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Application of Radar to Detect Pedestrian Workers Near Mining Equipment

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Between 1990 and 1996, 133 accidents occurred and 23 mine workers were killed when haulage trucks used in surface mines collided with another smaller vehicle, a mine structure, or a pedestrian worker. These accidents were caused by a lack of visibility from the cab of the truck. Similar accidents are common with other types of equipment, such as front-end loaders and shovels. There are several methods for improving the operator's awareness of objects or people around the equipment including improved mirror designs, video cameras, and sensor technologies. Researchers at the National Institute for Occupational Safety and Health (NIOSH) are evaluating collision warning systems that are based on radar technology. These systems are mounted on the mining equipment to monitor one or more of the blind areas. An alarm is provided to the operator if an object or person enters the radar's detection area. Tests consisted of mounting the systems on a 50-ton-capacity truck typically used in quarries and a 240-ton-capacity truck used at a surface mine. This article summarizes the test procedure and results of evaluations of several off-the-shelf and prototype radar systems. False alarm rates and reliable detection zones for pedestrians were recorded for various mounting configurations on the rear of the trucks. Mounting radar systems on large equipment presents several challenges; however, the technology does show promise for this application.

Keywords Collision Warning System, Radar, Proximity, Alarm, Surface Mining, Haulage, Dump Truck

Between January 1990 and July 1996, 133 accidents occurred involving large haulage trucks colliding with another object or person. Twenty-three of these accidents resulted in a fatality.(1) The most common accident involves a dump truck colliding with a smaller vehicle or another piece of mining equipment; however, accidents involving pedestrian workers are also common and are almost always fatal. Similar accidents are common with other types of equipment, such as front-end loaders and shovels.

The high number of fatalities attributed to these types of accidents has prompted the Mine Safety and Health Administration (MSHA) to propose a rule that would require some type of camera or sensor system to monitor the blind spots around surface mining haulage equipment. This rule, first introduced in 1998, is still under consideration and would apply to all off-highway rear dump trucks and articulated front-end loaders.(2)

Researchers at the National Institute for Occupational Safety and Health (NIOSH) are investigating available technologies that can detect the presence of an obstacle such as a person or smaller vehicle in the blind spots of large surface mining equipment and provide a warning to the operator. These collision warning systems are available and being used in other industries. However, applying these technologies to surface mining equipment, especially large off-highway trucks, has been difficult. Only recently have a few systems become available that are specifically made for mining equipment.

A collision warning system consists of some type of sensor that detects the presence of an object or person, an alarm display that warns the equipment operator, and the communications link between the sensor and display. Several technologies exist that can detect a person that is out of view; these include radar, ultrasonic sensors, infrared sensors, and radio-frequency signal detection/identification systems (RFID). Other technologies exist that can improve visibility around the equipment, but provide no alarm. These include improved mirrors and camera systems. While a combination of technologies can be used, the current research focuses on those systems that can provide an alarm to warn an equipment operator of an impending collision.

This article summarizes a portion of the results of an extensive effort to evaluate collision warning systems on mining equipment and presents new findings on the performance of radar systems. For a full disclosure of results and in-depth descriptions of available technologies, refer to NIOSH *Report of Investigations 9652*.(3)

APPROACH

A product search was conducted to determine the availability of collision warning systems that could be effective on mining equipment. There are many systems available for other industries, especially automobiles, delivery vans, trucks, recreational vehicles, and some construction equipment. There are a few foreign systems specifically manufactured for surface mining equipment.

Next, researchers talked with mining personnel, MSHA engineers, and mining equipment manufacturers to determine why existing collision warning systems are not being used extensively by the mining industry. They indicated that the main factors are (1) lack of field testing and research to determine effectiveness of the systems, (2) poor reliability because of false alarms, and (3) poor reliability and high maintenance due to the harsh operating environment. Based on this information, NIOSH researchers decided that further product development and extensive testing was needed before collision warning systems would be widely accepted by the mining industry.

The next step involved narrowing down the available technologies to those that would be most suitable for the mining application. Criteria for selecting a system for mining included (1) the ability to operate in all weather and light conditions, (2) the ability to operate with mud and dirt buildup on the sensor and other components, (3) the ability to protect the sensors from high vibration and impact from flying debris, and (4) successful applications in similar environments. For these evaluations, only radar and RFID-based systems were selected. Only the results of radar system tests to detect a person will be discussed here.

Test results for four off-the-shelf (OTS) and one prototype radar system are discussed. Preliminary tests in the lab showed that test results vary depending on the equipment on which the system is mounted. Accident data show that the majority of fatal accidents involve off-highway dump trucks. These trucks also present challenges to the successful application of collision warning systems due to their size and limited mounting locations. Therefore, dump trucks typically used in surface mining and quarries were selected as the test equipment for this phase of the evaluations.

TEST PROCEDURE

Test of the collision warning systems were designed based on experience gained from previous tests, from portions of the Society of Automotive Engineers (SAE) standard J1741,[4] and from input from MSHA. The tests were conducted on a rigid frame, off-highway, large-capacity dump truck that represented those used in the mining industry. Because of time constraints, most of the tests were conducted at a NIOSH site using a Komatsu 210M 50-ton-capacity dump truck (Figure 1). However, two radar systems were also tested on a Caterpillar 793B 240-ton-capacity truck at the Phelps Dodge Morenci mine (Figure 2). Table I lists general specifications for each truck so that the mounting locations and physical configurations can be compared.

FIGURE 1
Komatsu 210M parked in the test field.

Each collision warning system was mounted on the dump truck according to the manufacturer's directions and with the requirement that the system not interfere with normal operations. To monitor the rear blind spot of the dump truck, the sensor was mounted near the light bar above the rear axle. To monitor the

FIGURE 2
Caterpillar 793B at the Phelps Dodge Morenci mine.

