3.1.3 Infrared

Infrared proximity sensors transmit an invisible infrared light beam and detect reflections from nearby objects. A few of these systems were available for refuse collection vehicles, utility trucks, and automobiles at the beginning of this study. Infrared proximity sensors were not evaluated due to limited detection range and concerns with reliable operation in the mining environment (Johnson et al., 1986). Improved systems with detection ranges of up to 9 m (30 ft) are now available and these technologies are gaining popularity in some construction and industrial applications. It is not known how effective they would be in a mining environment and they should be included in any future test programs. Infrared video cameras (thermal imagers) detect the thermal signature radiated from a person and provide an enhanced image, especially in low-light conditions. Applications of these devices for avoiding collisions between vehicles and people were in the early stages of commercialization at the beginning of this project and were also not formally tested. For more information on infrared-sensing technology and thermal imaging see ITC, 2006.

3.1.4 Tag-based

Tag-based proximity warning systems use electronic tags that are worn by workers, attached to small vehicles, or attached to stationary objects. Tag detectors or readers are installed on mobile equipment (fig. 3). Two methodologies are popular. The first requires the tag to transmit a marker signal that is detected by the tag reader. If the tag is within a certain range (determined by either signal strength or time-of-flight methods), an alarm is generated in the cab of the equipment. Two-way communication between the reader and the tag allows alarms to be generated at the tag also. The second method is similar, but the reader transmits the marker signal. If a tag detects this signal, an alarm condition is sent to the reader and an alarm is generated both in the cab and at the tag. Several technologies have been used to generate the marker signals that determine tag proximity: ultrasonic, magnetic, and radio frequency (RF). At the beginning of this study, several of these systems were being developed for mining applications and early versions of five tag-based systems were selected for preliminary tests on a small dump truck at NIOSH (Ruff, 2000; Ruff, 2001). By 2006 at least six systems were commercially available and some were being used at surface mining sites outside of the United States. Limited tests at a surface mine were conducted for two of these systems during this study.

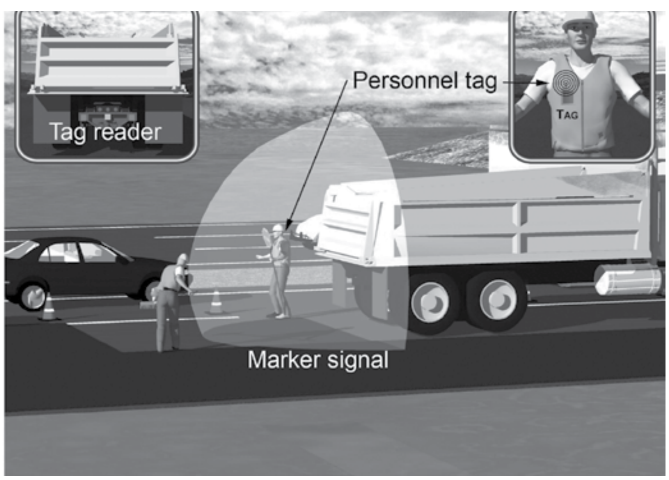

Figure 3. Illustration of tag-based system operation.

3.1.5 System Selection

Proximity warning systems selected for preliminary tests consisted mainly of those that used radio frequency electromagnetic waves (including low frequency (LF) and microwave). This transmission medium was thought to be the most robust for the mining environment due to its ability to transmit through any environmental conditions (rain, snow, dust, and extreme temperatures), its ability to transmit long ranges at relatively low power levels, and its tolerance of moderate amounts of dirt or mud buildup on sensor components. Not all available systems could be tested, but a representative sample of systems provided general information on the advantages and disadvantages of a particular technology. Recommendations are therefore applicable to a technology type in most cases, not just the particular system tested.

3.2 Preliminary Tests

Figure 4. Preliminary tests conducted using a 50-ton-capacity off-highway dump truck.

Preliminary evaluations of systems that showed potential for use on mining equipment were conducted at the NIOSH Spokane Research Laboratory using a 50-ton-capacity, rigid frame, off-highway dump truck (fig. 4). While smaller than trucks typically used at surface mining operations, the 50-ton truck provided a test bed that allowed researchers to determine important parameters for each system. This task occupied researchers for the first two years of the study, as systems were selected for preliminary tests, evaluated under controlled conditions, modified to meet the needs of large equipment, and retested. Several systems went through this process as described in early reports by this author (Ruff, 2000; Ruff, 2001). Mounting considerations, false alarm rates, and detection zones were determined and this information was used to select systems for more extensive tests on larger trucks at a surface mine.

Most accidents resulting in injuries involve a piece of equipment colliding with either a pedestrian worker or a smaller vehicle. Thus, the detection zones for a person and a passenger vehicle were recorded for each candidate system. At the beginning of the tests, there were questions regarding the use of standardized test objects to simulate people or vehicles. For instance, trihedral corner reflectors, metallic spheres, and test manikins have all been used to evaluate radar systems (Skolnik, 1990; SAE, 1999). A study was initiated that compared the detection of all of these objects to that of an actual person and found that the most accurate results were obtained when a person was used to determine detection characteristics (Ruff, 2002). See Appendix B for a suggested proximity warning system evaluation procedure using a person and a passenger vehicle.

Systems that passed the initial tests were then taken to a surface mine to be tested on larger trucks used at the mine. The following criteria were used to select systems for field tests:

- Ability to reliably detect a person and a passenger vehicle near the truck and at a distance of at least 6 m (20 ft) from the truck (front and rear)
- Ability to provide an effective alarm to warn the truck driver of a nearby obstacle

- Low false alarm rate
- Apparent ability to handle the harsh environmental conditions at a mining operation
- The ease with which the system could be installed without making extensive modifications to the truck
- Reasonable cost (under approximately US$15,000 per truck)

3.3 Field Tests

After the preliminary tests were completed, researchers chose the most promising systems for tests at a mine site. A cooperative agreement with Phelps Dodge Morenci, Inc., Morenci, Arizona, was established that allowed NIOSH and system manufacturers to test systems on Caterpillar model 793 and 797 dump trucks used in mine production. The extent of the test depended on the type of system tested. For instance, radar systems do not depend on any other infrastructure or communication with obstacles—all components for the proximity warning system are on the truck. On the other hand, tag-based systems require potential obstacles and workers on the mine site to be outfitted with electronic tags. For a meaningful test, a significant number of employees and light vehicles would need to be outfitted with tags and this was cost prohibitive. For these reasons, more extensive tests during production were possible for radar-based systems, while tests of tag-based systems were limited to short-term trials or simulated load-haul-dump cycles.

On some trucks, evaluation forms were given to the truck drivers at the end of each shift and they were asked to provide feedback on how the system was operating and if it was helpful. Appendix C contains an example of a form used for collecting comments. Researchers also collected performance data during direct observations and informal driver interviews. Quantitative data was obtained during tests of the radar systems by recording all radar alarms along with time-stamped video footage of the areas being monitored by radar. This allowed researchers to later view the video and corresponding alarms to determine what caused the alarm and classify it as true, false, or nuisance (defined in section 4.1). While the focus of the tests was to determine the effectiveness of sensor-based systems, cameras were also used during some of the tests, resulting in some general recommendations regarding their use.

3.4 New Technology Development

During the early stages of this study, proximity warning systems marketed specifically toward surface mining equipment were rare. This prompted researchers to take a parallel approach by fostering the development of new technology while at the same time evaluating and improving existing technology. New systems were proposed and prototypes were developed in cooperation with industry partners. These new technologies included ultra-wideband (UWB) radar, a system based on the global positioning system (GPS), a stereovision system using advanced video processing techniques, and a tag-based system originally developed for underground mining equipment by researchers at the NIOSH Pittsburgh Research Laboratory. A summary of test results for these new systems is also included in the following section.

4 Test Summaries

4.1 Preview Heavy Duty Radar (from Ruff, 2006)

The most comprehensive field tests during this study were conducted on the Preview Heavy Duty Radar System from Preco Electronics, Boise, Idaho, which is packaged and marketed for off-highway earth-moving machinery. The system uses pulsed radar and time-of-flight signal measurements to sense the presence of and determine the distance to an object within the radar beam. An alarm display is mounted in the cab of the truck and provides both audible and visible warnings. A series of light emitting diodes (LEDs) light up in succession, and the warning tone changes frequency to indicate the distance to an object. Originally, the system consisted of one radar antenna per alarm display (fig. 1), but the detection area for one antenna was not adequate for large equipment. After suggested modifications were made during the course of the tests, the latest Preview system now allows multiple antennas to be networked to a single alarm display. This allows the system to monitor blind spots at the front and rear of the mining equipment.

A camera system from Vision Techniques, United Kingdom (UK), (consisting of one camera mounted on the rear axle of the truck, one camera mounted on the front of the truck, and a video monitor in the cab) was also installed on the truck to provide researchers and truck operators with a visual check of the front and rear blind areas. The camera view automatically switched between front and rear, depending on gear selection.

The camera and radar systems were mounted on a Caterpillar 793B 260-ton-capacity dump truck at the Phelps Dodge Morenci, Inc., copper mine in Morenci, Arizona. Two radar antennas were mounted on the rear axle of the truck (fig. 5), and two were mounted on the front bumper (fig. 6). The rear-mounted antennas required a special bracket so that the antennas could be mounted without welding on the axle casing. The rear antennas were also angled in toward each other by approximately 15° so that their beams crossed, providing a wider detection area behind the rear dual tires. The radar alarm display was mounted in the cab just above the dispatch system screen to the right of the operator's seat (fig. 7). For the final system, a single alarm display indicated the presence of objects either to the rear or in front of the truck, depending on gear selection.

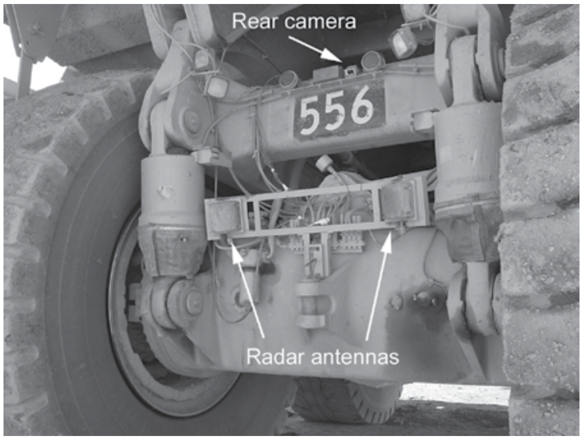

Figure 5. Preco radar antennas and Vision Techniques camera mounted on the rear of a haul truck.

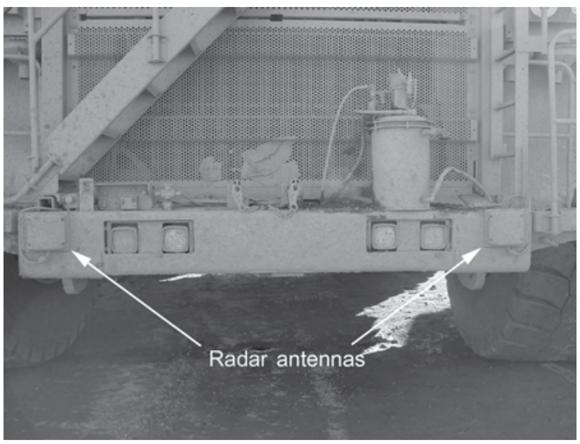

Figure 6. Preco radar antennas mounted on the front bumper of a haul truck.

Figure 7. Preco radar alarm display mounted in truck cab.

To determine the dimensions of the radar detection areas at the front and rear of the truck, a plot was made for the detection of a standing person. The locations where the radar detected the person were marked on the ground and later plotted on a graph (fig. 8). Note that the rear detection area does not cover the immediate area near the rear tires of the truck. Early tests showed problems with the radar generating false alarms due to detection of the tires. For these tests, the radar system was calibrated

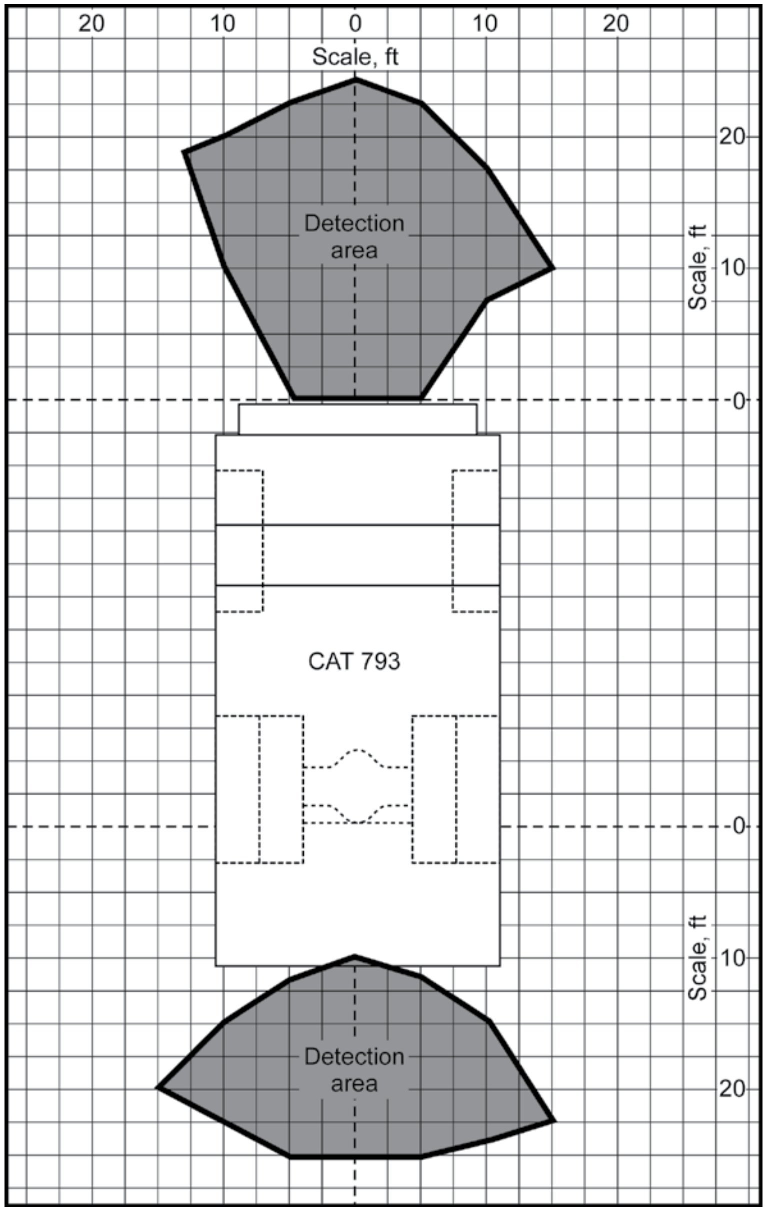

Figure 8. Preco radar detection areas for a person.

to ignore the tires, but this caused a person within 3 m (10 ft) of the rear axle to be missed. The height of the radar antennas also contributed to this problem because a person could walk underneath the radar beam when close to the antennas. While the rear detection area was not ideal, a trade-off must be made between close detection and false alarms from tires or other structures protruding from the truck. The outer range of the detection area was not affected by these limitations, and a person was detected at a distance of 7.6 m (25 ft) from the truck's rear axle. The front detection area extended from the front bumper to a distance of 7.6 m (25 ft).

The radar detection area for a person and the camera field of view (FOV) were then compared using video footage. It was important that the radar detection area was

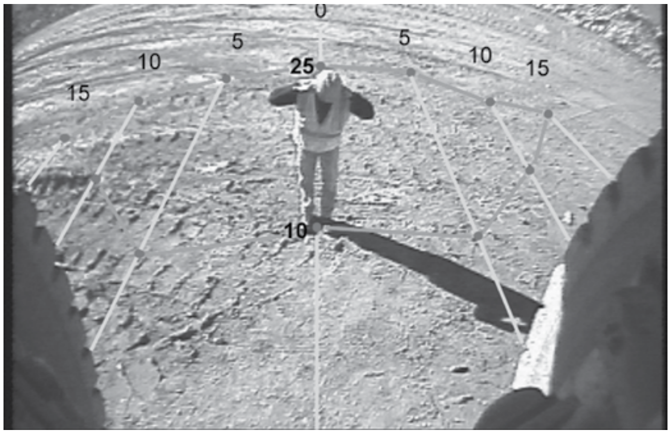

Figure 9. Rear radar detection area as seen from the video monitor (distances in ft).

Figure 10. Screen shot of video viewing software showing berm and radar alarm indicator (upper right).

totally contained within the camera's FOV so that the cause of radar alarms could be verified by the operator and by researchers. Figure 9 shows the rear camera view with the detection area overlain on the video screenshot. This graphic allowed researchers to estimate the distance between the back of the truck and objects in the camera's FOV during data analysis. Distances from the centerline of the truck were marked in increments of 1.5 m (5 ft) on longitudinal lines. Distances from the axle were marked along the centerline.

The researchers wanted to determine what types of objects were detected by the radar system and how often the system would alarm during the course of normal operations. To do this, video footage from the rear camera was recorded on a digital video recorder. The recorder also saved the date, time, and duration of all radar alarms from the rear system. When the video footage was reviewed, the recorder software overlaid text on the video to signify that an alarm had occurred. Figure 10 shows a screenshot of the recorder viewing software. The "Radar" text on the upper right of the video indicates that an alarm was occurring during that segment.

Video and radar alarms from the rear-mounted systems were recorded for 24 hours each day for seven days while the truck was in use during normal operations. This consisted mainly of the load, haul, and dump process and occasional parking maneuvers for break time or truck maintenance. Video and radar alarms were recorded only when the truck was in reverse gear. Because of data storage limitations, data from the front of the truck were not collected. Researchers later manually reviewed the seven days of video footage for five variables. These variables included date and time of reverse movement of the truck, the activity of the truck (loading, dumping, and parking), the alarm type based on what was visible in the video during the alarm (true, false, nuisance, or missed), and a description of what was visible in the video.

A radar alarm was considered true if an object larger than approximately 30 cm (12 in) high was inside the area contained in the detection area of the radar. For example, true alarms occurred when a large rock, a person, or another vehicle was detected by the radar. True alarms were further classified to distinguish those that required extra caution or immediate braking action from those that did not require any attention from the operator (nuisance alarm). Nuisance alarms are defined as those alarms caused by objects of which the operator is already aware and which pose little or no risk. Nuisance alarms are partially determined from context because the truck operator's awareness is assumed. For example, backing to a rock pile in the loading area presents little risk because (1) the truck tires may contact the rock pile without causing damage, (2) the truck cannot over-travel the rock pile, and (3) the operator is aware of the rock pile and positioning the truck while moving at a slow speed. On the other hand, detecting the berm at a dump point is considered a true alarm, not a nuisance alarm, even if the driver is aware of the berm. Backing to a dump point requires extra caution and over-traveling the berm, in most cases, would result in the truck going over the edge of a high embankment.

