MONITORING BLIND SPOTS: A MAJOR CONCERN FOR HAUL TRUCKS

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Introduction

Researchers at the National Institute for Occupational Safety and Health (NIOSH), Spokane Research Laboratory, are investigating technology and methods to monitor the blind areas around large haulage equipment used in surface mines. On average, six fatalities a year can be attributed to equipment colliding with other vehicles or pedestrian workers, or backing over the edge of a dump point. Several off-the-shelf technologies exist for monitoring areas that an equipment operator cannot see from the cab, including radar, video cameras, and radio signal detection systems. NIOSH researchers have tested many of these systems on large dump trucks both at their test facility and at surface mines. This article discusses the technologies available for this application and their effectiveness in detecting objects near an off-highway dump truck. Also, guidance is presented for mine safety personnel who are planning to evaluate collision warning systems or cameras on their haulage equipment.

Available Technology

Over the past few years, the number and types of systems available for monitoring the blind areas around heavy equipment have increased. Systems marketed for the automotive and recreational vehicle industries have been around for a while. Small video cameras can be found on motor homes, and several car manufacturers now provide ultrasonic parking aids integrated into the rear bumper of new cars and vans. However, off-the-shelf systems specifically for mining and construction equipment were, until recently, quite rare. Those systems that were marketed for this industry consisted mainly of closed-circuit television systems. Now systems based on radar and radio-frequency identification (RFID) are available for heavy equipment [4], and other systems based on ultrasonic sensors are being developed. However, the application of these new devices in actual mining operations is rare. This is due, in part, to a lack of field trials that prove the reliability of these new devices. We hope that this article will shed some light on the effectiveness of collision warning and camera systems and what can be expected from each type of technology.

Video Cameras

Video cameras are one exception when it comes to the rare use of off-the-shelf systems in surface mines. Video cameras have been available for mining equipment for several years, and many improvements have recently been made that include reduced size and cost. Consequently, several surface mines are using video cameras on dump trucks with success. More information can be found regarding the use of cameras in a video released by the Mine Safety and Health Administration [1].

Usually, two or three cameras are needed to monitor the blind areas around the front, right side, and rear of a large dump truck. The lenses of these cameras must be cleaned occasionally and more often in wet conditions or in bad weather. A good system will allow all the cameras to be connected to a single video display that has the capability of automatically switching camera views depending on the truck's direction of motion or gear selection. The less-expensive cathode ray-tube (CRT) and the newer and smaller liquid crystal display (LCD) monitors are the choices for the video display. Cost and space requirements are usually the deciding factor in monitor selection.

While video cameras have proven to be an effective means of monitoring blind areas, it is good to be aware of some of the challenges in using them on haulage equipment. One challenge can be finding a system that can withstand the operating conditions. Shock and vibration can shorten the life of a video camera and video monitor. Cables must withstand high heat and abrasion from flying rock. Cameras must be housed in tough enclosures that can handle impacts from flying rocks and mud and that are resistant to the direct, high-pressure water spray used during truck washing.

One improvement that can be made to camera systems is the addition of a collision warning system that senses when an object or person is near the equipment and sends an alarm. The alarm prompts the operator to check the video monitor before moving the equipment any further. The absence of an alarm with video systems alone does not prohibit the effective use of cameras, but it does allow for the possibility of an accident if the operator forgets or is unable to check the video monitor before moving the equipment. Many manufacturers of the new collision warning systems on the market have realized the benefits of combining cameras and sensors.

Radar

Radar is a popular technology for collision warning systems, but only a few systems are specifically designed for heavy mining equipment. These systems are simplified and lowerpowered versions of traditional radar used in tracking aircraft and measuring the speed of vehicles. A microwave signal (usually between 4 and 12 gigahertz) is transmitted from the system's antenna, resulting in a beam of electromagnetic energy directed toward the area to be monitored. The energy is very low in power and safe for human exposure. A separate receiving antenna and associated electronics detect reflections of this energy from objects within the transmitted beam. Radar systems can detect people, rocks, buildings, and foliage. They are especially good at detecting metal objects. An alarm, usually flashing lights and an audible warning, is mounted in the cab of the equipment to warn the operator of an object or person nearby. Some systems provide a readout of distance to the detected object. Figure 1 shows an example of a radar system marketed for heavy equipment.