TABLE I
Dump truck specifications

Truck make and model	Komatsu 210M	Caterpillar 793B
Haul capacity	50 tons	240 tons
Overall length	30′3″	42′3″
Overall width	14′7″	24′4″
Tire diameter	6′6″	11′10″
Distance—axle to edge of tire	2′	3′6″
Distance—between inner dual tires	4′7″	8′2″
Height to light bar	5′8″	10′
Distance—truck bed extended past axle	9′	15′
Height of front bumper	30″	48″
Max speed forward	40 mph	34 mph
Max speed reverse	not available	7 mph

front blind spot, the sensor was mounted on the front bumper or on the grill.

The alarm display was usually mounted near the sensor so that researchers could easily monitor the alarm condition while testing. Normally, the alarm display is mounted in the cab of the truck. The general effectiveness of each alarm display was noted; however, long-term tests of the display in the cab should be conducted on each system to thoroughly evaluate how effective the alarm is in alerting the driver.

A test area that consisted of a large open lot approximately 200 feet long and 100 feet wide was constructed at each test location. The gravel and dirt surface was graded flat with no ruts, large rocks, or debris. This gave researchers a clear area in which to test the collision warning systems under ideal conditions. The frequency of false alarms in a clear field was noted when the dump truck was moved. The system's mounting and settings were adjusted to minimize false alarms. Obstacles were then added as each test progressed.

Common accidents involve a dump truck colliding with a smaller vehicle, such as a pickup, or with a pedestrian worker. Other accidents involve collisions with stationary objects, such as mine buildings or pit structures. Information presented here applies to pedestrian workers at the rear of the dump truck only. For test results involving pickup trucks and front detection zones refer to NIOSH *Report of Investigation 9652*.[3] To determine the reliable detection zones for each system, a human subject, with a height of 75 in and weight of 190 pounds, stood within the potential detection area of the system (Figures 2 and 3). The subject was wearing a hard hat, cotton shirt and jeans, and steel-toe boots.

The reliable detection zone for a person was recorded by standing on the points of a grid with 2.5 ft spacing that was marked in the sensor's potential detection area. For the rear blind spot, the dump truck was moved slowly (<5 mph) in reverse and the state of the alarm was monitored. If the alarm turned on immediately (<200 ms) and consistently after the truck moved, then that point was recorded as a reliable detection point. The recorded points on the grid were then joined to form an outline of the reliable detection zone. A second zone was recorded as needed and labeled "sporadic" if obstacle detection occurred some of the time, but not always (less than 100% detection, but more than 10%). Note that in certain areas near the dump truck, it is not safe to move the truck toward a stationary person. In these cases, the dump truck was kept stationary and the person moved toward the sensor. The reliable detection zone was recorded using the same subject and procedures for each collision warning system and for each truck type.

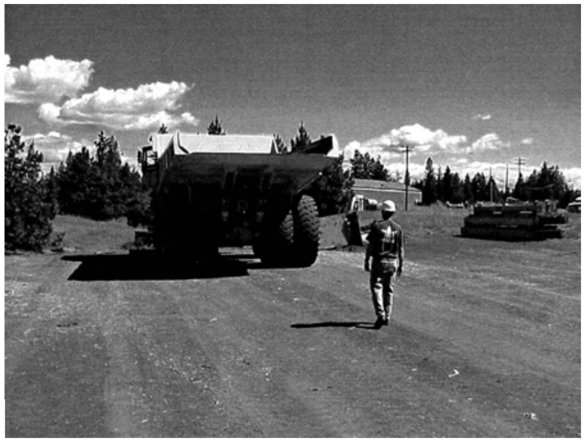

FIGURE 3
Determining the detection zone for a person.

TEST RESULTS

System: Radar Backup Alarm System 201, R. F. Knapp Co., Spirit Lake, Idaho

Description: This is a microwave radar system that senses Doppler shift. The system has been used on light trucks, utility vehicles, and front-end loaders. The radar antenna and processing electronics are encased in a hard plastic case. The alarm consists of a single-tone buzzer and a red light that is activated when an obstacle is detected. The radar was mounted on the Komatsu truck near the light bar with a slight downward tilt of 5° (Figure 4). A sensitivity setting was available on this system and was set to 75 percent.

Results: A mounting bracket had to be constructed that moved the radar system out beyond the rear tires. Otherwise, the radar would detect the rotation of the tires and cause false alarms. This may not be practical on larger trucks. This system did have other occasional false alarms possibly caused by detecting the ground. The sensitivity setting could be lowered to eliminate false alarms, but at the cost of decreasing the size of the detection zone.

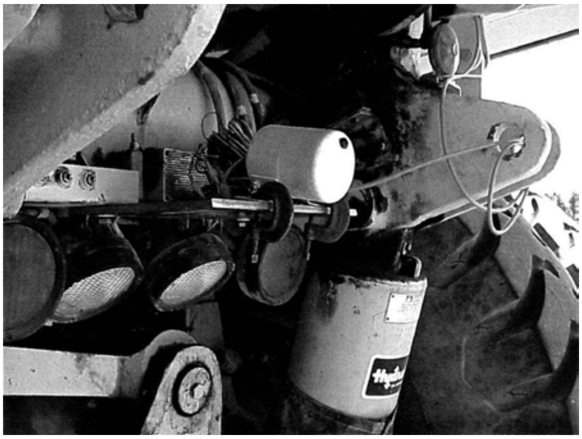

FIGURE 4
R.F. Knapp Co. radar system.

This radar system detected a person only if the truck or person was moving. A person was reliably detected out to 22.5 ft, and the width of the radar beam was adequate for the smaller dump truck (Figure 5). It is important that a collision warning system detect a person within 1 to 2 ft of the outer dual tires. This system did have adequate width to do this for smaller trucks. However, the beam width may not be sufficient for larger trucks. Earlier tests with this system showed that two radar units with narrow beams could be used to adequately cover the blind spot behind a larger truck.[5]

System: Guardian Alert, Sense Technologies, Vancouver, British Columbia, Canada

Description: This is a motion-sensing radar system that operates at a microwave frequency. This system is used on automobiles, light trucks, and delivery vans. It is a packaged in a small sealed housing and has an alarm display that indicates three distance ranges with both LEDs and audible alarms (Figure 6). The radar was tested on both the Komatsu and the Caterpillar trucks and mounted near the light bar. The mounting location on the Caterpillar truck required a 10 degree downward tilt. No user-selectable settings are available on this system.