An alarm was considered false if no object larger than 30 cm (12 in) high was present inside the detection area. False alarms included detection of ruts, small dirt berms, small rocks, or foliage. Missed alarms occurred when a large object was within the radar detection area, but no alarm was generated. These events are summarized in table 2 according to the number and types of alarms recorded during a seven-day period.

Table 2 - Radar alarm data

Event	Quantity	Percentage
Reverse movements of truck	618	
Total alarms	580	
True alarms (requiring action or extra caution)	235	40% of all alarms
False alarms	102	18% of all alarms
Nuisance alarms	243	42% of all alarms
Missed alarms	0	
Reverse movements with no alarm	38	

During the 7-day test, the truck was moved in reverse 618 times. Ninety-four percent of the time, an alarm was generated during reverse movement, but only 40% of alarms actually required immediate action or extra caution from the truck operator. The high number of alarms that do not represent dangerous situations, including false and nuisance alarms, will be problematic if operators lose confidence in the system and start to ignore alarms altogether (Breznitz, 1984; Bliss et al., 1995).

A trade-off exists between adequate sensitivity for detecting objects near the truck and the probability of false alarms (Parasuraman et al., 1997). Sensor manufacturers have an understandable propensity toward alarming because of the potentially high cost of a missed detection. If an object as small as a person must be detected, then other objects, such as ruts or rocks, may be detected also. Nuisance alarms are unavoidable, but methods can be incorporated that allow the source of the alarm to be verified. If verification does not increase driver workload, e.g. a quick look at a video monitor, nuisance alarms may be better tolerated.

The following additional observations were made during these tests:

- Mounting positions for the radar antennas are critical and require trial and error to eliminate false alarms from tires or structures on the truck itself.
- System sensitivity settings can effect false alarm rates and detection zone dimensions; experimentation may be required to obtain optimal detection.
- The presentation of audible alarms in the cab may be more important than the visual alarms provided by lamps or LEDs. Drivers may not look at the alarm display, especially while reversing.
- This system reliably detected large obstacles such as people, other equipment, passenger vehicles, and large rocks or rock piles.
- Nuisance alarms are inevitable because maneuvering is required near objects that are not in danger of being hit.
- A simple and quick method to check the source of alarms must be provided. A camera view of the area being monitored is sufficient.
- The detection range of 7.6 m (25 ft) is only effective for slow moving situations.

4.2 Ogden Radar System

The Ogden radar system, manufactured by Ogden Safety Systems, Ltd., Yorkshire, UK, is used extensively on loaders and articulated trucks at mines and quarries in the United Kingdom. The system uses frequency-modulated continuous wave (FMCW) technology and operates between 13 and 14 GHz. The radar transmits a low-power signal and measures any return signals that are reflected from objects within its transmitted beam. The characteristics of the reflected signal contain information on distance and movement. Using this principle, it is possible to determine the speed at which the object is approaching the radar and the distance to the object. An alarm that consists of a single LED and an audible warning is activated in the cab of the truck when an object is detected by the radar. Tests of this system were limited because it is not yet approved by the Federal Communications Commission (FCC) for use in the United States.

The radar beam can be configured to meet the requirements of different mining equipment. The width and depth of the four zones within the beam can be adjusted to accommodate unique shapes for the detection zone. For example, on larger trucks, it is important to detect objects near the radar and inside the rear dual tires. But it is also important to detect objects immediately behind the rear tires, requiring a widening of the beam after the tires are cleared. This is a challenging requirement and the ability to shape the radar beam was unique to this system.

Tests were conducted at Phelps Dodge Morenci, Inc., on a Caterpillar 793B dump truck. The rear radar system was originally mounted near the light bar on the steel beam that runs above the axle at a height of approximately 2.7 m (9 ft) with a downward tilt of 15 degrees. This high mounting location resulted in a smaller detection zone than expected for a person because the person could walk underneath the beam when close to the truck. A lower mounting height was desired and a special bracket was made for the final mounting location at a height of approximately 2.1 m (7 ft) (fig. 11). A person could still walk under the beam when very close to the axle, but a lower mounting height was not available.

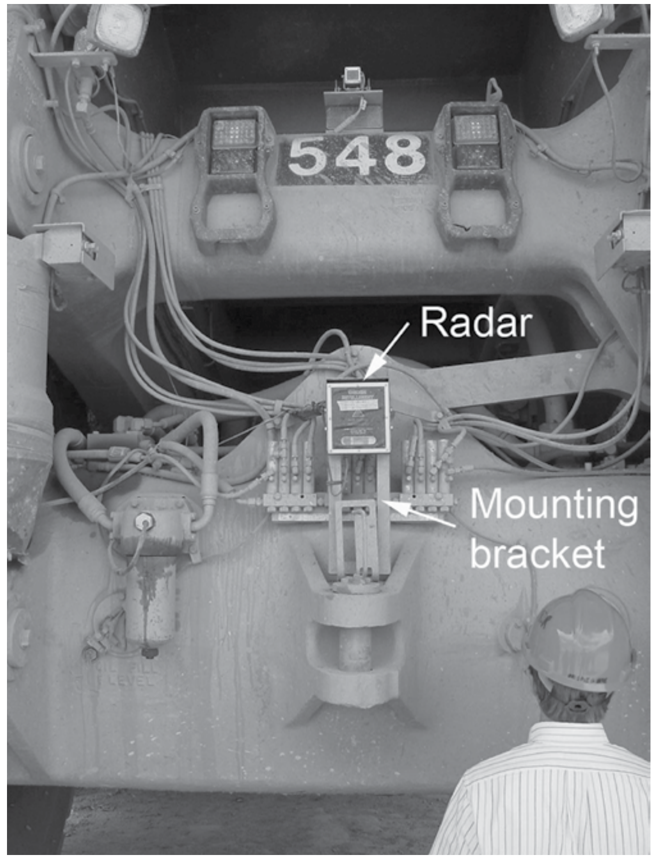

Figure 11. Ogden radar system mounted on the rear of a haul truck.

The radar system was tested for false alarms in a clear field while the truck was slowly moved in reverse. The Ogden radar did not detect the movement of the tires and did not generate false alarms. Also, no false alarms from the ground were seen as the truck moved in reverse. This system was left on the truck for several months and an attempt was made to obtain feedback from the truck drivers regarding the reliability of the system. It was difficult to draw any definitive conclusions from the comments on the feedback forms, so a video camera system was set up to collect video footage of the rear blind area that the radar was monitoring. The occurrence of radar alarms was also recorded with the goal of using the video to verify the cause of the alarms and provide information on the number of false and true alarms. Due to reliability issues with the mobile video cassette recorders that were used, an inadequate amount of video footage was collected. (The use of digital video recorders proved to be more reliable in other tests and supplied much-needed quantitative data as discussed in the previous section.)

Another short test was conducted in cooperation with Caterpillar, Inc., on a Caterpillar 785 150-ton-capacity truck at their proving grounds near Tucson, Arizona. This test determined the detection zone for a person with the radar system at a lower mounting position of 1.7 m (67 in). The radar system's detection pattern was set up by an engineer from Ogden Safety Systems using a laptop that was temporarily connected to the radar enclosure. The detection pattern can be customized to accommodate various truck widths and detection ranges and the settings were adjusted to result in a fairly large detection zone. The detection zone for a person was determined with the dump truck stationary. The detection zone for two people of different heights was recorded as shown in figure 12. The shorter person's zone was slightly different

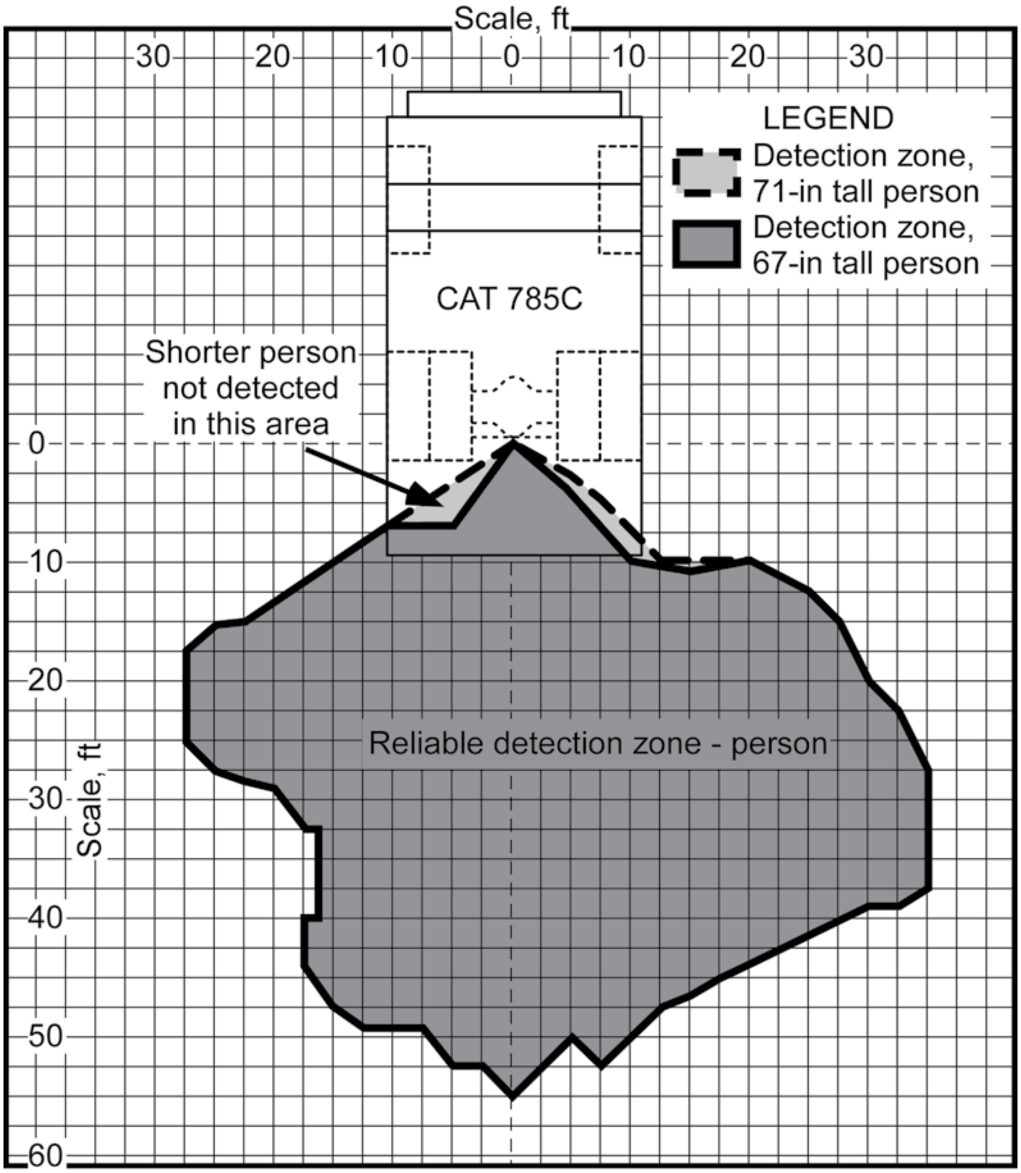

Figure 12. Ogden radar detection area comparing two people of different heights.

at points close to the radar due to the mounting height of the radar. The radar system was evaluated further by driving the dump truck around the test area and directly observing alarms in the cab.

The limited field tests at Morenci and at the Caterpillar proving grounds illustrated that the system had potential for monitoring blind areas if improvements were made. The following general observations were made using data from obstacle detection tests, video footage, and comments from drivers:

- This system reliably detected people, passenger vehicles, and rock piles that were within the radar beam.
- Due to the mounting height of the radar antenna on the larger truck, workers close

to the truck could walk under the radar beam undetected.

- Drivers complained of numerous false alarms. The cause of the alarms could not always be determined and no distinction could be made between false and nuisance alarms. The alarm display was found disconnected when inspections of the system were made.
- Changes to antenna mounting positions and system sensitivity would be needed to reduce false alarm rates. A representative from Ogden Safety Systems or someone very familiar with the radar setup software should be available to make adjustments to the radar sensitivity and zone configuration.
- Driving next to berms or other obstacles in forward or reverse caused alarms, even when the object was not in the path of the truck. Large detection zones require increased sensitivity that may result in more false and nuisance alarms.
- An occasional alarm was generated when the truck was jostled during gear changes (or loading) near berms or rock piles because relative movement was detected.
- Improved sealing of the enclosures was needed for the mining application after water was found to have entered the radar antenna enclosure.
- A redesign of the system would also be needed in order to meet FCC requirements that would allow it to be used in the United States (Ogden engineers are currently working on new versions of this radar).

4.3 Advanced Mining Technology CAS-CAM/RF System

The AMT CAS-CAM/RF system is a tag-based proximity warning system manufactured by Advanced Mining Technology, Chittaway Bay, New South Wales, Australia. It operates using radio frequencies (not approved by the FCC) and consists of radio transceivers (RF units) mounted on the front and rear of the haul truck and radio beacons or tags mounted on passenger vehicles (AMT, 2005). No wearable tags were available for workers at the time of these tests. Tags transmit a unique code that identifies the vehicle type. If a tag is within the preset detection zone as determined by the marker signal strength, the vehicle identifier is presented to the haul truck driver on a video display, along with an audible alarm. Multiple video cameras can be integrated into this system and camera views are also shown on the display. If detected by a haul truck, tags also generate alarms in the cab of passenger vehicles using a smaller and less expensive display.

Limited field tests of the AMT system were conducted on two Caterpillar 793B haul trucks, a dozer, and two passenger vehicles at Phelps Dodge Morenci, Inc. Phelps Dodge safety personnel conducted independent tests of this system over a period of several months, but NIOSH involvement was limited to assisting with the design of the tests and recording detection characteristics of the system. Consequently, only the detection characteristics for the system will be discussed.

The RF unit was mounted slightly off center on the rear of the haul truck using a custom bracket at a height of 2.4 m (8 ft) (fig. 13). Figure 14 shows the front RF unit mounted off center on the truck's railing at a height of 2.7 m (9 ft) and 0.6 m (2 ft). Figure 15 shows the light vehicle tag mounted on the roof of a passenger vehicle. The RF unit's ability to detect the passenger vehicle was determined by driving the smaller vehicle toward the haul truck (fig. 16), stopping the passenger vehicle as soon as an alarm was sounded in the cab of the haul truck, and recording the position of the center of the front bumper when the tag was detected (the tag was actually located 2.7 m (9 ft) from the front of the passenger vehicle and centered on the roof). Each of the zones for the front and rear of the haul truck (fig. 17) exhibited detection dissymmetry which could not be explained. The small area in the front detection zone where tag detection was sporadic may have been due to interference from a small conveyor stored near that area.

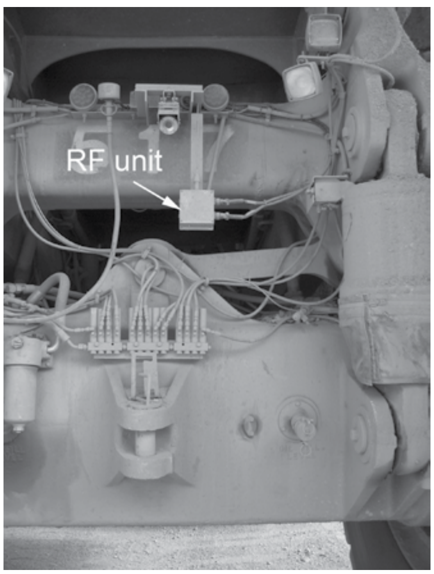

Figure 13. AMT RF unit mounted on the rear of a haul truck.

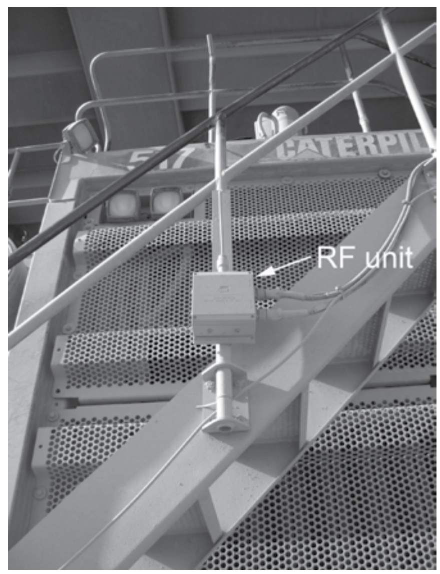

Figure 14. AMT RF unit mounted on the front of a haul truck.

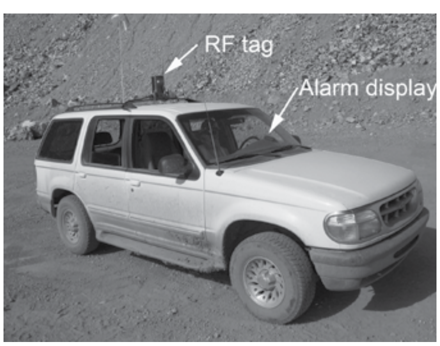

Figure 15. AMT RF tag mounted on a passenger vehicle.

Figure 16. Tests to determine the detection characteristics of the AMT CAS-CAM/RF system.