The advantages of radar include low price, reliable operation in all weather conditions and dusty environments, and reliable detection of large objects such as other vehicles or people. However, radar is susceptible to false and nuisance alarms. False alarms, or alarms caused for no apparent reason, are rare, but can be generated by reflections from distant buildings, the ground, build up of dirt, mud, and/or snow on the radar enclosure, and sometimes even equipment vibration. Nuisance alarms are alarms from objects of which the operator is already aware or from objects that pose no danger. For instance, an alarm would be generated from the highwall as the truck backs into a loading area. Or an alarm could be generated from rocks larger than 20 cm in diameter (8 in) as the truck backs up in an otherwise clear area. For these reasons, it is recommended that a method of verifying alarms be used in conjunction with radar systems. It would be unacceptable for the operator to climb down from the cab to verify the cause of every alarm, so the use of video cameras is the best solution. As mentioned earlier, video cameras and radar should be used in combination to provide the important alarming function and the method to verify the location and cause of each alarm.

Radio-Frequency Identification

Application of RFID to collision warning systems is a relatively new approach. In the last year, two systems have been introduced that were developed specifically for heavy surface mining equipment. Figure 2 shows an example of one of the systems. Several more systems are in development. The two available systems, one by Nautilus International (Burnaby, B.C., Canada) and the other by Advanced Mining Technology (Chittaway Bay, Australia), operate on the same basic principle, but use different communications schemes. Both systems require the use of electronic tags attached to light vehicles, pedestrian workers, other mining equipment, or stationary objects such as utility poles and buildings. Any worker or vehicle entering the mine site must be outfitted with a tag to be protected. Heavy equipment in the mine is outfitted with tag reader electronics to detect the presence of a tagged object or person that is near the equipment. If a tag is detected within a certain range, an alarm is generated and displayed to the equipment operator. A unique identification can be transmitted from each tag so that the type of obstacle can be presented along with the alarm. For example, the operator would be able to distinguish between an alarm caused by a worker and one caused by a service vehicle.

The advantages to using RFID include the rare occurrence of false or nuisance alarms, the ability to identify the cause of the alarm through its unique identification code, better detection of objects near the equipment, and the ability to monitor around the entire piece of equipment with just one or two tag readers. Drawbacks include a higher price than other options and the requirement that all workers and objects that need to be protected must be outfitted with a tag, which further increases price and maintenance. Also, while the available systems can differentiate between alarms from the back or front of heavy equipment, the exact location of the tag that caused the alarm will not be known. Manufacturers of both these systems provide a video camera system as an option so that alarm locations can be verified. In fact, the collision warning alarms are integrated and overlain on the video monitor display.

Evaluating Technologies

Very little data exist that show the performance of collision warning systems when mounted on actual mining equipment. Engineers at NIOSH have undertaken an evaluation of all available technologies in order to verify their effectiveness on large off-highway dump trucks. Dump trucks were chosen because of the severity and number of accidents involving this type of equipment and the extensive blind areas that are typical around these trucks. A simple test procedure was used to evaluate the ability of a system to detect a person and a smaller vehicle such as a pickup truck. This procedure is described along with results and recommendations for mine safety personnel who will be evaluating systems on their own trucks or other equipment.

Test Procedure

It is important to evaluate a collision warning system on the actual piece of equipment on which it is going to be used. Laboratory test data are fine for comparing systems for initial selection, but variables are introduced when the system is actually mounted on the equipment. These variables are mostly related to mounting position, where height, proximity to steel truck structures, and proximity to tires can affect the shape of the detection zone and the frequency of false alarms. Because of this, NIOSH researchers have tested systems on a Komatsu 210M 50-ton-capacity, rigid-frame, off-highway dump truck typically used in quarries and construction. Systems that performed satisfactorily on this truck were then taken to equipment manufacturers and mine sites to be tested on larger trucks. Further guidance on test procedures can be found in the SAE standard J1741 entitled “Discriminating Backup Alarm System Standard.”