Results: This system generated an occasional false alarm on both dump trucks. The alarm occurred when the dump truck lurched during shifting or quick braking. The system

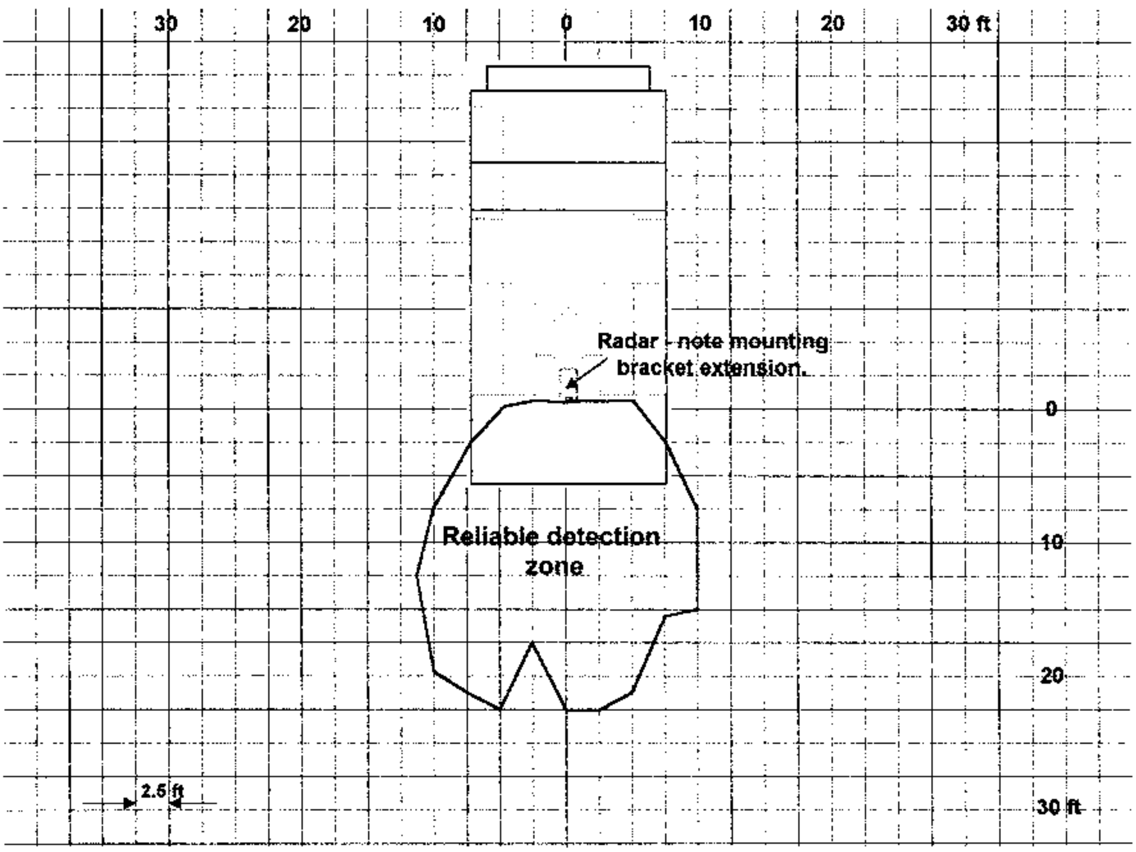

FIGURE 5
Detection zone for a person and the R.F Knapp radar on the Komatsu truck.

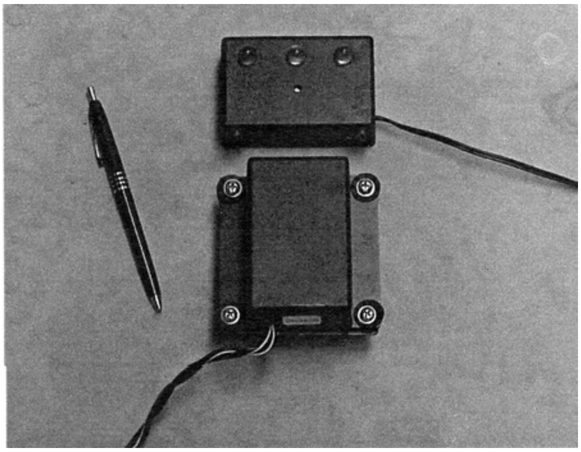

FIGURE 6
Guardian Alert radar system showing alarm display (top) and antenna/electronics enclosure (bottom).

did not detect tire rotation when the truck was moved in reverse.

On the Komatsu truck, the radar detected a person out to 25 ft with adequate width to detect someone near the outer tires. This would be sufficient for this truck (Figure 7). However, when the system was mounted on the Caterpillar truck, the detection zone was significantly different. Figure 8 shows the detection zone, which would not be effective for a truck of this size.

System: Ogden Radar, Ogden Safety Systems, Brodsworth, Doncaster, United Kingdom

Description: This is a microwave radar system that uses frequency-modulated continuous-wave technology to detect objects within the radar beam and calculate distance and speed. The system is used on front-end loaders and articulated trucks in mines and quarries in the United Kingdom. It is not currently available in the United States. The radar packaging is well suited for the mine environment. The alarm display provides three LEDs and three different audible frequency alarms to indicate different distance ranges. The radar was tested on both the Komatsu (Figure 9) and the Caterpillar trucks and mounted near the light bar. The mounting location on the Caterpillar truck required a 15 degree downward tilt.

Results: This system did not detect tire rotation and did not generate any false alarms when the dump truck was moved in a clear field.