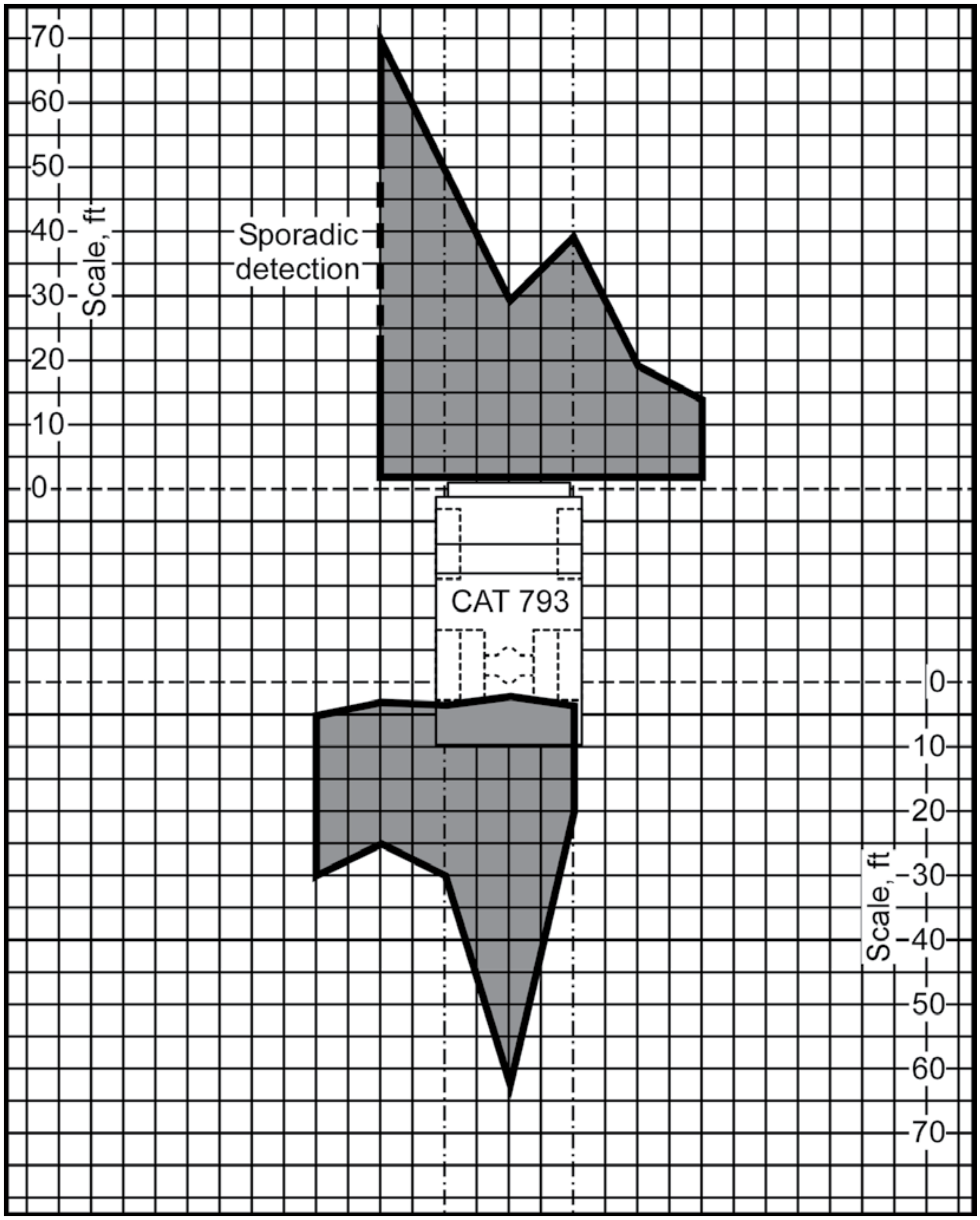

Figure 17. AMT CAS-CAM/RF detection zones for a passenger vehicle.

At the time of these tests, the system had been operating on all test vehicles during production for two months without failure. Adjustments to the detection ranges were made mid-way through the tests to change the distance at which small vehicles were detected by the haul trucks in order to decrease nuisance alarms. Detection range can be adjusted independently according to vehicle type, i.e., utility trucks can be set for one range and other haul trucks another.

This system demonstrates the potential to reduce collisions between large equipment and smaller vehicles. It is more expensive than radar-based systems, but it may have some advantages that include two-way alarming (both the haul truck driver and the small vehicle driver are alerted when the two are in close proximity), and a reduction in false alarms. The system tested did not protect pedestrian workers and this would be an important improvement. This product is in use in Australian mines and it is recommended that more extensive tests be conducted on this system or other tag-based systems in mines in the United States.

4.4 Ultra-wideband Radar (from Ruff, 2001)

In the early stages of this study, no radar-based proximity warning systems were available that had been developed specifically for large mining equipment. Multispectral Solutions, Inc., Gaithersburg, Maryland, developed an Ultra-wideband (UWB) radar system under contract with NIOSH in order to address specific issues related to the mining application. This contract resulted in the development of a prototype radar system that was tested on the 50-ton-capacity truck as described in the section on preliminary tests. Development did not continue and field tests were not conducted due to FCC concerns with UWB interference issues and limited funding. Recently, interference issues have been resolved and development work may resume (Fontana, 2004).

Ultra-wideband technology uses nanosecond radar signal pulses to produce a wide, instantaneous bandwidth waveform. It transmits at a center frequency of 5.65 GHz. The circuitry for a UWB system consists of a low-noise amplifier, broadband tunnel detector, and digital signal processing. A transmitter module emits UWB radar pulses at a fixed repetition rate from the transmitting antenna. A receiver antenna picks up both the transmitted pulse and pulses reflected from the environment and/or obstacles. A radio-frequency module amplifies and filters the pulses and sends them to a processing board. The transmitted pulse is picked up by one detector of a dual short-pulse detector (initialization pulse) while the second detector picks up target and clutter information. A high-speed time-detector circuit measures the relative positions of the two pulses and passes this information to a digital signal processor. The signal processor then performs calculations to control detector sensitivity and to convert the time difference to a precise measurement of distance to an obstacle.

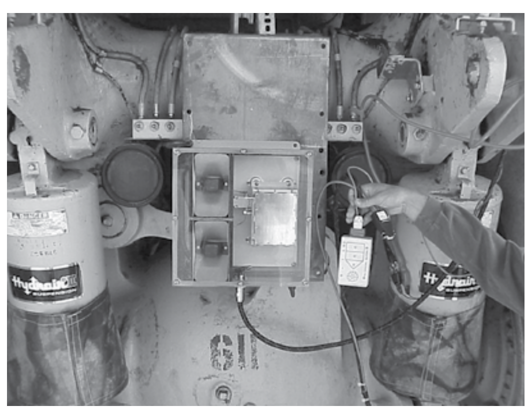

Figure 18. UWB radar and alarm display (right) on the rear of a 50-ton-capacity haul truck.

The first version of this radar had difficulty detecting objects close to the antennas and was only reliable from 9.1 to 13.7 m (30 to 45 ft) (Ruff, 2000). Modifications were made to remedy this problem and the system was retested. For the rear blind spot of the truck, the UWB radar system was mounted level near the light bar at a height of 137 cm (54 in) (fig. 18). Range information and an audible alarm were provided by the graphical alarm display. After making adjustments to minimize false alarms, the reliable detection zone for a person standing behind the truck was determined (fig. 19). This zone extended to 15.2 m (50 ft) from the radar system. The radar detected a person standing near the outer dual tires with small sporadic detection regions on the fringes of the detection zone. The detection zone was verified at several positions with the person remaining stationary while the dump truck moved in reverse. The rear detection zone for a pickup truck was also recorded (fig. 20). The plot indicates the areas where the pickup truck was detected with the front bumper as the reference point. The zone was 15.2 m (50 ft) in length and it adequately covered the width of the dump truck.

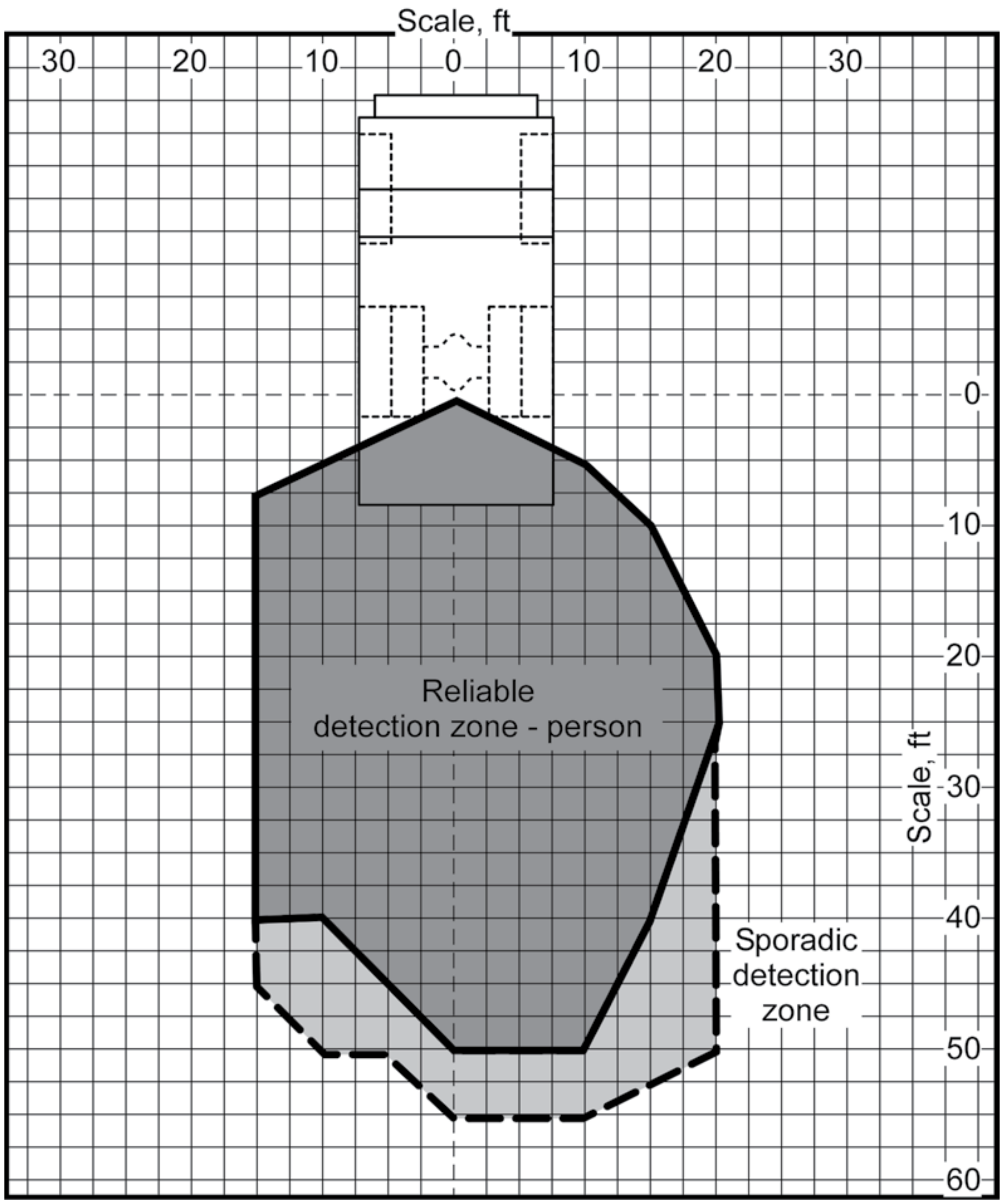

Figure 19. UWB radar detection zone for a person.

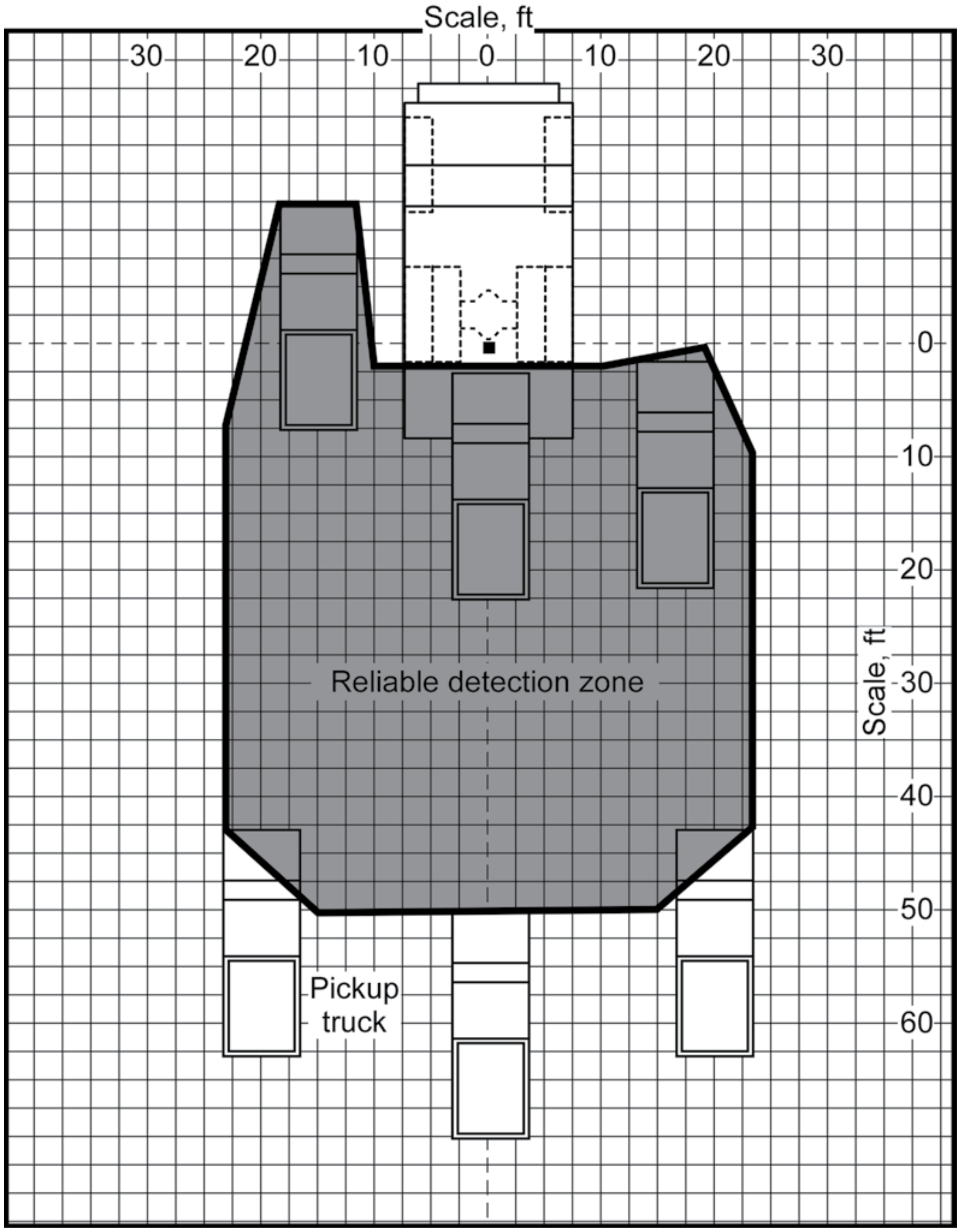

Figure 20. UWB radar detection zone for a pickup truck.

A proof-of-concept test to integrate a separate radar antenna to monitor terrain changes at the rear of the truck was also conducted. This separate test showed the potential for allowing the system to warn of nearby drop-offs, such as dump points, in addition to potential collisions. Development work is needed to further integrate these functions, but combining proximity warning with edge detection could provide a significant improvement to safety. The flexibility of this new radar design and its long detection range may provide desired characteristics not seen in other proximity warning systems. However, further improvements need to be pursued, such as hardening the system components and wiring to protect against weather and vibration, decreasing the size of the display and radar antenna enclosure, and addressing interference issues.

4.5 GPS-based Proximity Warning (from Ruff & Holden, 2003)

The concept for GPS-based proximity warning for mining equipment entails the use of differential GPS receivers and radios on all equipment having reduced visibility, all smaller vehicles on the mine site, and all pedestrian workers. This would allow the location of all moving objects to be determined and updated in real time. This information could then be transmitted and displayed to all nearby equipment operators to help avoid collisions. In addition, the location of stationary structures, such as buildings, utility poles, and dump points, can be stored in a database of potential obstacles. An alarm display in the cab provides a visible and audible warning when another vehicle, worker, or stationary obstacle is within a preset danger zone around the equipment.

In 2000, NIOSH and Trimble Navigation, Ltd., Sunnyvale, California, began developing a GPS-based proximity warning system. Prototypes were tested in an outdoor laboratory setting on passenger vehicles. Further development resulted in a mine-ready system that was demonstrated at Phelps Dodge Morenci, Inc., in 2002. The mine-ready system consisted of the following Trimble components: a GPS antenna; a Windows CE-based computer with LCD display to run the proximity warning software; an eight-channel, single-frequency, differential GPS receiver (integrated into the computer enclosure); and a SiteNet 900-MHz Internet Protocol (IP) radio. All of these components were designed for mounting on heavy equipment.

GPS was used to determine the location of the vehicle on which a system was mounted. Differential correction information from a base station was also received by the proximity warning system. The corrected location of the vehicle was then transmitted once per second via the IP radio to all other vehicles in the area equipped with a proximity warning system. The locations of other vehicles were also received by the IP radio and shown on the computer's display if they were within a specified range. The location of stationary obstacles, such as dump points, power lines, and mine buildings, did not require radio transmission. Their coordinates were entered into the system database and they were presented automatically on the vehicle's display.

For tests at Phelps Dodge Morenci, Inc., a complete proximity warning system was installed on each of the following pieces of equipment: Caterpillar 797 360-ton-capacity haul truck, Caterpillar rubber-tire dozer, and two service trucks (pickups). A base station was also installed on a nearby hill to provide differential correction information to the individual systems on the vehicles. The GPS antennas and IP radios were temporarily mounted on the mining equipment and service trucks in typical locations, usually on or near the cab roof. The computer was securely mounted in each vehicle in a fashion similar to a final, permanent installation. The proximity warning system software ran on this computer and displayed a screen for the equipment operator that showed his or her equipment in the center, the detection zone radius, the warning zone radius, system status, and icons representing other vehicles or stationary obstacles in the area (fig. 21).

Each vehicle's warning and detection zones were adjusted according to the vehicle's size. The display mounted in the Caterpillar 797 haul truck had a 30 m (98 ft) radius warning zone and a 60 m (197 ft) radius detection zone. The zones for the dozer and service trucks were set at 20 m (66 ft) and 40 m (131 ft) for warning and detection. Audible alarms were generated whenever another vehicle or stationary obstacle was detected in either zone. Also, the color of another vehicle's icon changed from green (outside both zones), to yellow (inside detection zone), to red (inside warning zone) as it approached the center of the screen.

The demonstration and tests were held in an active area of the mine where production traffic was at a minimum. The test area consisted of a simulated loading area at the bottom of a small pit, a haul road, a dump area, and a large open area (fig. 22). A truck loading and dumping cycle was repeated several times to evaluate the reliability of the system. Another separate test was conducted several times to demonstrate the accuracy of the system, which consisted of distance measurements between the dozer and haul truck. The dozer was slowly moved toward the haul truck and stopped when the haul truck's proximity warning system indicated that the dozer reached the 30 m (98 ft) warning zone. The distance was then measured to check system accuracy. The distance between the GPS antennas, accounting for differences in antenna height, averaged around 28 m (92 ft), a 2 m error for this test.