Each system was mounted on the truck according to the manufacturer’s recommendations. Usually, at least two systems were required, one on the front of the truck and one on the rear. The front system was mounted above the front bumper at the center of the truck. The rear system was mounted above or near the rear axle housing (figure 3).

For initial tests, the dump truck was parked in a clear area with a dirt-gravel surface that was graded flat and cleared of rocks and debris. This gave researchers a clear area for testing the systems where false alarms could not be attributed to objects on the ground. If false alarms occurred, they were most likely caused from structures on the truck itself or from the flat ground, which could be remedied by relocating the system. Obstacles such as rocks, people, and smaller vehicles were then added as tests progressed.

The main obstacles to be detected consisted of a person and a passenger vehicle, such as a pickup truck, because these objects are involved in most accidents. It is important to test the system using an actual person of average height and build. The detection zone for other objects, such as mannequins or metal reflectors, may be provided in the product literature, but because the composition of inanimate objects is different than that of a human, the detection zone should always be verified for a person. The detection zones for a person and a passenger vehicle were recorded on graphs as shown in figures 4 and 5. The test procedure for a person consisted of determining the shape of the zone where a person was reliably detected by the collision warning system while the dump truck remained stationary with the engine running. The person walked toward the truck along grid lines spaced 75 cm (2.5 ft) apart. Reliable detection was recorded at points where forward movement of the person caused an immediate and consistent alarm. The detection zone was then verified for a moving dump truck and a stationary person by having the person stand on the extreme edges of the detection zone, where it was safe to move the truck a short distance. This required radio communications between the person performing the test and the equipment operator. A third person stood nearby to act as a spotter. Reliable detection was recorded when the alarm sounded immediately after the truck started moving. Detection very near the moving truck was not verified for safety reasons. Tests using a passenger vehicle were conducted in the same way, with the front of the vehicle facing either the front or rear of the dump truck, depending on which area was being tested.

It is important to test the detection zone with the heavy equipment's engine running. Vibration can effect the performance of a collision warning system. Also, it is important to verify the detection zone when the equipment moves in reverse. For example, some systems based on radar technology work fine when the equipment remains parked, but lose sensitivity when the equipment moves toward a stationary object. This can change the detection zone characteristics considerably.

Results

Figures 4 and 5 are just a few examples of detection zone plots as determined in our tests. Complete detection zone plots for people and passenger vehicles at the front and rear of the dump truck can be found in references [2] and [3].

Figure 4A shows the reliable detection zone for a person with Preco's (Boise, Idaho) Preview radar system mounted on the rear of a 150-ton-capacity dump truck. Several different mounting positions were tried. A position just above the hitch at a height of 170 cm (67 in) gave the best results (figure 3). This radar system did not generate false alarms in a clear area and could detect a person standing as far as 8.3 m (27.5 ft) from the rear axle. This result was consistent for a person moving toward the stationary truck and for the truck moving slowly toward a stationary person. One drawback with this system is that it does not detect objects near the rear tires of the dump truck. For a truck of this size, the ideal detection zone would cover immediately behind the tires and out 9 to 12 m (30 to 40 ft) behind the truck's axle.

Figure 4B shows the reliable detection zone for a person with the Ogden Safety Systems radar (Doncaster, England) mounted on the rear of a 50-ton-capacity dump truck. The radar unit was mounted near the light bar of this truck at a height of 135 cm (53 in). On some trucks, this radar system occasionally produced a false alarm when the truck rocked during gear shifting; however, the alarms were of short duration, and none occurred after the truck started moving. The false alarms were probably caused by the radar momentarily sensing the ground. On the Komatsu truck, a person was detected at 12 m (40 ft) away from the rear axle of the truck. The width of the detection zone was adequate, even near the rear tires. One advantage to this radar system is that the detection zone is adjustable in length and width according to the size of truck on which it is used.