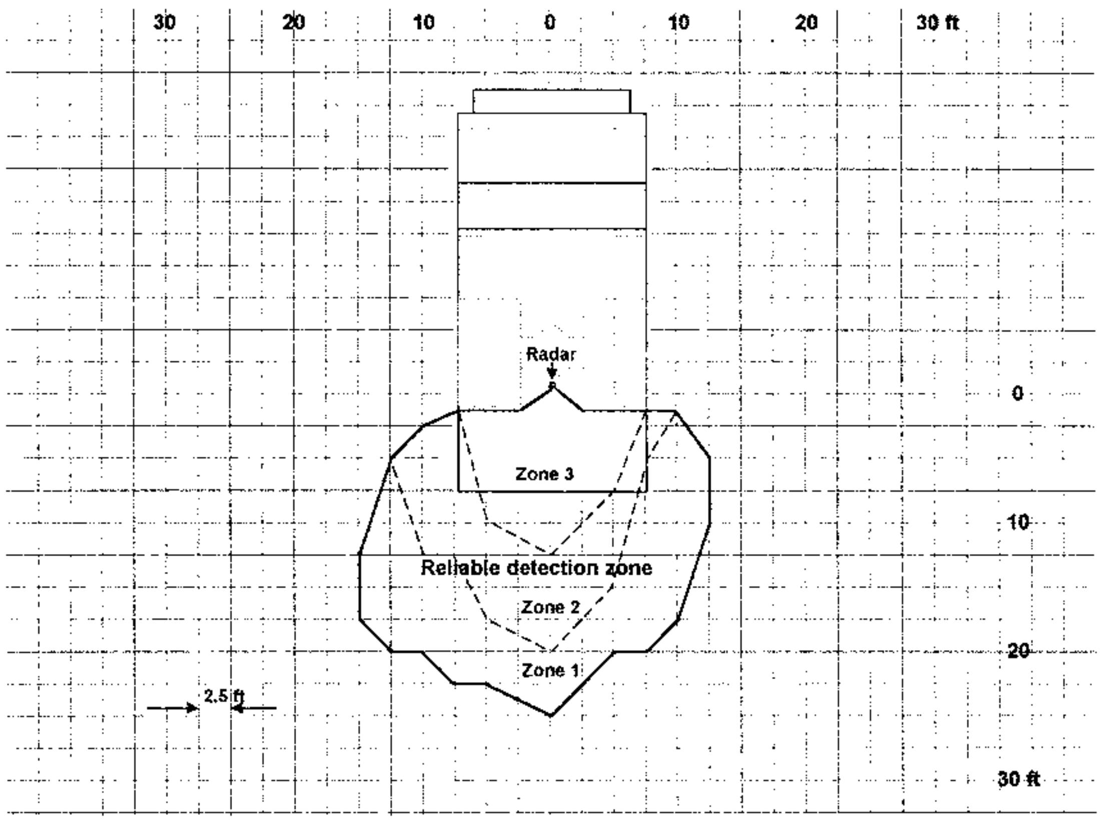

FIGURE 7
Detection zone for a person and the Guardian Alert radar on the Komatsu truck (alarm display's ranges indicated by dashed lines).

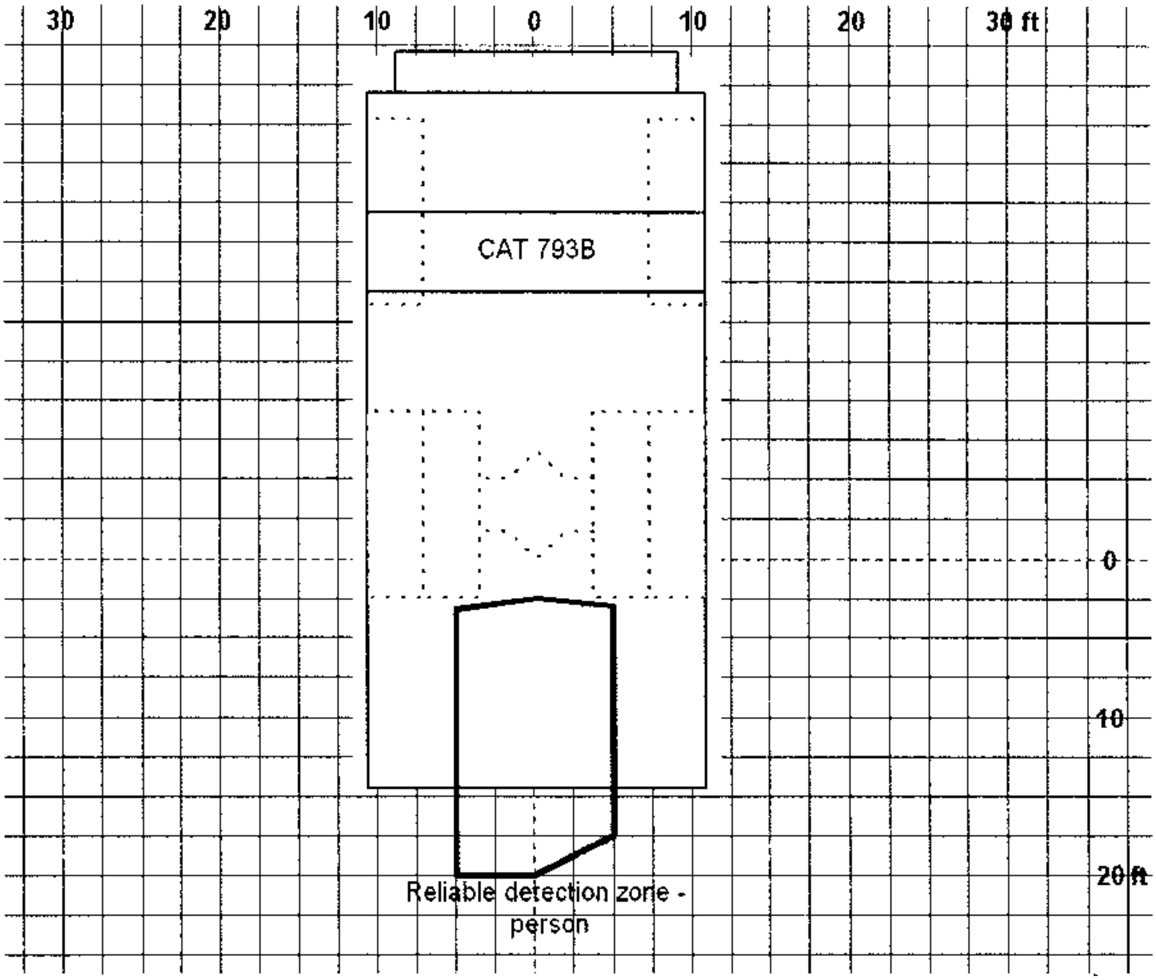

FIGURE 8
Detection zone for a person and the Guardian Alert radar on the Caterpillar truck.