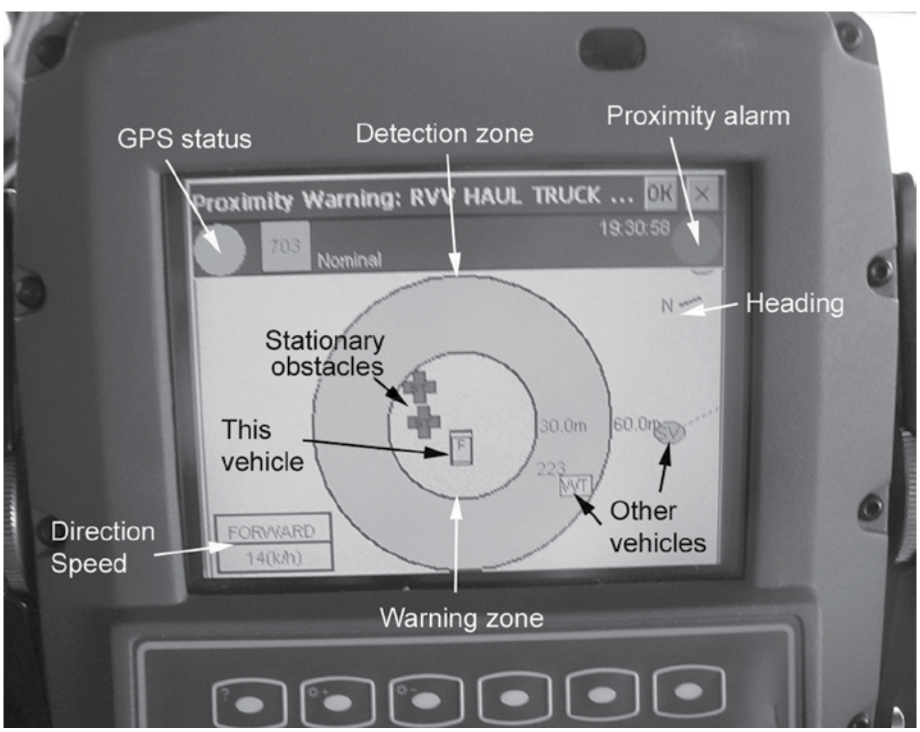

Figure 21. Operator's display for a GPS-based proximity warning system.

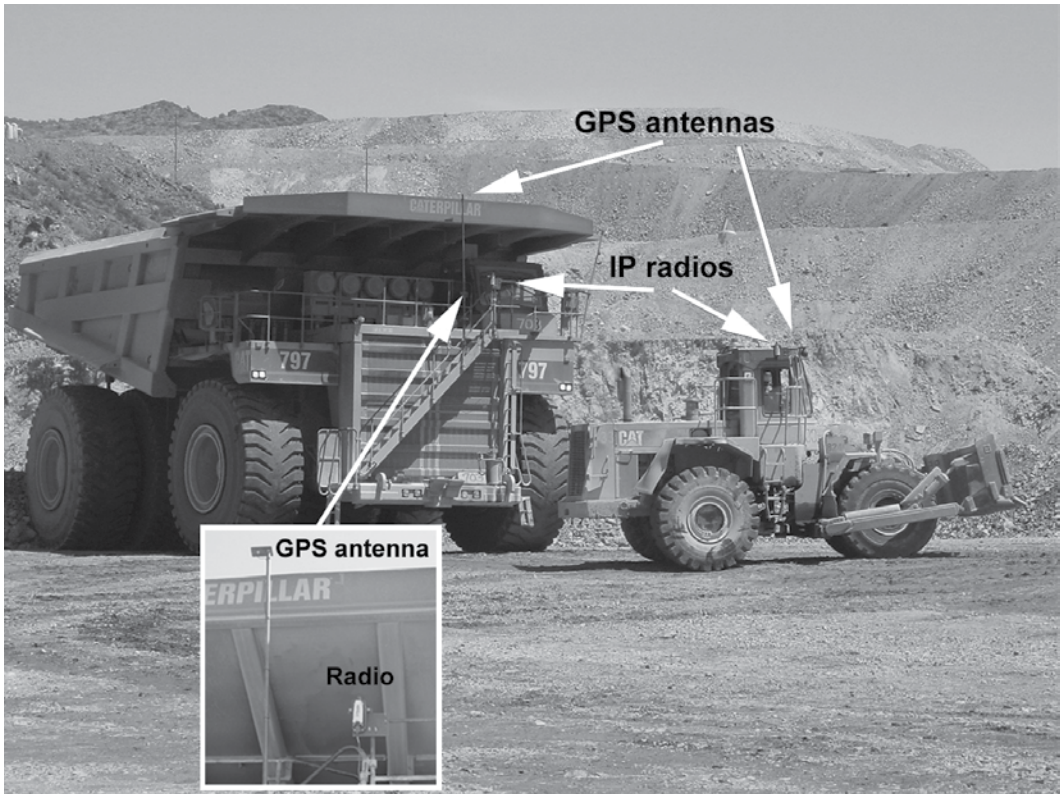

Figure 22. Tests of a GPS-based proximity warning system.

Each system successfully tracked three other mobile vehicles and six stationary obstacles. The expected accuracy of a vehicle or obstacle's position shown on the display was 2-5 m (7-16 ft) when using the computer's internal receiver with differential correction. Accuracy depends on many factors, including satellite positions (positional dilution of precision or PDOP), multipath interference, the status of "Selective Availability" (SA), and the type of GPS receiver used. During the tests, the observed accuracy was 2-3 m (7-10 ft). Higher position accuracies could be obtained using higher quality GPS receivers.

One instance of multipath interference occurred which caused an error in vehicle location during preliminary tests. Multipath interference occurs when a satellite range signal reflects off of objects and takes several paths before it reaches the receiver. This interference resulted in a service truck location that was briefly shifted by 15 m (49 ft) on the haul truck's screen. This was corrected as soon as the vehicle moved. However, methods to reduce multipath problems may need to be studied, including improved antenna designs and mounting locations. No other multipath errors were seen during the demonstration, and good location solutions were obtained even when a smaller vehicle was parked immediately next to the haul truck. This meant that the satellite constellation was adequate; the number of satellites visible to a vehicle never dropped below four, even when a larger vehicle blocked some of the satellites. This may change at different mine locations or at different times of day.

No satellite shadowing or blocked signals due to obstructions from mine pit walls were seen in the test area. However, in deep pits this may be an issue. The use of pseudolites (ground-based transmitters that simulate satellites) would increase the number of range transmissions used to calculate position, thereby increasing the accuracy and reliability of a proximity warning system or any other system using GPS at the mine. The existing system would need to be modified to allow the use of pseudolites.

These preliminary tests at a surface mine showed that a GPS-based proximity warning system could potentially reduce accidents involving collisions or situations in which operators drive over an edge at a surface mining operation. This would be possible because these systems provide operators with the location of objects, people, and vehicles that may be in the equipment's blind areas. The integration of additional sensor inputs or cameras would be needed to increase accuracy and reliability. Ultimately, the safety functions of proximity warning could be integrated into existing GPS-based dispatch and tracking systems. Researchers at the Colorado School of Mines are now testing a similar GPS system in quarries near Denver, Colorado (Dagdelen and Nieto, 2001).

4.6 Computer-based Stereo Vision

Researchers at the Colorado School of Mines, Golden, Colorado, have developed a stereo imaging system as part of an automated ore loading system for underground mining equipment. The application of this system to the proximity warning problem in surface mines was studied through a cooperative effort with NIOSH (Ruff and Steele, 2004). This technology could integrate cameras and obstacle detection into one system by using a computer to process video data from stereo cameras.

Calculating the distance to an obstacle is possible using stereo cameras and video processing. If an object is viewed by both cameras and the camera parameters are known, the distance to the object can be calculated from the disparity between the projected position of the object on the two image planes. The prototype system being developed consists of a stereo camera head (fig. 23) attached to a laptop computer via a Firewire (IEEE 1394) interface. A pair of images is captured from each camera and stored on the computer. Intensity-based correlation is then used to find a feature within the images that is common to an image pair. When an intensity match is found for a particular region, the disparity between the two regions can be calculated and converted to a distance. A statistical approach is used to calculate the distance to the ground plane. An object or feature that stands above the ground plane by some preset distance would cause an alarm.

The stereo cameras were mounted on the rear of an off-highway dump truck while image pairs were collected for various obstacles. Figure 24 shows one of the stereo images captured during a test at a quarry. The light-colored boxes represent areas identified on the ground. The darker boxes represent items that stood out from the ground and would cause an alarm. The pickup truck, people, and car in the background were correctly identified as objects that would cause an alarm. Other tests were conducted to

Figure 23. Stereo camera system.

see if the system would correctly detect a person or berm in the path of the truck. The results of these tests were promising.

With the system described here, calculations on image pairs were made after video footage had been collected. Future work would involve modifications to the software for image capture, distance calculation, and alarming, with updates to be run two or more times per second. Challenges to implementing this type of system will include hardening the cameras and computer processing equipment, reducing cost, and ensuring robust and reliable detection in varying environments and lighting. Further development of this system has been left to other research organizations, but this proof-of-concept study showed that advanced video processing could allow cameras to simultaneously provide a view of the blind area and obstacle detection functions.

4.7 HASARD System

Researchers at the NIOSH Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania, developed the Hazardous Area Signaling and Ranging Device (HASARD), a tag-based proximity warning system that relies on the generation and detection of a magnetic marker field around mobile equipment (Schiffbauer, 2005). Originally developed to protect workers near continuous coal mining machines, the technology has been tested on a small off-highway dump truck (Ruff, 2000) and is now being evaluated for use on on-highway dump trucks used in the construction industry.

Figure 24. Captured image from one camera with ground and alarm areas identified by boxes.

The HASARD consists of two main components: the magnetic field transmitter mounted on the equipment, and the small receivers or tags that are worn by workers. A low-frequency magnetic field is generated by the transmitter's loop antenna mounted on the front and/or rear of the equipment. The tag measures the strength of the magnetic field using a 3-axis receiver and produces an alarm if the signal strength reaches a preset threshold that corresponds to the desired detection range. Two-way RF communication is integrated into the transmitter and tags to allow alarm conditions to be generated at both the tag and the equipment cab. The magnetic field generated by the transmitter is roughly circular, resulting in a detection area of about 4.6 m (15 ft) radius in initial tests (fig. 25). Larger detection areas may be possible, but have not been tested.

Geosteering Mining Services, Huntsville, Alabama, is manufacturing a version of this device for underground mining equipment called TramGuard (marketed by Gamma Services International, Clay, Kentucky). A related company, Federick Mining Controls, Huntsville, Alabama, is currently modifying the TramGuard system for use on construction equipment. Additional tests are needed to determine the system's potential for large surface mining equipment.

4.8 Nautilus Buddy System

The Buddy System manufactured by Nautilus International, Burnaby, British Columbia, Canada, is a tag-based system that also uses a magnetic marker field to generate a detection zone around a piece of mining equipment. It consists of a tag reader

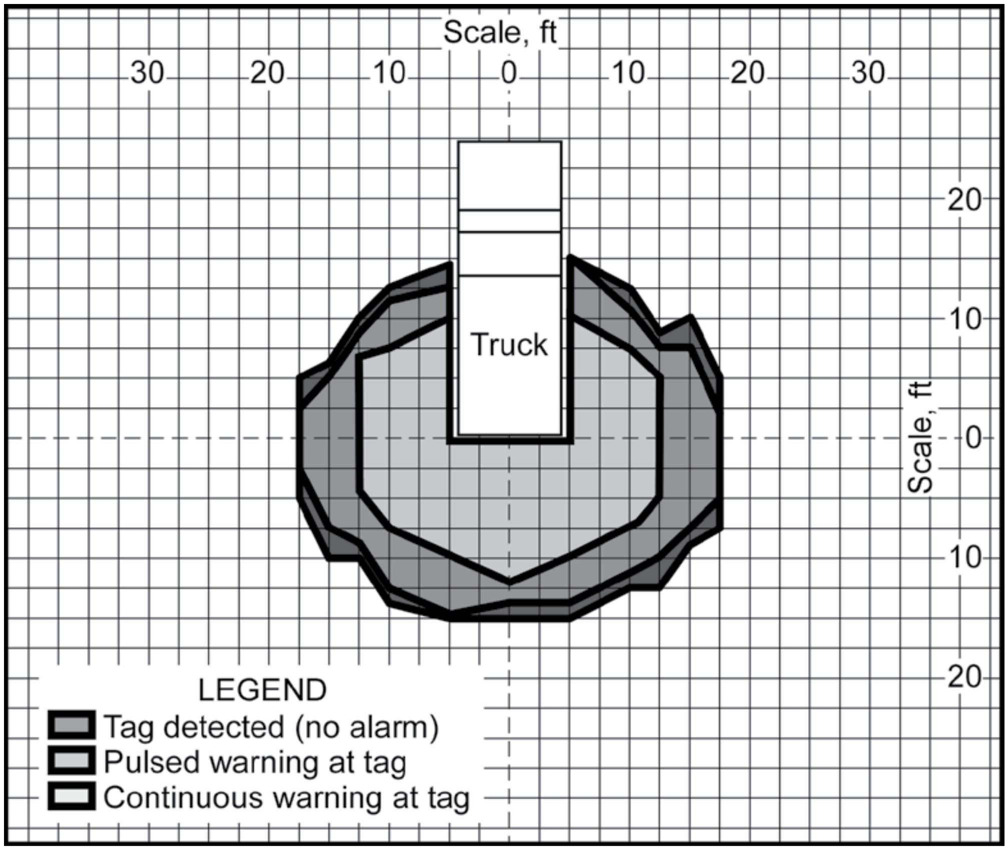

Figure 25. TramGuard detection zone for a person wearing a tag.

mounted on the mining equipment and tags attached to pedestrian workers or smaller vehicles (fig. 26). The tag reader consists of processing electronics and a loop antenna that transmits a low-frequency signal which encompasses the entire truck. The processing electronics also contain a separate radio to communicate with the tags. The tag measures the field strength of the marker signal generated by the loop antenna and generates an alarm condition if the signal strength reaches a preset limit. Tags are assigned a unique identifier and that information, along with an audible alarm, is presented on an LCD display in the cab of the equipment. An audible alarm is also generated at the tag.

Preliminary tests were conducted on a 50-ton-capacity dump truck with the loop antenna attached to the railing on the front deck in a vertical position. The radio communications antenna was also placed on the front deck of the truck. A tag was attached to the belt of a researcher who then walked around the truck and noted where reliable detection occurred. The reliable detection zone for a person when the system is set to a 15-m (50-ft) detection radius is shown in figure 27. All blind areas are monitored simultaneously with this system. As figure 27 shows, the detection zone extends farther in front of the truck than to the rear because of the position of the loop

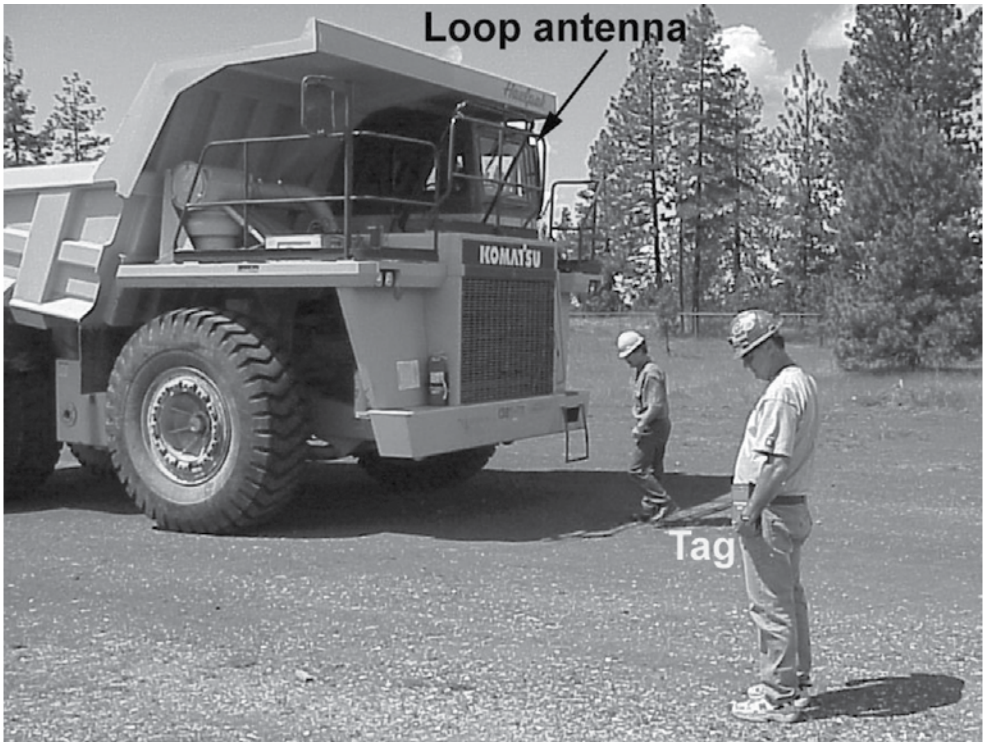

Figure 26. Early version of the Nautilus Buddy tag-based system.

antenna. The tag was detected at all locations and orientations within the zone shown, even under the engine compartment and wheel wells. The exact location of the tag is not provided, just the distance to the tag. Multiple loop antennas would need to be mounted on the dump truck to determine if a tag was at the front or rear.

Limited tests have been conducted on this system at two surface mines. NIOSH researchers provided input to the test procedures, but were not present during the tests. Phelps Dodge, Morenci, Inc. tested an early version of the system on a Komatsu 930E dump truck. The tests were conducted with the truck parked and a person outfitted with a tag walked around the truck to determine the detection zone. More recently, the system was tested on a stationary Caterpillar 793B dump truck at the Highland Valley Copper mine near Vancouver, British Columbia, Canada. Both tests resulted in similar detection zones to those determined in early NIOSH tests. Results from both mine site tests were not published, but can be obtained from Nautilus International.

4.9 System Manufacturers

Appendix D provides contact information for some of the proximity warning system and camera manufacturers that produce systems for heavy equipment as of August, 2006. This is not a comprehensive list and is subject to change. Not all of these systems were evaluated by NIOSH and including them in this list does not imply endorsement or approval.