Figure 5A shows the reliable detection zone for a person with the Nautilus International Buddy System on a 50-ton-capacity dump truck. This RFID system uses a single loop antenna to produce an electromagnetic field around the entire truck. Electronics tags, as shown in figure 2, sense the strength of this field and transmit an alarm condition back to the operator of the dump truck if the tag is within a preset warning distance. An alarm is also generated at the tag to warn a pedestrian worker of approaching trucks. Tags can be place on other equipment and smaller vehicles also. The loop antenna and processing electronics were mounted on the front deck of the dump truck, and the LCD monitor/alarm display was mounted in the cab. Alarms are generated on this display, which is also used to display camera views for the optional video system. The reliable detection area encircled the truck, extending 15 m (50 ft) from the front and back of the antenna and 9 m (30 ft) to the sides. The detection zone was not centered around the truck due to the antenna placement, which could be adjusted for more even coverage. No false alarms were seen with this system.

Figure 5B shows the detection zone for another RFID system manufactured by Advanced Mining Technologies. The tag readers were mounted on the rear axle and the front bumper of the Komatsu truck. Tags consisted of the processing electronics, antenna, audible alarm, and rotating strobe light mounted on the roof of a passenger vehicle. An alarm display was also mounted in the cab of the vehicle. Tags are currently being designed for use with pedestrian workers and will likely be integrated into a hard hat. The alarm display on the dump truck consists of an audible and visual alarm integrated into a video monitor. The video monitor also displays the view from an integrated camera system. The black outline of the detection zone in figure 5B shows where a passenger vehicle was reliably detected by the system. If the passenger vehicle was parked within 17.5 m (57.5 ft) directly behind or in front of the dump truck, an alarm would be generated at the dump truck display along with a code identifying the presence of a passenger vehicle. The width of the detection zone was adequate to detect a vehicle parked behind or directly beside the rear dual tires. The range of the detection zone can be adjusted between 0 and 100 m (328 ft).

Many other systems have been evaluated on the Komatsu 210M and larger trucks. The following table summarizes and compares some of the important parameters for available collision warning systems based on radar and RFID technology.

Table 1. A comparison of collision warning systems as tested on a 50-ton-capacity dump truck.

System	Nautilus Buddy System	Mintronics Body Guard	AMT CAS	Knapp System 201	Sense Technologies Guardian Alert	Preco Preview	Ogden Safety Systems
Phone number	604-430-8316	705-474-4759	61-2-4389-2344	800-831-4609	800-998-0555	800-453-1141	44-1254-679717
Technology	RFID	RFID	RFID	Doppler radar	Doppler radar	Pulsed radar	FMCW radar
User-adjustable zones	Yes	Yes	Yes	Yes	No	No	Yes
Motion required for detection	No	No	No	Yes	Yes	No	Yes
Maximum length of rear detection zone as tested (person/pickup in feet)	50/50	50/50	NA/57.5	22.5/65	25/45	30/27.5	40/40
Total coverage near outer dual tires	Yes	Yes	Yes	Yes	Yes	No	No
Maximum length of front detection zone as tested (person/pickup in feet)	50/50	50/50	NA/57.5	22.5/65	30/37.5	27.5/30	25/30
Total coverage near front bumper	Yes	Yes	Yes	Yes	Yes	No	Yes
Sporadic detection at zone edges	No	Yes	No	No	No	No	No
For use in all weather	Yes	Yes	Yes	Yes	Yes	Yes	Yes
False-alarm rate in clear field	None	None	None	Infreq.	Frequent	Infreq.	Infreq.
Cinder block detection	No	No	No	Yes	Yes	Yes	Yes
Multiple units needed for entire coverage (front/back)	No	Yes	Yes	Yes	Yes	Yes	Yes
Two-way alarming (warning provided for person detected).	Yes	No	Yes	No	No	No	No
Cost US$ (High = above $8000, Med. = $2000-$8000, Low = below $2000)	High	High	High	Low	Low	Low	Low

NA - not available

Looking Ahead

NIOSH is also investigating technologies that could be used in future collision warning systems for mining and construction. One technology that shows promise is based on the global positioning system (GPS). Trimble Navigation, Inc., Sunnyvale, CA, has developed a prototype system under contract with NIOSH. The system has been tested to a limited extent on a Komatsu dump truck and several smaller vehicles. Figure 6 shows the test setup with a Komatsu truck and a passenger vehicle.