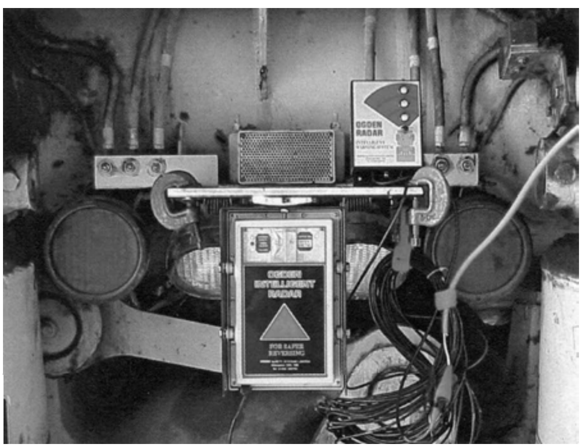

FIGURE 9
Ogden radar system mounted on the Komatsu truck and the alarm display (upper right).

On the Komatsu truck, the radar detected a person out to a distance of 40 ft. The width of the detection zone was adequate for this truck; however, a person standing immediately next to the outer tires may not be detected (Figure 10). Test results on the Caterpillar truck are shown in Figure 11. Again, the detection zone changed because of the higher mounting location and required tilt of the sensor. A person was not detected near the truck because he was walking underneath the radar's beam. Also, the range of the radar decreased to 20 ft. The settings on this system can be changed so that the beam width can be adjusted at several different distances. Improvements to the detection zone can be made using optional software from the manufacturer.

System: Preview, Preco, Inc., Boise, Idaho

Description: The Preview system is a pulsed radar operating at a microwave frequency. It detects both stationary and moving targets. This is a new system that was developed for highway and off-highway vehicles, such as construction and mining equipment. The alarm displays distance to the obstacle

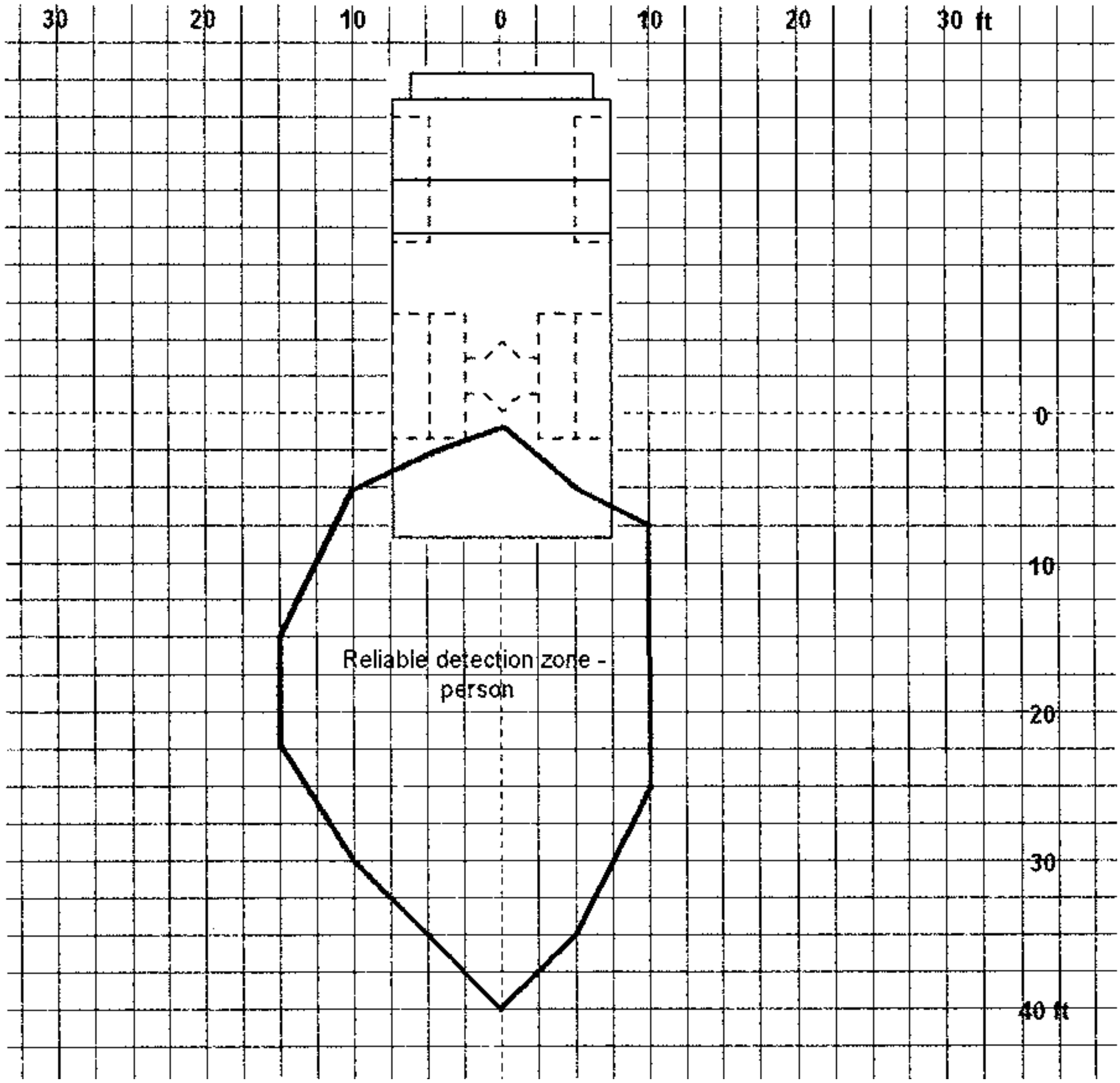

FIGURE 10
Detection zone for a person and the Ogden radar on the Komatsu truck.

by using eight LEDs and a variable-frequency audible alarm. No user-selectable settings are available on this system. The radar was mounted on the Komatsu truck below the light bar (Figure 12).