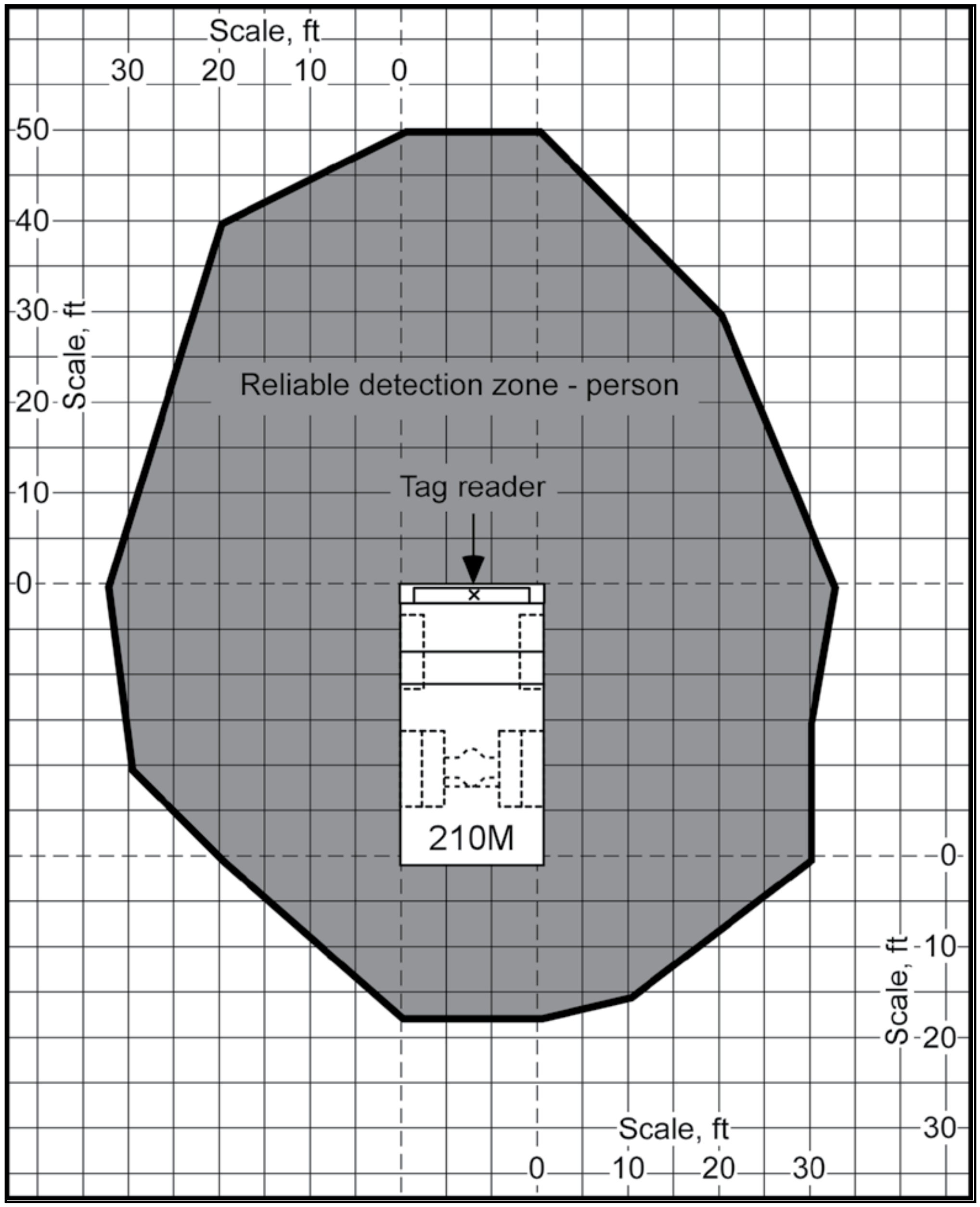

Figure 27. Buddy system detection zone for a person wearing a tag.

5 | Recommendations

5.1 Choosing a Technology

At the conclusion of this study, several proximity warning systems were being marketed for surface mining equipment. NIOSH had tested several systems to varying degrees and this resulted in familiarity with the limitations and advantages of each technology type. The following table summarizes the features of the technologies tested.

Table 3. Proximity warning technology characteristics.

Feature	Sonar systems	Radar systems	Magnetic field tag-based systems	Radio frequency tag-based systems
Adjustable detection ranges	No	Yes	Yes	Yes
Maximum detection range	3 m (10 ft)	7.6 m (25 ft) to 17 m (55 ft) depending on system	18 m (60 ft)	80 m (260 ft)
Minimum number of sensor units required for front and rear coverage	4 or more depending on system	2 to 4 or more depending on system	1 or 2 depending on system	2
Two-way alarming	No	No	Yes	Yes
Relative frequency of false alarms	Medium	Medium	Low	Low
Relative frequency of nuisance alarms	High	High	Medium	Medium
Tolerance to mud, dust, dirt buildup	Low	Medium	High	High
Installation and setup difficulty	Low	Low	Medium	Medium
Cost per piece of equipment: (High > $10,000 Low < $5,000)	Low	Low to Medium	Medium to High	High

The selection of a particular system or systems depends on many factors and a few considerations are listed here.

- What is the acceptable frequency of false and nuisance alarms?

Passive systems like radar and sonar depend on signal reflections from nearby objects and will alarm more often than active tag-based systems that require communication with a cooperative obstacle. There are significant trade-offs that must be considered including cost, maintenance, and infrastructure differences between these two types of systems.

- What detection range is desired—close-in for slow-moving situations only, or long detection ranges?

A trade-off exists between extending the detection range and increasing nuisance alarms. Most accidents happen after a person or vehicle approaches a stationary piece of equipment and the equipment moves unexpectedly. The shorter range detection works well for this situation and it can warn the operator that something is nearby before moving the equipment. The longer detection ranges work better for situations involving a smaller vehicle pulling out in front of a moving piece of equipment. Ideally, detection range would automatically adjust with equipment speed, but this option was not available on the systems tested. Available radar, sonar, and infrared systems for proximity warning typically have shorter detection ranges (< 9 m (30 ft)) than those for some tag-based systems (30 m (100 ft) or more is possible). When determining detection range for situations involving higher speed collisions, parameters such as operator and pedestrian reaction times, maximum speed of the equipment, braking distances, and the equipment dimensions must be considered. See SAE standard J1741 (SAE, 1999) for more details on calculating sensor detection ranges.

- Is additional functionality desired?

Tag-based systems offer two-way alarming so that the vehicle or worker that is outfitted with a tag also receives a warning. This may be an important safety improvement, but it adds cost. Also, tag-based systems have the potential to be used for other applications such as vehicle tracking and security check-in.

- What types of equipment will be outfitted with the proximity warning system?

Certain types of equipment will have a higher probability of working near smaller vehicles and pedestrian workers. Some types of equipment have larger blind areas than others. A risk analysis should be performed to identify which equipment should be outfitted with proximity warning systems. If one system is used on all types of equipment at a mine site, a system that has adjustable detection ranges and zone widths will be easier to fit to differing equipment.

- What areas should be monitored around the mining equipment?

The probability of a collision can be determined, in part, from an assessment of the blind areas around a machine, the frequency of past collisions involving a given part of the machine, and the level of light vehicle and foot traffic that operates near the machine. See the plots of blind areas around five pieces of off-highway mining equipment in Appendix A. For example, monitoring the front and rear blind areas of off-highway dump trucks would help prevent the majority of accidents. For front-end loaders, monitoring the rear blind area may prevent accidents, but the front blind area is critical when the bucket is raised. Around skid-steer or tracked machines, detection close to the sides of the machine may be important due to the ability to quickly rotate about the machine's center point. For excavators and shovels, detection of obstacles within the swing radius of the shovel and engine/operator deck is of primary concern.

- Should multiple technologies be combined?

Another important consideration emerged as test results, accident data, and feedback from operators was collected during this study. An effective proximity warning system will require multiple technologies that combine obstacle detection and alarm functions with the ability to make a visual check of the blind area. This can be done by combining video cameras with any of the sensing technologies described here. The high probability of false and nuisance alarms associated with proximity warning systems require the use of some method to quickly verify the alarm's cause. At the same time, the alarm from the proximity warning system can prompt the operator to check the video monitor so that a potential collision does not go unnoticed. The combination of cameras and a proximity warning system could potentially overcome the drawbacks of any single system operating alone. As such, many manufacturers of proximity warning systems now offer this option. On smaller equipment, mirrors may be sufficient to provide a visual check of blind areas, but on most large pieces of mining equipment, mirrors cannot provide a complete view around the machine.

5.2 Mounting Considerations

The process of mounting sensors and alarm displays on mining equipment presents several challenges that must be considered before installation. For example, the sensing portion of the system, such as antennas and transducers, are typically mounted on the rear and front of the equipment and oriented toward the area to be monitored. Multiple sensors are sometimes needed to adequately monitor the entire width of the equipment. The quality of transmitted and received signals can be significantly affected by structures protruding from the equipment itself. For systems mounted on the rear of dump trucks, it is not uncommon for a system to erroneously detect the rear tires. Obstacle detection characteristics can also change depending on mounting location, especially for systems that use radio frequency signals that are affected by nearby electrically conducting surfaces. A certain amount of trial and error is required during installation to determine the optimum mounting location.

In many cases, special brackets will need to be constructed for sensor mounting. Examples of brackets for radar antennas on a dump truck are shown in figures 5 and 11. This illustrates another challenge—welding directly on the truck axle housing was not recommended by the truck manufacturer, so the bracket had to use existing mounts. It is recommended that the equipment manufacturer be consulted prior to welding or drilling holes anywhere on the equipment.

Mounting height and tilt angle of directional antennas will affect the detection characteristics of the system also. It is recommended that mechanisms be included on the bracket for adjusting these parameters. When possible, sensors should be mounted no higher than chest height for an average person. Higher mounting locations will allow workers to walk underneath the transmitted beam when close to the equipment. This is sometimes unavoidable so conveying detection characteristics and limitations to operators and workers is important.

Cabling and connectors for proximity warning systems should be rated to handle high heat, vibration, abrasions, high-pressure water spray, and all weather conditions. Additional sheathing may be required for sections of cable routed through the engine compartment, attached to vibrating components, or mounted in areas where flying debris, dirt, or rock might contact the cable. While most systems that use radio frequency signals can tolerate some mud buildup on the sensors, periodic cleaning will still be required. Care should be taken when selecting a mounting location to avoid areas of mud buildup caused by the tires.

The mounting location for the alarm display in the cab should be determined after consulting with the equipment operators. The audible alarm will be the primary warning mechanism; however, many systems generate obstacle distance information or visual warnings that can be helpful also. The display should be placed in a convenient location that allows the equipment operator to see the display while simultaneously checking mirrors or a video monitor. Feedback from operators will be helpful in avoiding placement of the alarm in areas that interfere with other tasks. If the display is mounted on the dashboard, the display enclosure should not create additional blind areas. Also, avoid placing the display in a position that will cause glare off of the windshield during operations at night.

5.3 Video Cameras

Closed-circuit video cameras have been available for heavy equipment for some time and recently, durability has increased and cost has decreased. A recent accident involving a haul truck outfitted with cameras that ran over a passenger vehicle has raised concerns about using camera systems only. While camera systems were not a formal part of this test program, it is recommended that they be used in combination with a proximity warning system as discussed earlier. In this context, some general recommendations can be made based on the camera systems used during the study.

It is important to select a camera system that is designed for and has been proven on surface mining equipment. Many inexpensive systems are available for consumer applications, but systems designed for heavy equipment will last longer and function better in harsh environments. Large equipment with extensive blind areas will require more than one camera. For example, the common practice for haul trucks is one camera monitoring the front of the truck, one camera monitoring the right side, and one camera monitoring the rear of the truck. This requires either switching the camera views shown on the monitor depending on travel direction, or multiplexing the camera views so that they can be viewed simultaneously. If switching camera views is desired, it is recommended that the switching occur automatically depending on gear selection, turn signal activation, or some other sensor input. Requiring the equipment operator to switch between views manually or activate the system on startup is not recommended. If all views are shown simultaneously, the video monitor must be large enough for sufficient resolution and identification of objects and workers shown by the camera(s).

The location of the video monitor in the cab should be determined in cooperation with equipment operators. Care must be taken to ensure that the monitor is placed in an intuitive and convenient location. It can be helpful to place it near an area where the operator will be looking while checking mirrors. However, glare from the monitor during night shifts can be a distraction and safety concern; hence, monitors should not be placed in locations that cause direct glare off of windows. Glare can be further mitigated by using a monitor that has automatic brightness adjustments. If the monitor is mounted near windows or on the dashboard, verify that the enclosure does not create additional blind areas. Liquid Crystal Display (LCD) monitors (fig. 28) are becoming popular and are smaller in size than Cathode Ray Tube (CRT) monitors. Avoid mounting the monitor in areas of high vibration or use vibration isolation mounting

Figure 28. Example of LCD video monitor mounted in the upper right corner of truck cab.

hardware in order to reduce the shocks and vibrations that can affect the life of the monitor.

Because it is recommended that proximity warning systems be used in combination with cameras, legitimate concerns are raised regarding the multiple displays that the driver must monitor (in addition to equipment/engine indicators, a dispatch system, and radios). It is recommended that the camera and proximity warning information be integrated into one display. This would require the proximity alarm signals and/or obstacle distance information to be overlaid on the video signal and shown on the monitor. The camera's sound system could also be used to convey audible proximity alarms. Combining video and obstacle warnings into one display may decrease the operator's workload and increase acceptance of the system (Bliss and Dunn, 2000; Flannagan and Sivak, 2005). Some of the tag-based systems already incorporate this feature, while the less expensive systems such as radar do not and would require more development work.

5.4 Alarm Presentation

Test results caused researchers to reconsider the design of the audible functions of the proximity warning system display. For example, the audible alarm on the Preview radar, as tested, provided continuous pulses that changed pulse frequency as an object came closer to the truck—the nearer the object, the faster the pulses. Driver feedback indicated that this was annoying, especially when the majority of alarms did not signify danger. Driver feedback consisted mainly of researchers finding the audible functions of the alarm display disabled at the end of the shift, and some anecdotal evidence.

In the surface mining application, it could be argued that the radar system's audible alarms should primarily be used to prompt an operator to check a video monitor that shows a corresponding camera view. The alarms rarely merited an immediate braking action. After the operator is prompted to check the video, then he or she can make a determination as to the need for braking action, continuing to drive with extra caution, or continuing to drive with no added concern. The importance of providing redundant information is supported by Bliss and Acton (2003) in a study of automobile collision warning systems in which low alarm reliability caused test subjects to rely heavily on the rearview mirror to verify alarms. Another consideration is the fact that off-highway dump trucks are not often operated in congested areas; therefore, the probability of a collision is low.

Researchers worked with Preco engineers to modify radar alarms to more accurately reflect the severity of the situation. The goal was to further grade the warning, while considering the low probability of the need for immediate braking; that is, instead of a continuous audible alarm when an object is detected at the outer ranges of detection, the alarm now sounds a series of three fast pulses only once. No additional audible alarm is generated until the object is within 3 m (10 ft) of the truck, at which point the audible pulses become continuous again. The intent was to use the less severe warning to prompt the driver to check the video monitor before making a decision to apply the brakes. This alarm scheme was implemented, but further testing is required to determine its effectiveness. Other types of alarm presentations remain to be studied. For example, it could be instructive to examine the feasibility of using a synthesized voice warning that simply states "check video" once after an object enters the detection area. It may also be beneficial to integrate the radar's visual alarms and distance readout with a camera view so they can be simultaneously displayed on the video monitor. This may simplify the alarm response task and eliminate the need for an additional display enclosure.

Due to the high probability of nuisance alarms, it is not recommended that the brakes on a large piece of equipment be automatically activated in response to input from the proximity warning system. The goal of these systems is to increase situational awareness and allow the operator and nearby workers to take the action necessary to avoid a collision.

5.5 Training

Information about the proper use and limitations of a proximity warning or camera system must be conveyed to equipment operators and ground personnel. A graphical representation of detection zones for workers and passenger vehicles should be presented to them in order to increase their understanding of the detection characteristics of the system. In the same way, they should also be made familiar with the field of view for the camera system. However, it is important to stress that these systems should not replace safe operating procedures for personnel approaching a piece of surface mining equipment. Many mines have effective practices that ensure equipment operators are aware of nearby workers, vehicles, and equipment. Proximity warning systems are meant to supplement these practices, not replace them.

In addition to presenting the detection areas, blind areas around a machine should be illustrated and explained during operator and/or general safety training for all employees. Visualizing the extent of the blind areas can be an effective tool for reminding workers of the dangers of approaching equipment while on foot or in a smaller vehicle. Blind areas around five pieces of large mining equipment can be found in Appendix A and blind areas for many other types of smaller equipment used in mining and construction can be found in Hefner, 2003.

The proper use of proximity warning system controls that are available to the operator should be explained. During this study, some options such as display brightness and alarm volume were adjustable. Some operators were unaware of these adjustments, which resulted in complaints and reluctance to continue using the systems. This could have been avoided with more thorough training. Also, proper procedures for reporting failed systems and obtaining maintenance may prevent long down times and increased risk associated with inoperable proximity warning systems.

5.6 Economics

The cost of proximity warning systems and cameras must be weighed against the probability and cost of an accident. In surface mines and quarries, fatalities related to equipment blind areas comprise approximately 7% of all fatal accidents (2000-2005), which points to a significant problem. While a detailed cost analysis is outside the scope of this report, some examples of these costs may be helpful.

The cost per piece of equipment for a proximity warning system depends on the technology selected, how many sensors are needed to adequately monitor the blind areas, and whether installation assistance is needed. For instance, the cost of the Preview Heavy Duty radar system at the time of this report was approximately $3,200 for four sensors, cabling, and an alarm display. Adding a video camera system would add an additional $2,500 to $5,000 depending on the selected system. Tag-based proximity warning systems are more expensive and require tags for all small vehicles on the mine site and/or all personnel that may work near large equipment. For instance, the cost of the AMT CAS-CAM/RF system is approximately $15,600 for each haul truck (includes two RF units, four cameras, monitor, and cabling). Each light vehicle tag is approximately $1,600. (Updated costs for these products and installation assistance should be obtained from the manufacturers). The mean-time between failures was not determined during these tests due to the short test durations, but regular maintenance is obviously required. The more complex systems, such as tag-based systems, will require more attention to ensure all tags are operational and recharged.

According to Miller and Galbraith, 1995, a fatality on the mine site can cost a company approximately $2.5 million (1990 dollars that includes medical services, lost wages, household and work disruption, legal fees, and possible lawsuit awards, but not possible fines). These costs and the tragic loss of life associated with an accident should be the driving factors in decisions to implement proximity warning and camera systems.

5.7 Future Research

This study identified promising technologies, verified their ability to detect obstacles, and identified limitations and needed improvements; but the tests did not determine the effectiveness of the devices in accident reduction. It is recommended that a larger study be conducted in which accident rates are compared before and after proximity warning systems are introduced at several mines.

Research to determine effective audible and visible alarms should also be conducted specifically for the surface mining industry. There are many questions regarding which alarm indicators (audible, visible, tactile), frequencies, pulse rates, and presentation schemes are most effective in this environment. Consideration of operator workload and other ergonomic factors will be an important part of future research. Other factors influencing effectiveness also need to be better understood, e.g., interior and exterior equipment noise, interactions with other audible alarms (backup alarms, engine alarms), the use of ear protection by workers, and extreme environmental conditions.

The integration of two or more technologies will likely be needed in order to 1) provide redundancy, 2) allow for both close-in detection at low speeds and long range detection at higher speeds, 3) provide visual verification of an obstacle's presence and location, 4) integrate road edge detection, and 5) decrease nuisance and false alarms. Future developments will focus on the fusion of multiple sensors and visual information, along with innovative ways to warn equipment operators and pedestrian workers of an impending collision. Adding functionality to proximity warning systems might also increase their proliferation in the mining industry. For example, the same system could also be used for security, tracking, hazard warning near stationary machines, lockout/tagout, and communications.