The prototype system consists of a GPS antenna and receiver, a computer interface, and internet protocol (IP) radio communications. This system would be installed on all vehicles and heavy equipment in the mine. The location of each vehicle is determined and then transmitted to all other vehicles and equipment in the area. The data processing and alarm display uses a Windows CE computer platform. Figure 7 shows the computer temporarily mounted in the cab of a dump truck.

The display shows two warning areas in concentric circles around the vehicle, represented by an icon in the center of the screen. The outer circle warns the operator that a vehicle is nearby, but not in immediate danger. The inner circle gives a more emphatic warning that another vehicle is very near. Utility and passenger vehicles could have a simpler and less expensive interface, but the essential components of the system would be the same.

Initial tests at the NIOSH facility in Spokane, WA, have shown that the prototype system is effective. Errors in vehicle position using receivers with differential correction were between 1 and 2 m (3.3 and 6.6 ft), depending on the number and position of satellites. Update rates for vehicle position were approximately 1 s with the current algorithms and IP radios.

Future work will involve improvements to the graphic interface, higher bandwidth IP radios for increased update rates, development of miniaturized systems for pedestrian workers, and smaller, tougher packaging of the heavy equipment and smaller vehicle systems.

Another concern with this system involves the loss of GPS signals because of the potential for poor satellite access. This can occur in open pits where equipment can work near the "shadow" of mine walls or other heavy equipment. It can also occur during certain times of the day as satellites move in and out of view. Possible solutions are being studied including the use of wide-area augmentation systems and/or pseudolites. Near-term solutions to this problem will probably require a secondary system, such as cameras, radar, or RFID.

Conclusions

Devices are available to help eliminate blind spots and associated accidents involving large off-highway mining equipment. Camera systems and, more recently, radar and RFID systems designed specifically for heavy equipment are now on the market. Successful implementation of these systems can be achieved if their shortcomings are realized and anticipated. Cameras can benefit from the addition of a sensor system so that the equipment operator is prompted to check the video monitor while moving the equipment. Radar is good at detecting people and small vehicles, but it is susceptible to nuisance alarms, requiring cameras to verify the cause and exact location of the nearby object. RFID, while more expensive than other solutions, is very reliable, and its increased functionality and integrated camera system make it an attractive long-term solution.

No collision warning system can replace the training and caution necessary for operating heavy equipment. However, technology can aid in reducing some of the guesswork required when operating equipment that has extensive blind spots.

References

1. Mine Safety and Health Administration, “What You Can’t See Could Kill Someone.” Video VC-951, May 2000. Available by calling (304)256-3200.

2. Ruff, Todd M., “Test Results of Collision Warning Systems for Surface Mining Dump Trucks.” NIOSH Report of Investigations 9652, 2000, 44 pp.

3. Ruff, Todd M., “Test Results of Collision Warning Systems on Off-Highway Dump Trucks: Phase 2.” NIOSH Report of Investigations 9654, 2001, 21 pp.