Results: Mounting this radar level and near the light bar caused false alarms from the detection of the overhanging bed of the truck. A lower position was necessary to eliminate these false alarms. This may be a problem on larger trucks also. The system did not generate false alarms when the truck was moved in reverse in a clear field.

The detection zone for a person is shown in Figure 13. Reliable detection occurred out to a distance of 30 ft. The width of the detection zone was adequate for this truck; however, detection did not occur near the outer edges of the tires. Small sporadic regions were seen on the edges of the detection zone.

System: Ultrawide-Band Radar, Multispectral Solutions, Inc., Gaithersburg, Maryland

Description: This radar system is based on ultrawide-band (UWB) technology that uses nanosecond radar signal pulses to measure distance to an obstacle. This is a prototype system developed specifically for large haulage trucks. The alarm display consists of three LEDs and an audible variable-frequency alarm that indicates the approximate distance to an obstacle. Sensitivity and range settings are software selectable. The radar was mounted on the Komatsu truck near the light bar (Figure 14).

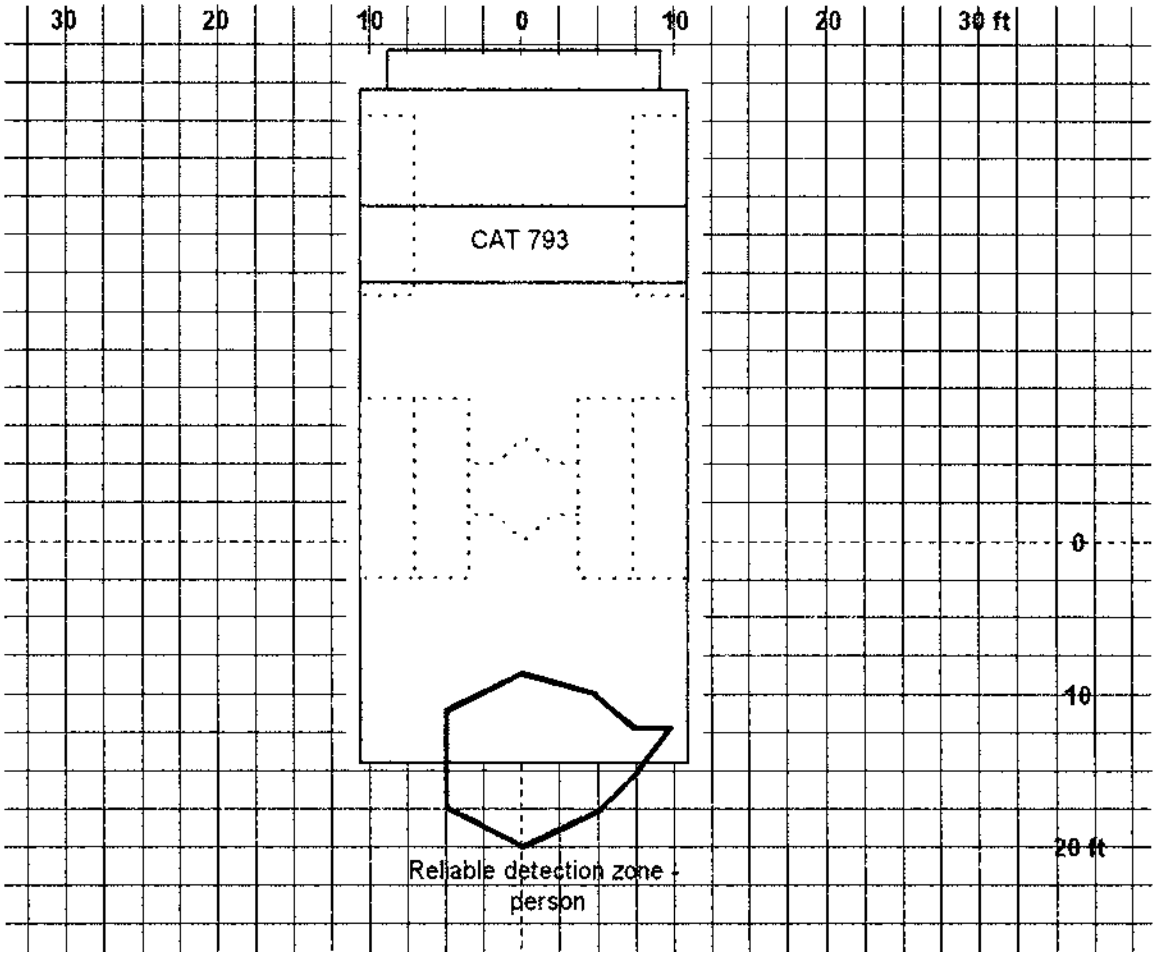

FIGURE 11
Detection zone for a person and the Ogden radar on the Caterpillar truck.

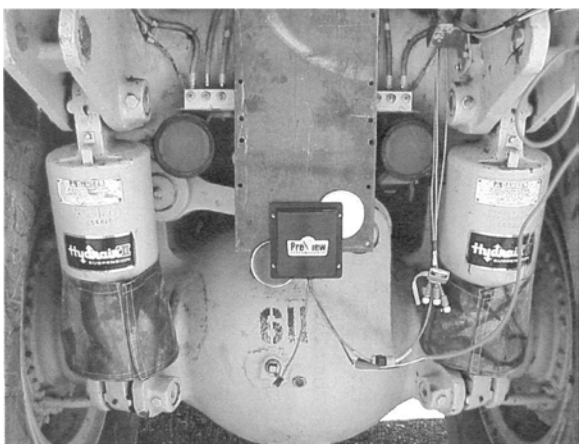

FIGURE 12
Preview radar system mounted on the Komatsu truck.