6 Summary

This study demonstrated that many types of proximity warning systems are effective in detecting workers, smaller vehicles, other mining equipment, and other large objects in the blind areas of surface mining equipment. However, limitations for all of these technologies exist and they must be communicated to equipment operators and personnel that work near the equipment. This study did not determine the effectiveness of proximity warning systems for accident reduction—this would require a much larger effectiveness study and may be the subject of future research. The following conclusions summarize the study findings:

- A proximity warning system evaluation must be conducted on the actual equipment that it will be installed on before any conclusions can be made about reliable detection areas, false alarm rates, or alarm effectiveness. Many factors influence these characteristics including equipment size, available mounting locations, equipment configuration, and layout and noise levels in the cab.

- Evaluation of a proximity warning system should be conducted using a person and a passenger vehicle as test obstacles to determine the reliable detection characteristics and zones. Detection characteristics should be presented to equipment operators and personnel that work near large equipment so that limitations are understood.

- Required detection characteristics for a system depend on the equipment it will be installed on, e.g., a system that works well on haul trucks may not be suitable for excavators. Ideally, detection range would automatically adjust according to equipment travel speed. Some systems have limited detection range and would only be effective in very slow-moving situations.

- Passive sensors such as radar, sonar, or infrared proximity detectors are lower in cost, but will alarm often in the mining environment due to the detection of all large obstacles including rocks, berms, and deep ruts. Tag-based systems are more expensive and will only alarm when an obstacle outfitted with a tag is near the equipment. This feature may reduce false alarms, but also has the disadvantage of increasing the potential of collisions with obstacles that are not outfitted with a tag. This is also true for GPS-based systems that require cooperative obstacles. These and other trade-offs must be considered when selecting a proximity warning system.

- Due to the high probability of nuisance alarms, automatically controlling the brakes based on obstacle detection by a sensor is not recommended. The goal of these systems is to increase situational awareness and allow the operator and nearby workers to take the action necessary to avoid a collision.

- Due to possible false and/or nuisance alarms, proximity warning systems should be used in combination with video cameras or some other method to make a visual check of the blind areas. Video cameras can benefit from the use of proximity warning systems because the proximity alarm can remind the operator to check the video monitor.

- A lack of effective training on the use and limitations of a proximity warning system can severely affect its acceptance by operators. Obtaining operator feedback during system installation is also important to ensure that alarm displays do not interfere with other displays or with visibility.

- Proximity warning and camera systems can aid an operator in monitoring blind areas near equipment, but these systems are only a part of a comprehensive safety program that stresses safe operating procedures, communication between operators and workers near the equipment, and effective safety training.

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Appendix A:

Blind Area Diagrams

Figure A.1. Euclid EH4500 280-ton-capacity haul truck.

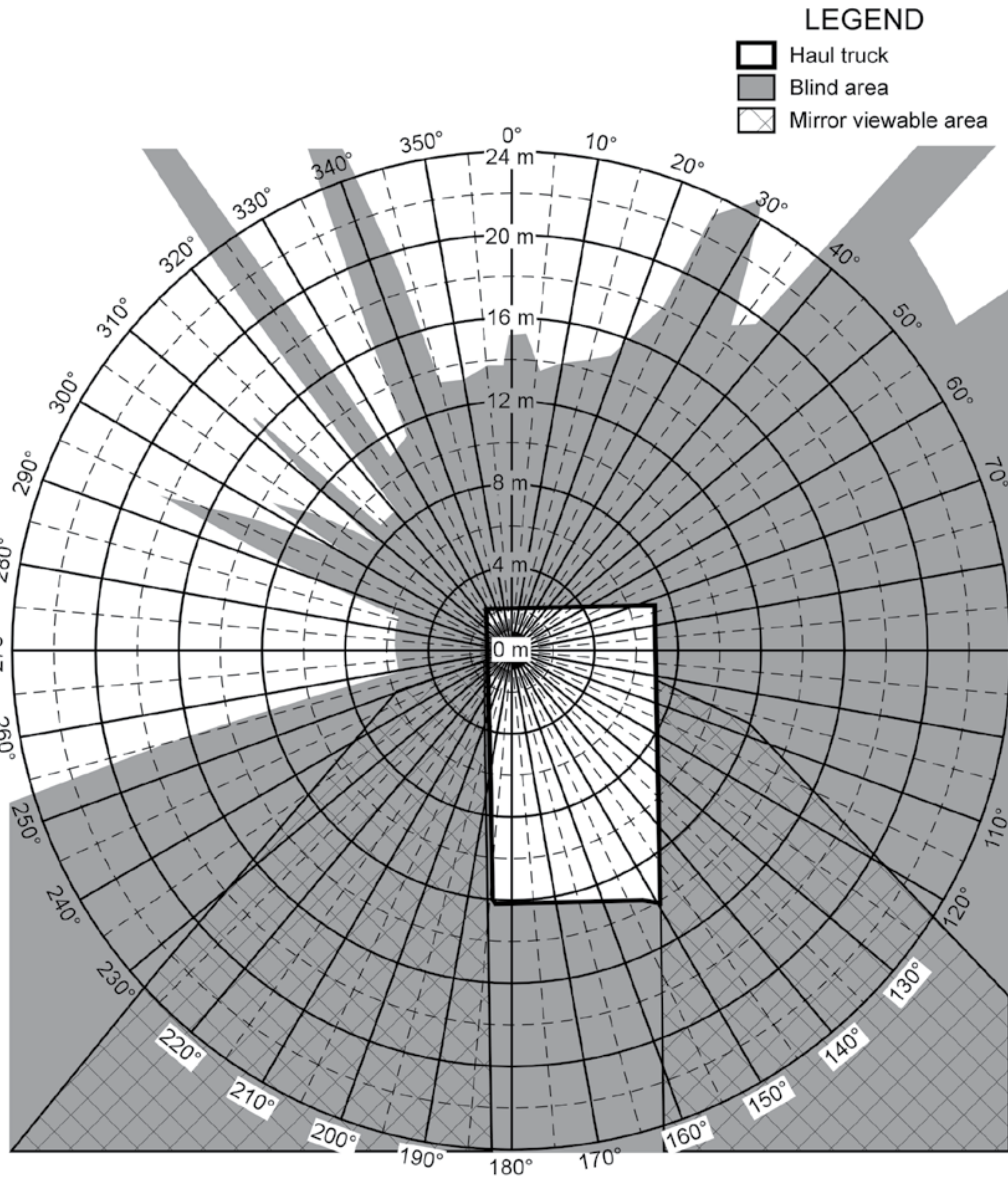

Figure A.2. Blind area diagram for a Euclid EH4500 280-ton-capacity haul truck (ground plane).

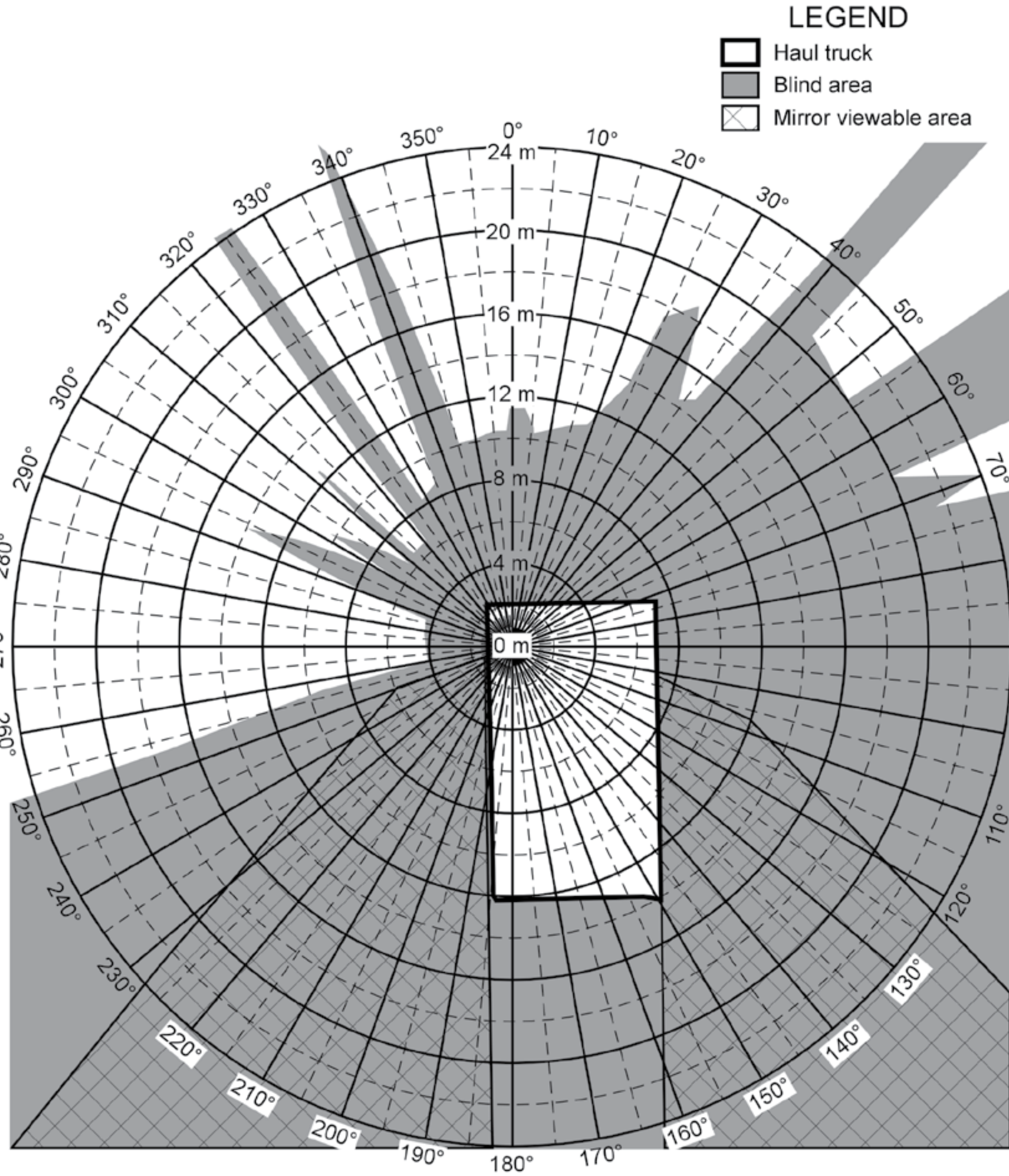

Figure A.3. Blind area diagram for a Euclid EH4500 280-ton-capacity haul truck (1.5 meter plane).

Figure A.4. Caterpillar 992G front-end loader.

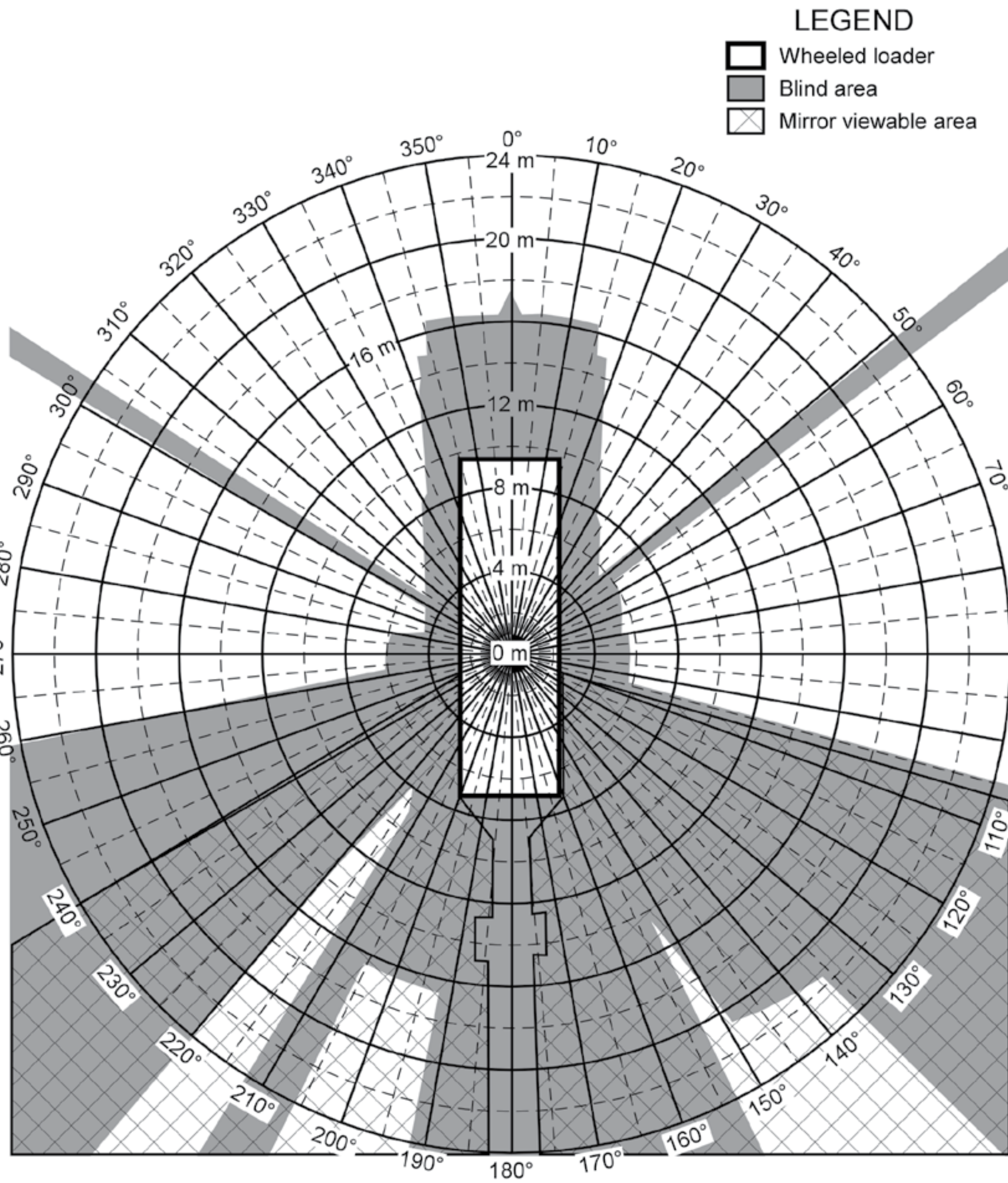

Figure A.5. Blind area diagram for a Caterpillar 992G front-end loader (ground plane).

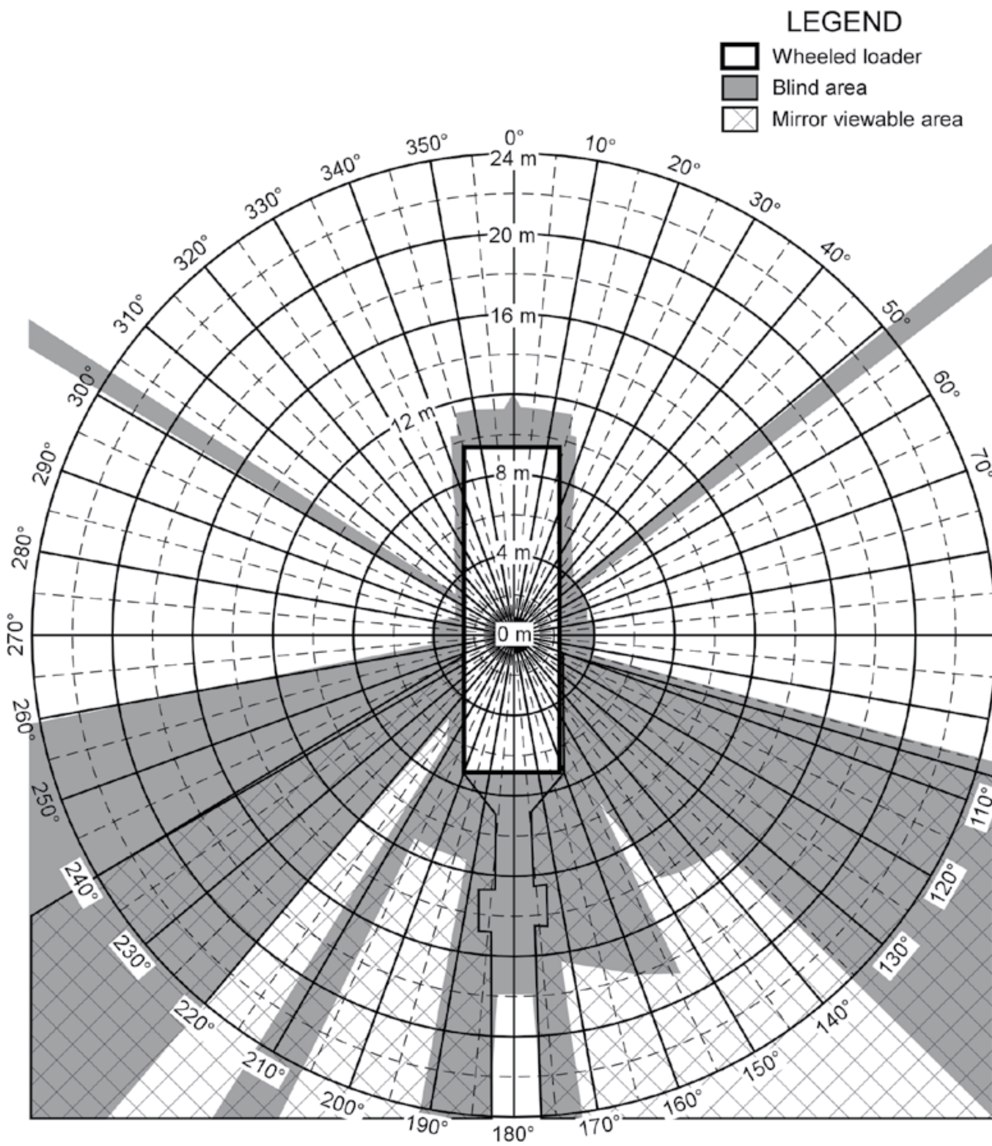

Figure A.6. Blind area diagram for a Caterpillar 992G front-end loader (1.5 meter plane).

Figure A.7. Hitachi EX5500 excavator.