4. NIOSH, “Devices to Monitor Blind Spots Near Large Haulage Equipment.” NIOSH Technology News No. 484, January 2001.

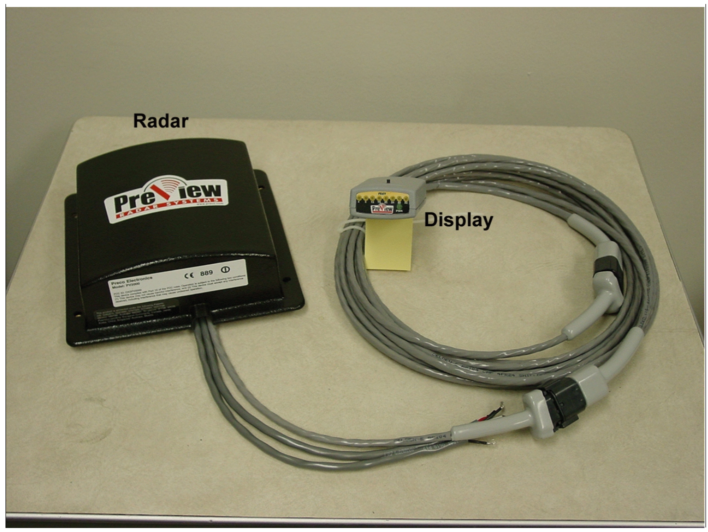


Figure 1. Preview radar system by Preco, Inc.

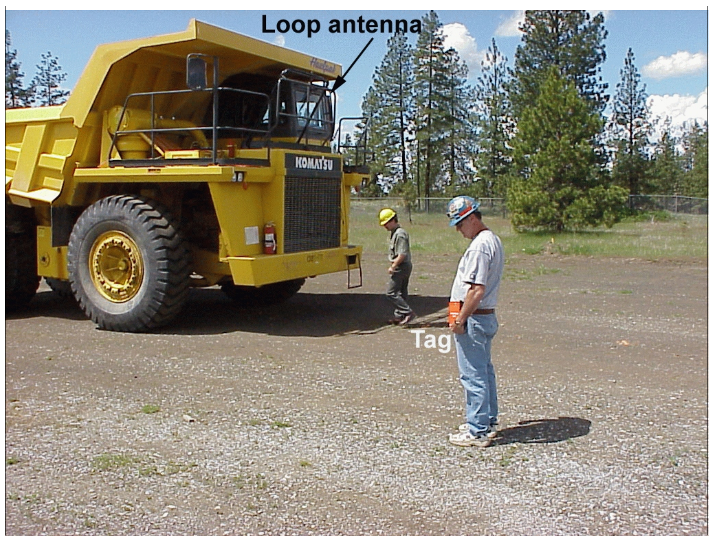


Figure 2. The Nautilus Buddy System on a Komatsu 210M.

Figure 3. Mounting position for radar system on rear of CAT 785C dump truck.