Results: After sensitivity settings were adjusted to eliminate false alarms, none occurred when the truck was moved in reverse in a clear field. Tire rotation was not detected either.

A person was reliably detected out to 50 ft (Figure 15). The width of the detection zone was adequate for this truck and detection occurred near the outer tires. A sporadic detection area extended from 50 to 55 ft. While detection to 50 ft may be too far for the smaller Komatsu truck, this is an adequate distance for larger trucks.

CONCLUSIONS

Collision warning systems based on radar are attractive because of their low price, high durability, and ease of mounting. However, there are some drawbacks to this technology that may limit its application if they cannot be overcome.

One drawback is a radar system's susceptibility to false alarms or nuisance alarms from objects that pose no danger, such as rocks or ruts in the roadway. There are also alarms from objects

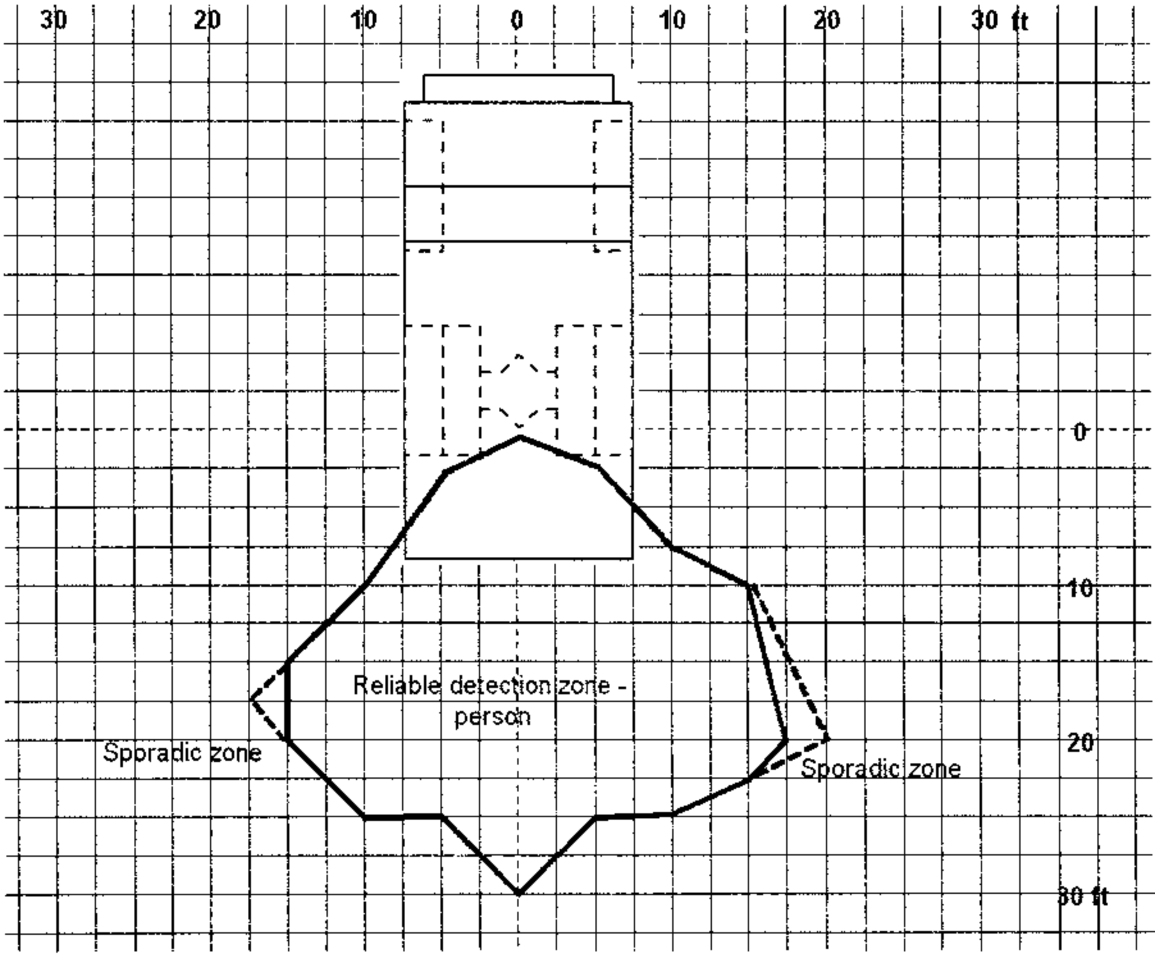

FIGURE 13
Detection zone for a person and the Preview radar on the Komatsu truck.

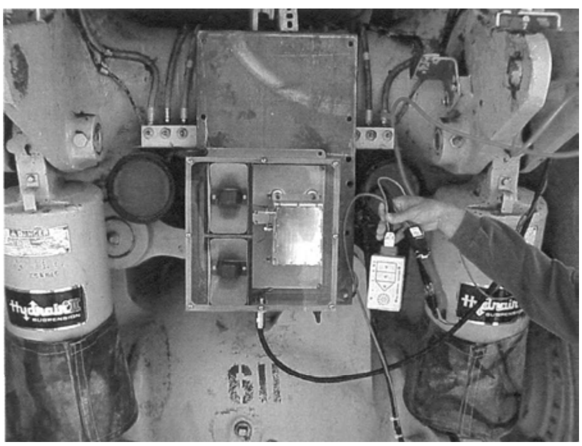

FIGURE 14
Ultrawide-band radar system mounted on the Komatsu truck and the alarm display being held to the right.

that the equipment operator is already aware of, such as pulling up to shovels or next to a pit wall. All of these alarms are a major concern because the equipment operator may become frustrated and start ignoring alarms. It is very difficult to climb out of the truck to verify the source of every alarm. Because of this problem, it is recommended that radar systems be used in conjunction with another secondary system, such as a video camera. This will allow the operator to verify the source of an alarm without leaving the cab. It also improves the reliability of a collision warning system by providing a method of verifying the location of an obstacle and the number of obstacles in the blind area. As radar-based collision warning systems' functionality and reliability improve, the secondary system may become optional.