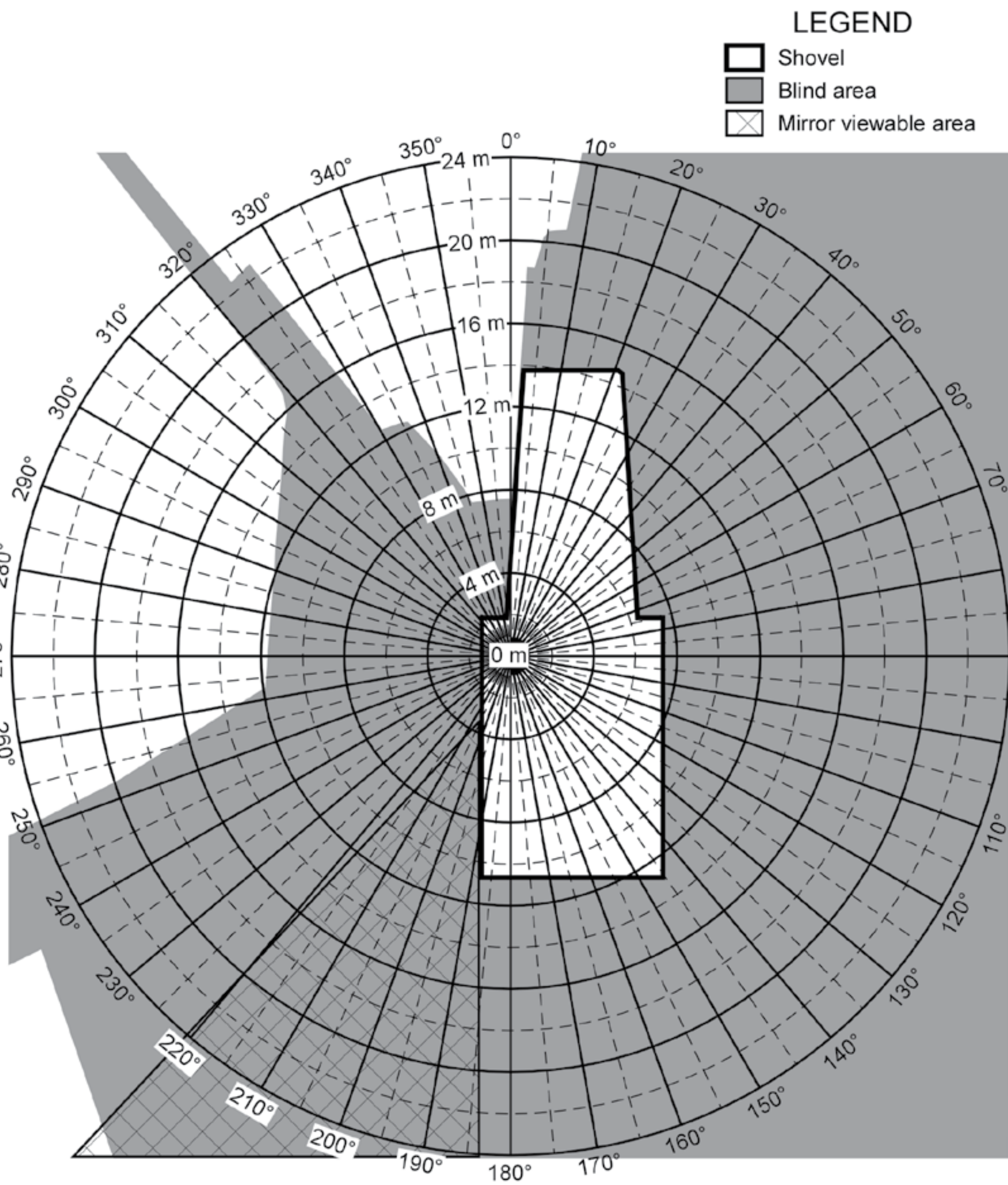

Figure A.8. Blind area diagram for an Hitachi EX5500 excavator (ground plane).

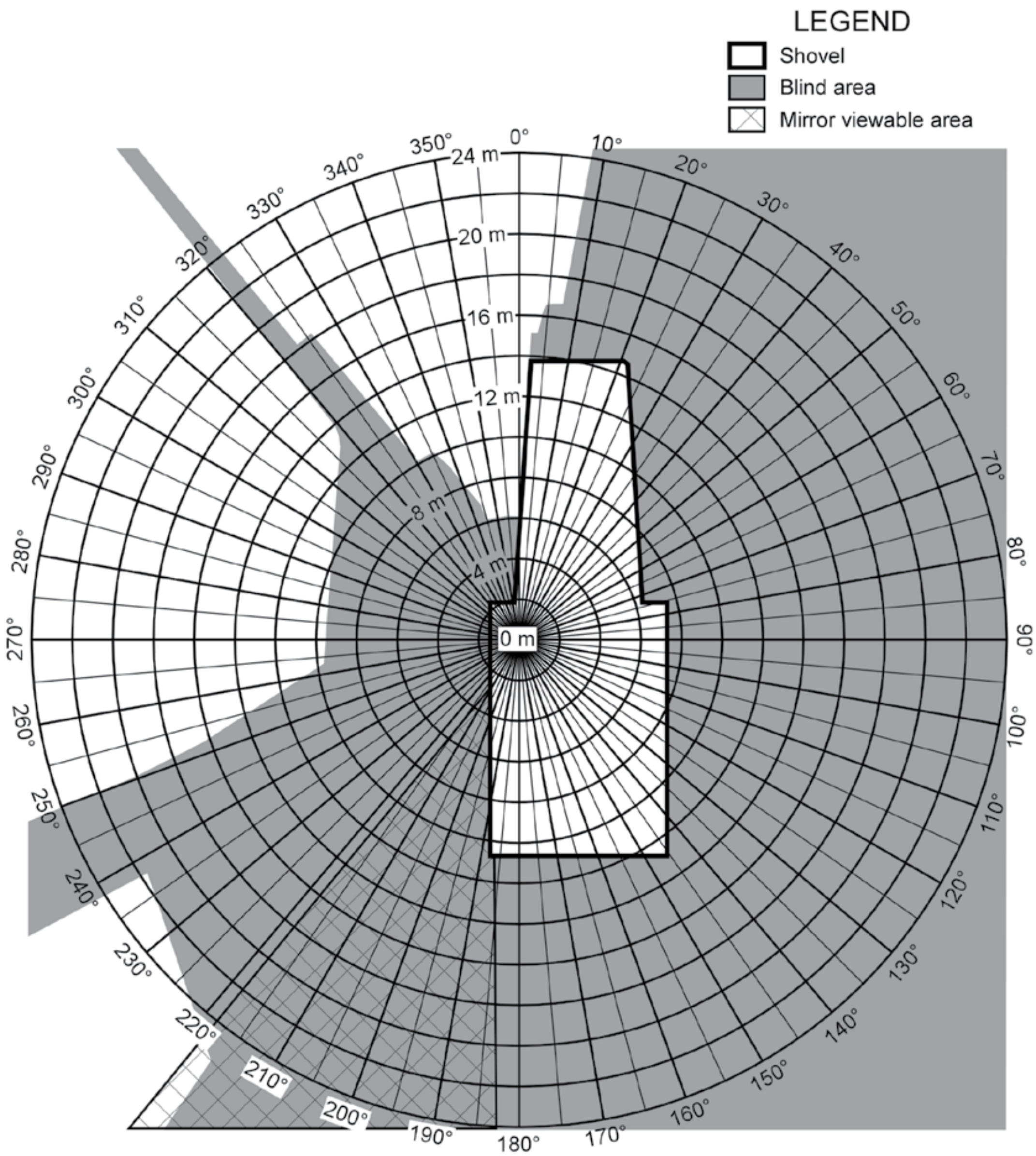

Figure A.9. Blind area diagram for an Hitachi EX5500 excavator (1.5 meter plane).

Figure A.10. Caterpillar D11R dozer.

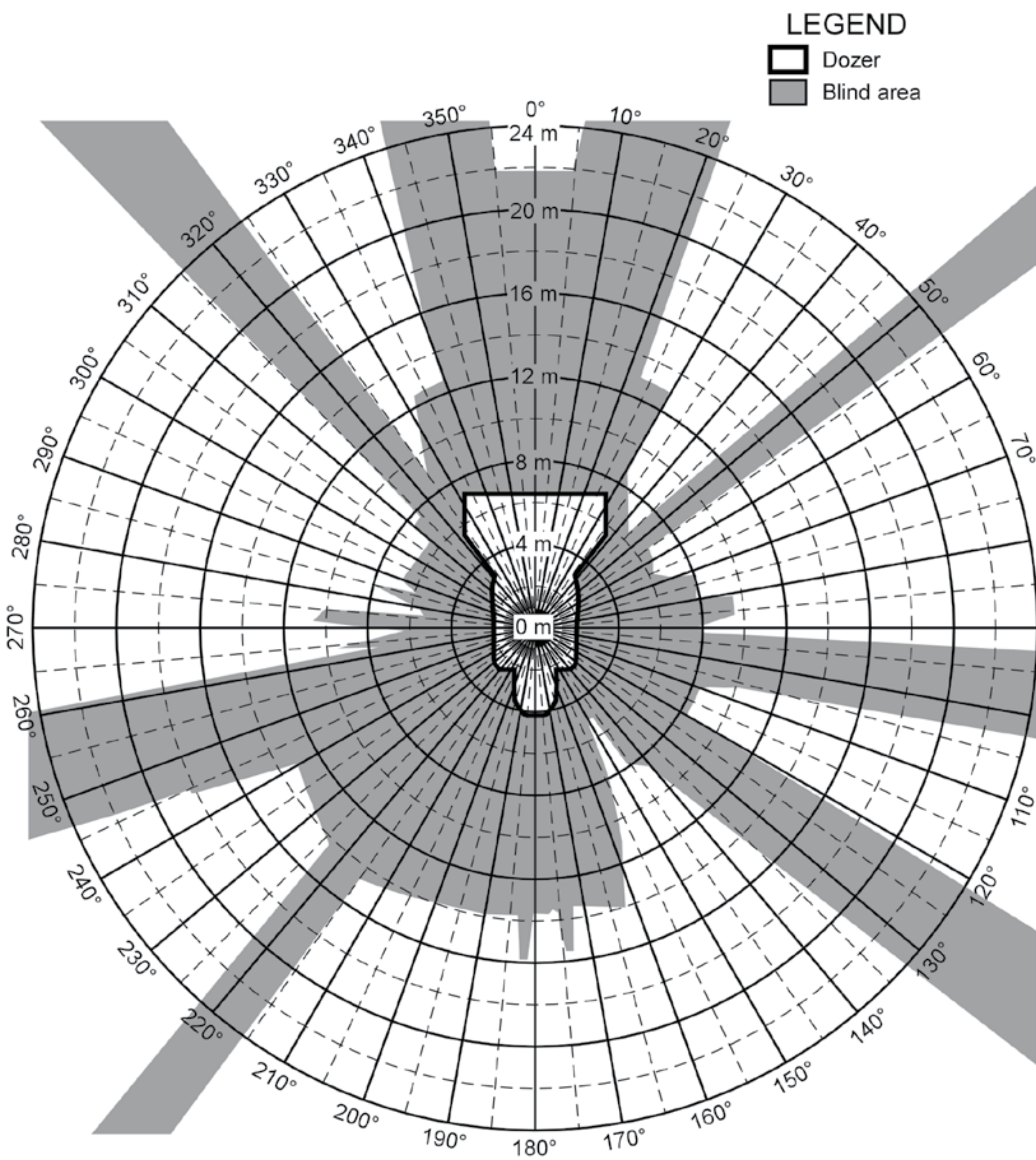

Figure A.11. Blind area diagram for a Caterpillar D11R dozer (ground plane).

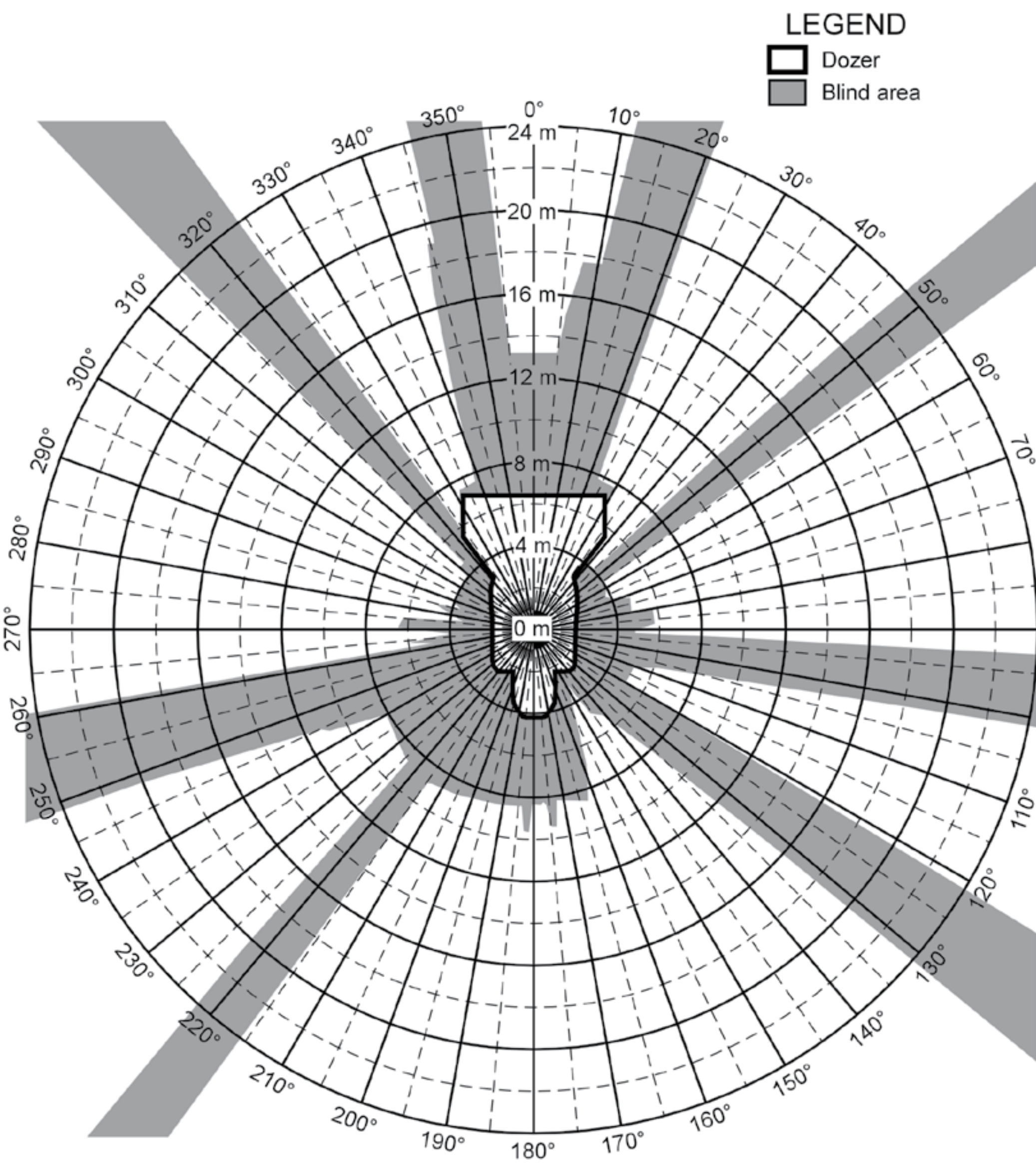

Figure A.12. Blind area diagram for a Caterpillar D11R dozer (1.5 meter plane).

Figure A.13. Caterpillar 16G motor grader.

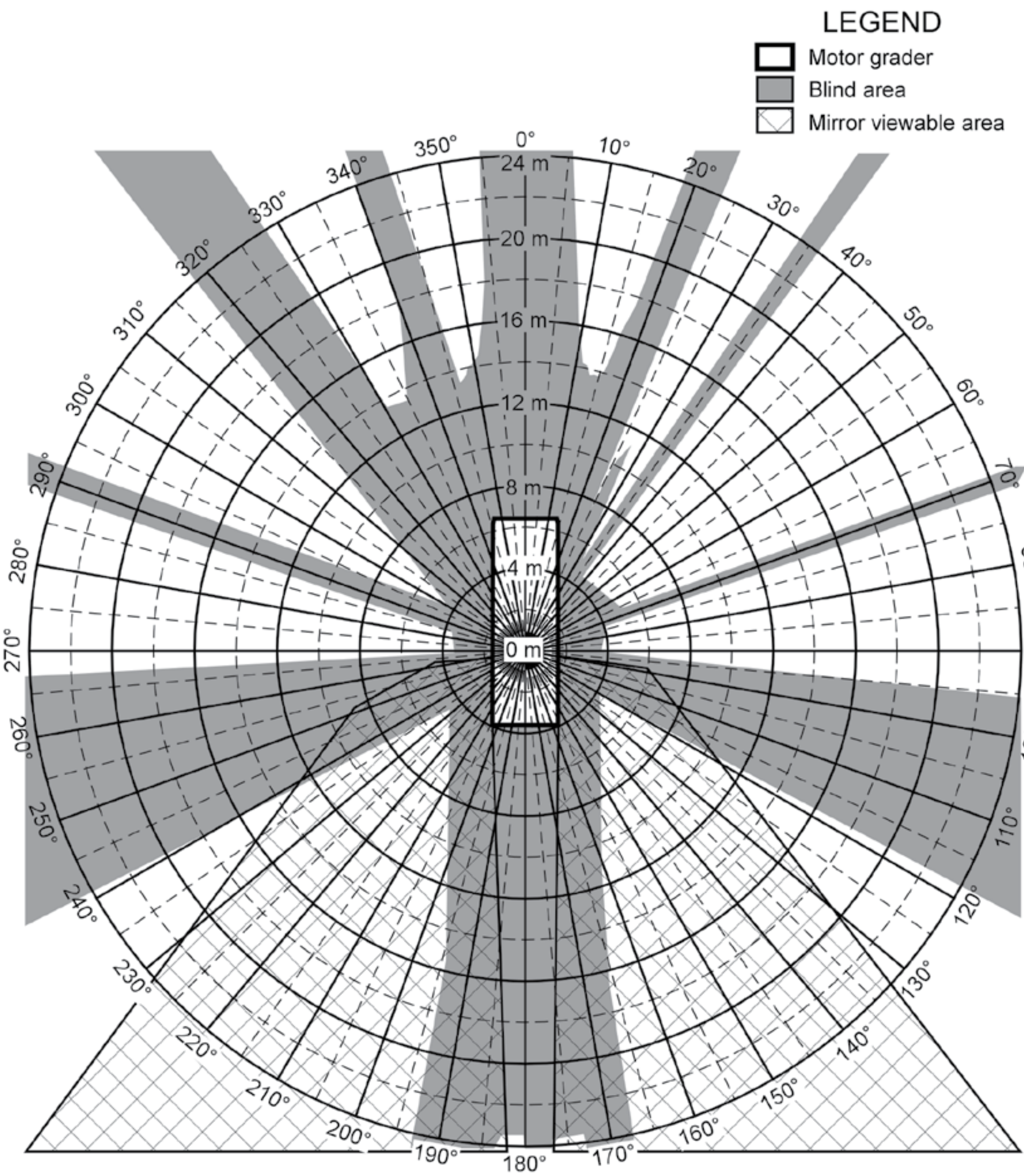

Figure A.14. Blind area diagram for a Caterpillar 16G motor grader (ground plane).