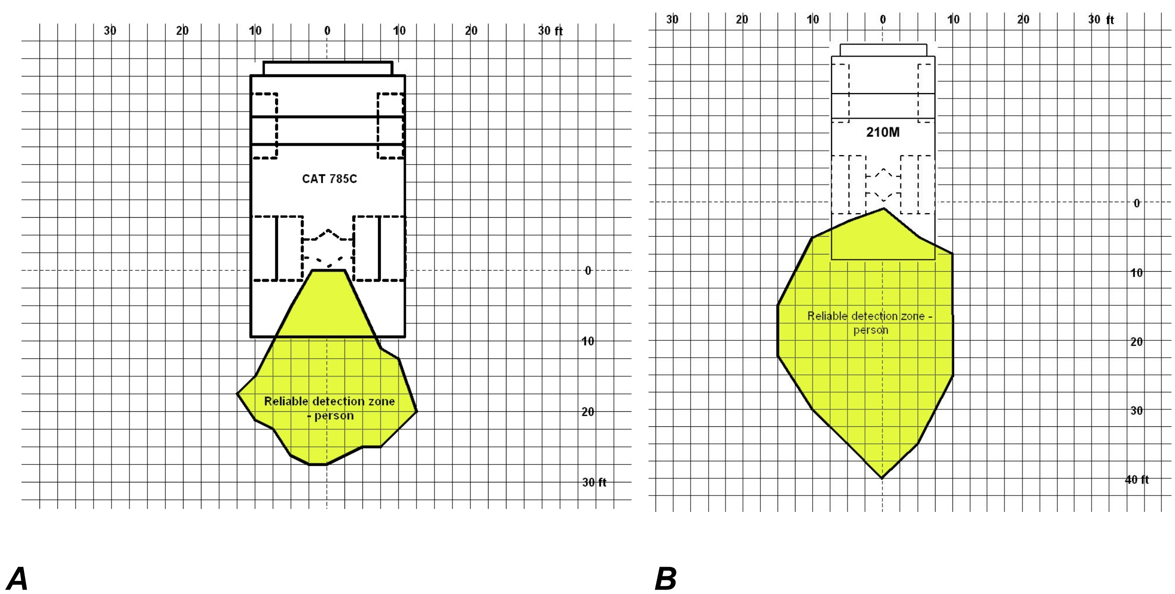
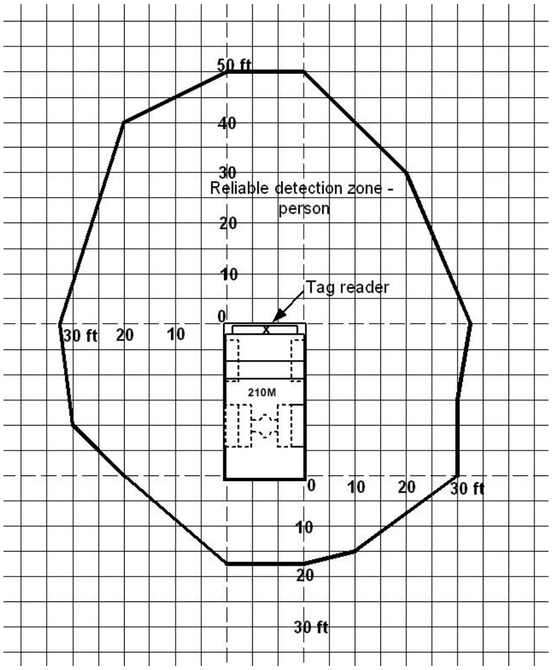
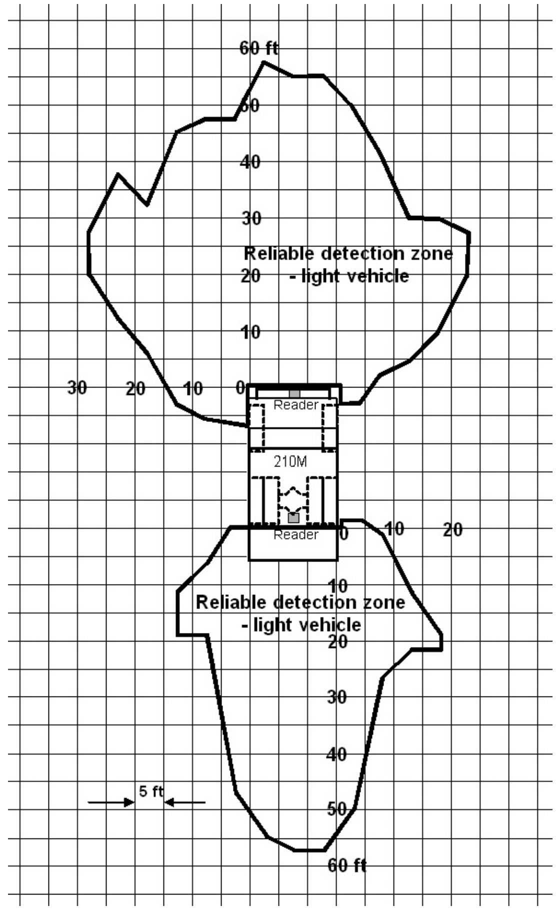


Figure 4. Reliable detection zone for a person behind ***A***, Preview radar system on CAT 785C and ***B***, Ogden radar system on Komatsu 210M.





A ***B***

Figure 5. ***A***, Reliable detection zone for Nautilus Buddy System around Komatsu 210M dump truck (tag on worker's belt). ***B***, Reliable detection zone for AMT CAS system on the front and rear of Komatsu 210M dump truck (tag on pickup truck with front bumper as detection point).

Figure 6. Tests of collision warning system using GPS and peer-to-peer communication between dump truck and passenger vehicle.

Figure 7. Graphics display for GPS-based collision warning system.