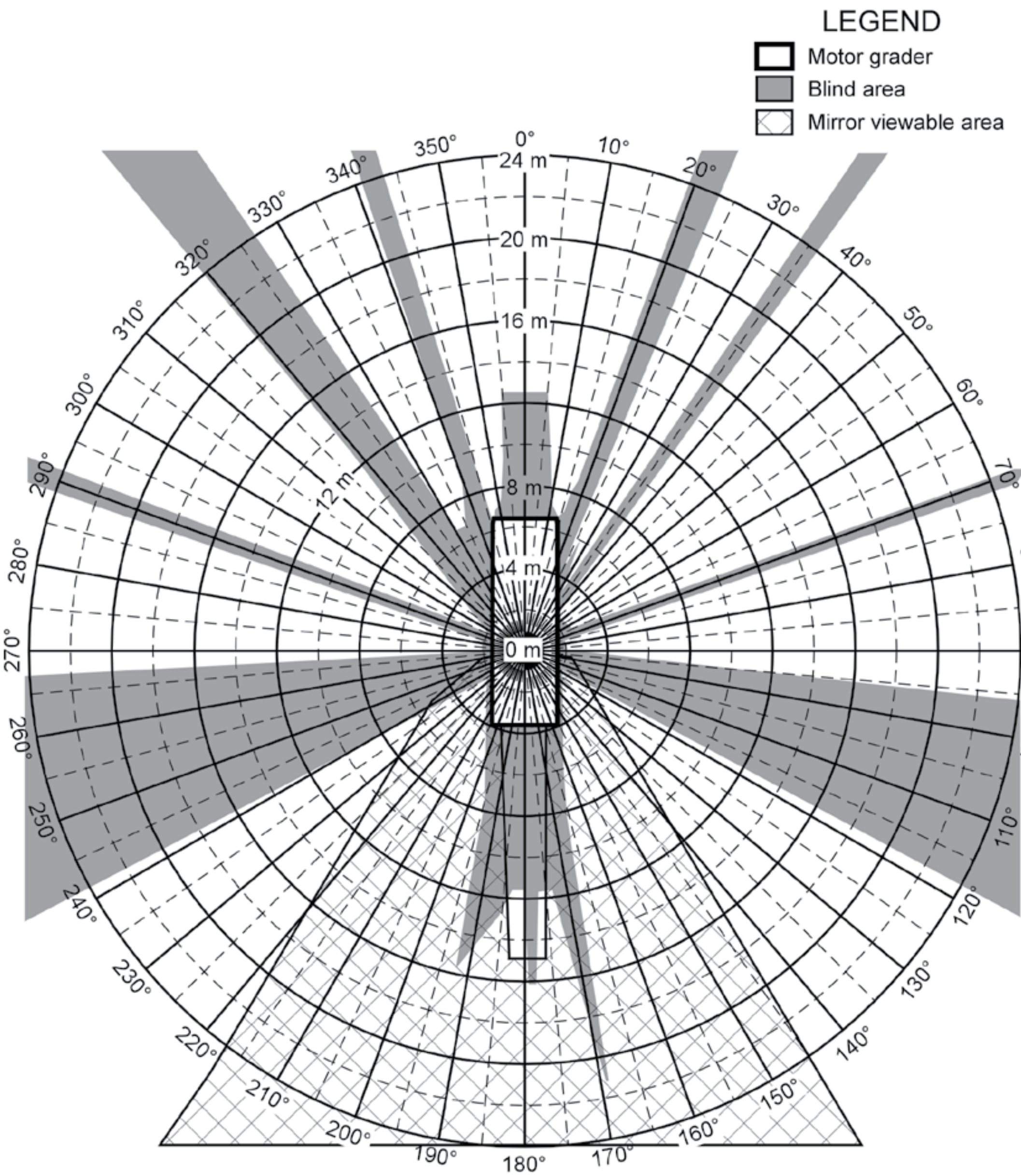

Figure A.15. Blind area diagram for a Caterpillar 16G motor grader (1.5 meter plane).

Appendix B

Procedures for Determining the Detection Characteristics of a Proximity Warning System

This section describes procedures for determining the detection characteristics of a proximity warning system mounted on heavy equipment. These descriptions include definitions of related terms, explanations of test obstacles, test setup procedures, methods for testing false alarms and obstacle detection capabilities, and data recording practices.

B1.1 Definitions

Proximity Warning System: A system consisting of a sensor(s) and an alarm display that detects nearby objects and provides a warning to the equipment operator.

Obstacle: An object that must be detected by the proximity warning system. For these tests, the obstacles should consist of a person and a passenger vehicle.

Sensor: The part of the system that senses signal reflections or transmissions from nearby objects, e.g., radar antenna, tag reader, ultrasonic sensor.

Alarm Display: The part of the system located in the cab of the equipment that provides a visible and/or audible alarm indicating that an obstacle is in the system's detection zone.

False Alarm: An alarm indicating the presence of an object or obstacle in the proximity warning system's detection zone when no obstacle exists.

Reliable Detection Zone: The area in which an obstacle is detected 100% of the time.

Sporadic Detection Zone: The area in which an obstacle is detected less than 100% of the time, but more than approximately 10%.

Recorded Detection Zone: A plot of the detection zones transcribed on graph paper with a grid spacing of either 1 m or 2.5 ft.

B1.2 Test Obstacles

The proximity warning system must reliably detect the obstacles that are most commonly involved in collisions, such as workers on foot (persons) and smaller passenger/utility vehicles, such as trucks or vans.

Person: For tests to detect a person in the detection zone of a proximity warning system, a person should stand or walk in the area of interest near the sensor as the following test procedures describe. At least one test should be conducted with an average-sized person measuring 172 cm +8 cm (5 ft 7 in + 3 in) in height. An additional test can be conducted to represent a small adult female using a person approximately 150 cm (4 ft 11 in) in height.

Smaller Vehicle: For tests to detect a smaller vehicle in the detection zone of a proximity warning system, a passenger vehicle that is typically used at the mine site should be parked or driven in the area of interest as described in the test procedures to follow. At a minimum, one orientation for the vehicle should be tested in which the vehicle's longitudinal centerline (the long axis of the vehicle) is parallel with the longitudinal centerline of the heavy equipment on which the sensor is mounted.

B1.3 Test Setup

Test Area: The test area should be an open space on flat terrain with a dry soil and/or gravel base. No rocks, foliage, or debris larger than 8 cm (3 in) in diameter should be in the test area. To establish a sensing zone, no objects should be within the sensing direction of the proximity warning system for a distance of approximately 50 m (160 ft). For example, 50 m of clear area should lie behind the equipment to establish a rear sensing zone. No large objects should be within 25 m (80 ft) on either side of the proximity warning system. (The test area size may need to be increased for sensors with longer detection ranges than those listed here.) All personnel, except the person acting as the test obstacle, should remain in an area outside of the detection zone.

Sensor Mounting Locations: For forward sensing, the sensor should be mounted on the front bumper or grill of the mining equipment according to the manufacturer's instructions. For rear sensing, the sensor should be mounted on the rear bumper area. If this is not possible, as with large off-road trucks, it can be mounted near or on the rear axle. Other locations may be acceptable, depending on the proximity warning system's installation instructions. The sensor's tilt angle, if adjustable, should be adjusted according to the manufacturer's instructions.

B1.4 Test Procedures

B1.4.1 Testing for False Alarms

Tests of the proximity warning system should start with no obstacles or objects near the system. With the potential detection zones totally clear, the equipment should be moved at slow speed (less than 8 kph (5 mph)) in the direction of interest for approximately 15 m (50 ft) to determine the frequency of false alarms. If false alarms occur, the cause of the alarms should be determined, if possible, and noted, e.g., "System detected the ground" or "Detected rotating tires." The system should then be adjusted or relocated in order to minimize false alarms within the clear test area. Once the false alarms are minimized, the system settings and mounting position should be recorded.

B1.4.2 Testing Obstacle Detection

The detection zones for the proximity warning system should be determined by placing the obstacle at various distances and locations behind the stationary equipment according to a test grid pattern. Test points in the potential detection zone should be defined by a grid with a spacing of no more than 1 m or 2.5 ft between test points. Detection at each grid point should be determined by recording whether or not an alarm is activated when the obstacle moves toward the sensor in a line parallel to the longitudinal centerline of the equipment. For a person, movement toward the sensor should be at a slow walking speed of approximately 5 kph (3 mph). For a smaller vehicle, movement toward the sensor should be less than 8 kph (5 mph).

The reliable detection zone includes only the area in which the obstacle is detected 100% of the time. The obstacle must be detected and an alarm must be generated immediately (<200 ms) after the equipment starts moving toward the stationary obstacle or after the obstacle moves toward the stationary equipment. The sporadic detection zone includes only the area in which the obstacle is detected less than 100% of the time, but more than approximately 10% of the time. Less than 10% detection should be considered outside of both detection zones, but may be noted as a false alarm.

Example Obstacle Detection Test: The obstacle detection test for a person is comprised of the following steps. (Small vehicle tests can be conducted by substituting a vehicle for a person.) The starting position for the person should be in front of the sensor portion of the proximity warning system, but at a distance well outside the potential detection zone.

1. Starting on the centerline of the equipment (0-m line) and outside the detection zone, begin the test by walking toward the sensor.
2. When the alarm is activated, place a marker on the line where detection occurred.
3. Back up until the alarm stops and then walk toward the sensor again to verify the position of the first detection point.
   Repeat this step until a consistent detection point is determined.
   Note: If there are points where the alarm is not consistent (sporadic detection), mark the first point where this occurs with a different-colored marker.
4. Continue walking toward the sensor along the 0-m centerline.
5. Place a marker at the point where detection stops and the alarm ceases.

Note: The alarm may be activated up to the point directly in front of the sensor. In this case, place the marker at this point.

6. Walk out of the detection zone to the initial starting point.
7. Move from the 0-m centerline to the next gridline to the right (1 m or 2.5 ft). Repeat steps 2 through 4 along this line.
8. Repeat steps 2 through 4 along each line until detection does not occur at any point on the lines.
9. To determine the detection zone left of the centerline, move to the left side of the centerline and repeat steps 2 through 4.
10. Record the position of the markers as described in the last section of Appendix B, "Recording Data."

Detection Zone Verification: The detection zone should be verified for a moving piece of equipment by allowing the person or small vehicle to remain stationary at several points at the far edge of the detection zone and moving the equipment slowly toward the obstacle. The equipment may continue backing for several meters, but must be stopped before it reaches an unsafe distance to the obstacle. Any discrepancies over 30 cm (1 ft) between detection zones for moving equipment/stationary obstacle and stationary equipment/moving obstacle should be noted. The following steps can be used to verify the detection zone.

1. Verify the detection zone for moving equipment by standing at the detection zone point that is farthest from the proximity warning system on the 0-m line.
2. Using a spotter and radios, signal the equipment operator to move slowly forward a few meters.
3. Signal the operator to move the equipment slowly in reverse.
4. Stop the equipment when the alarm activates and record the distance between your position and the sensor on the equipment.
   Note: If the alarm does not activate when expected, stop the equipment at a safe distance, note that this occurred, and discontinue this test.
5. Move the equipment back to the starting position.
6. Conduct the test again for the outer detection point on the next gridline.
   Repeat until the outer edges of the detection zone are verified. Record any discrepancies greater than 30 cm between this test and the test using the stationary equipment and walking person.

Recording Data

False Alarms: False alarms should be noted when testing the proximity warning system as described above in the section on "Testing for False Alarms." Possible causes of false alarms and optimum mounting configurations to minimize false alarms should be noted.

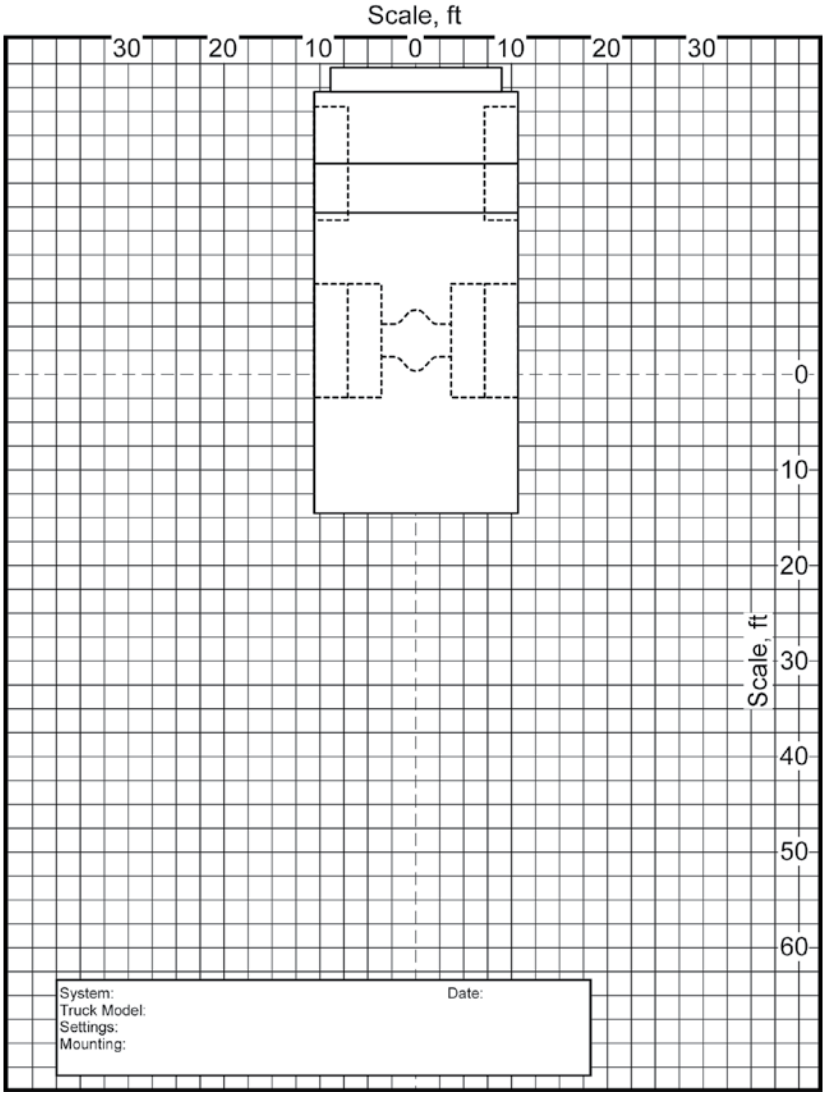

Figure B.1. Example of test grid for rear detection zone.

Appendix C

Data Collection Form

<table>
<tr><td colspan="3">Data Collection Form – Radar and Camera Systems</td></tr>
<tr><td>Date:</td><td>Time: [] am
[] pm</td><td>Weather:</td></tr>
<tr><td colspan="3">Truck Number:</td></tr>
<tr><td colspan="3">RADAR
Check the appropriate box(es).

☐ Radar system operated reliably today.

☐ Radar system had some problems today. See below.

False alarms – alarms with no apparent cause.
☐ Frequent ☐ Occasional ☐ Very rare

Missed alarms – an object was behind the truck but was not detected.
Describe: ____

☐ Other problems – Describe: ____

☐ A collision was avoided because an object was detected by the radar system.
Describe: ____
____</td></tr>
<tr><td colspan="3">CAMERA
Check the appropriate box(es).

☐ I regularly use the camera system to:
☐ Check the blind areas near the equipment.
☐ Assist in backing to the dump point.
☐ Assist in positioning the truck in the loading point.

☐ I do not use the camera system.

☐ There were problems with the camera system today.
Describe:____
____

☐ A collision was avoided because an object could be seen in the video monitor.
Describe:____
____</td></tr>
<tr><td colspan="3">Other comments:</td></tr>
<tr><td colspan="3">Drivers initials (optional):</td></tr>
</table>

Appendix D

System Manufacturers and Distributors

D1.1 Radar-based Systems

Eaton Vorad radar system
Mineco
Huntingdon Valley, PA
215-938-7304
www.mineco.us

Heavy-Duty Preview radar system
Preco Electronics
Boise, ID
208-323-1000
www.preco.com

Ogden Intelligent Radar
Ogden Safety Systems
Tadcaster, North Yorkshire, UK
44-1937-835395
www.ogdenradar.com

RF Knapp Co.
Spirit Lake, ID
208-623-4555
www.rfknappco.com

D1.2 Sonar-based Systems

Eagle Eye
Transportation Safety Technologies
Castle Rock, CO
303-814-1592
www.tst-eagleeye.com

Hindsight 20-20
Sonar Safety Systems, Inc.
Santa Fe Springs, CA
800-326-6949
www.hindsight20-20.com

Rear Guard
Castleton, Inc.
Westminster, CA
714-799-4045
www.rearguard.com

VCAS
Vertuel Systems, Ltd
Dorset, UK
44-1202-697976
www.vertuelsystems.com

D1.3 Infrared Sensors and Thermal Imaging Systems

Fork Alert
RAY-Safe
Cleveland, OH
216-533-5490
www.ray-safe.com

PathfindIR
FLIR Systems
North Billerica, MA
978-901-8000
www.flir.com

Search Eye Sensor System
Global Sensor Systems, Inc.
Mississauga, Ontario, Canada
905-507-0007
www.globalsensorsystems.com

X-Vision
Bendix Commerical Vehicle Systems
Elyria, OH
440-329-9000
www.bendix.com

D1.4 Tag-based Systems

Buddy – Haul Truck
Nautilus International Control & Engineering, Ltd
Burnaby, BC, Canada
604-430-8316
www.nautilus-intl.com

CAS-CAM/RF
Advanced Mining Technology
Chittaway Bay, NSW, Australia
61-2-4389-2344
www.advminingtech.com.au

EV Alert
Victoria, Australia
61-3-9553-0922
www.evalert.com.au

HaulTAG
Minecom
Tasmania, Australia
61-3-6424-5666
www.minecom.com.au

Mine Mate
International Mining Technologies
Perth, Western Australia
61-08-9244-3200
www.internationalmining.com.au

TramGuard
Gamma Services International
Clay, KY
270-635-0482
www.gsimining.com

D1.5 Video Cameras

ECCO
Boise, ID
800-635-5900
www.eccolink.com

Intec Video Systems
Laguna Hills, CA
877-468-3254
www.intecvideo.com

Safety Vision, Inc.
Houston, TX
713-896-6600
www.safetyvision.com

Vision Techniques Group, PLC
Blackburn, UK
44 [0]1254-679717
www.vision-techniques.com

WAVS (Work Area Vision System
through Caterpillar, Inc.)
Peoria, IL
309-578-6298
www.cat.com

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