A second drawback to existing radar systems is that the detection zone is dependent on the equipment on which the radar is mounted. High mounting positions require the radar to be tilted downward, which decreases the length of the detection zone. Such positions also allow a person to walk near the truck undetected because of the narrow beam width near the antenna. This

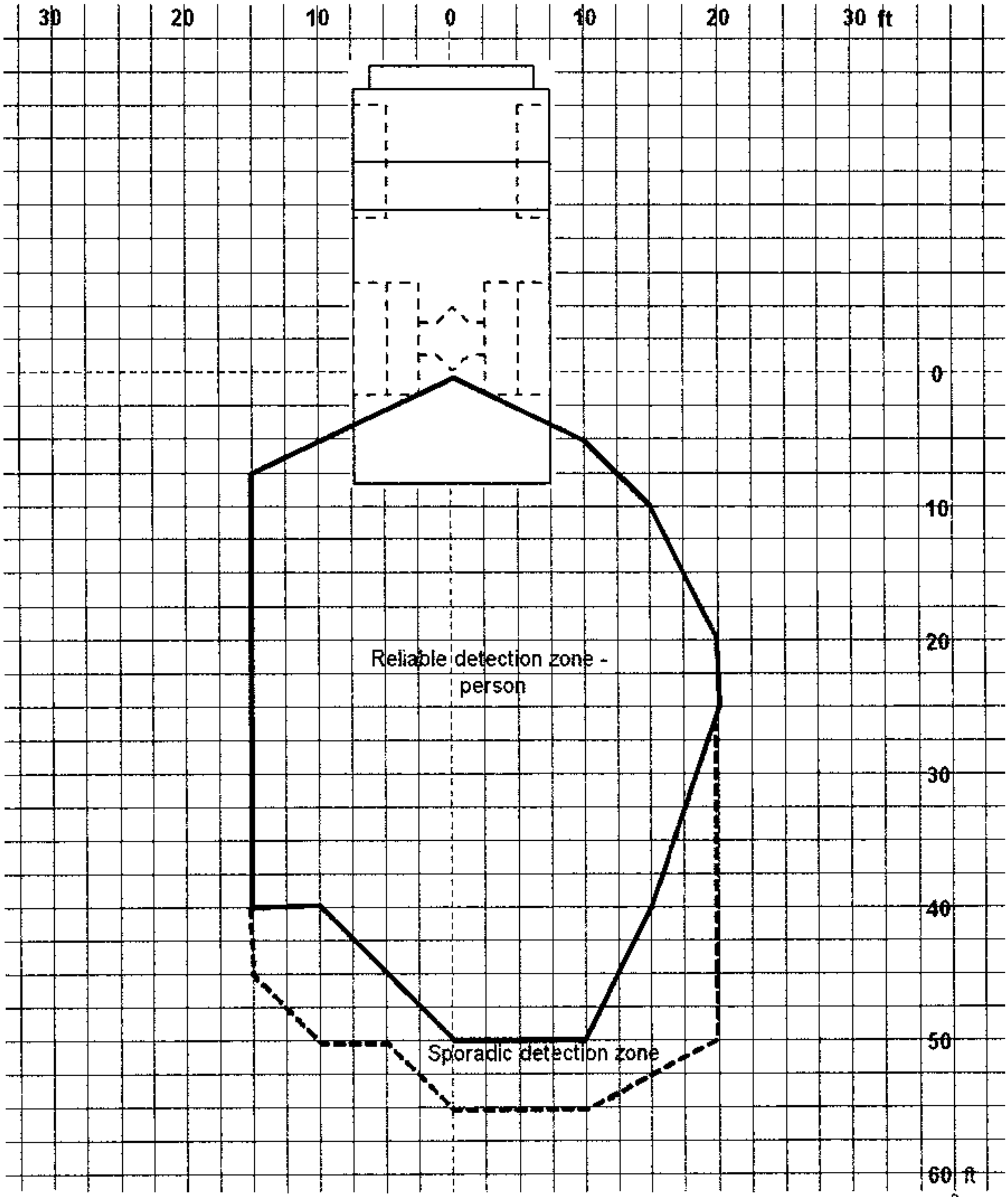

FIGURE 15
Detection zone for a person and the ultrawide-band radar on the Komatsu truck.

can be solved with improved antennas that are designed specifically for monitoring the rear detection zone of large trucks. Also, smaller radar system packages might allow lower mounting positions to be used.

Several different alarm displays were tested. These preliminary tests showed that the displays that indicated an approximate range to the obstacle were preferred over a single light or buzzer. Also, changing the frequency of the audible alarm in the cab as an obstacle moved closer was an effective method of indicating the level of urgency to the operator. Overall, the alarm must be kept simple, yet convey useful and understandable information.

The test results verified the importance of testing a collision warning system on the actual equipment on which it is going to be mounted. Results varied significantly between the two trucks used in these tests. The length of the detection zone, the ability to detect obstacles near the tires, and even false alarm rates vary according to mounting height and the physical characteristics of the mounting location. This is especially true for the rear mounting positions where the truck bed and tires protrude beyond the axle and light bar.

Radar systems show promise for assisting an equipment operator in monitoring the blind spots of surface mining equipment. Additional field tests are planned that will further verify the reliability and challenges associated with this technology. As these collision warning systems improve, it is anticipated that they will become a popular and useful tool for reducing mining equipment accidents.

REFERENCES

1. Fesak, G.M.; Breland, R.M.; Spadaro, J.: Analysis of Surface Powered Haulage Accidents. Holmes Safety Association (Bulletin Reprint), U.S. Dept. of Labor, MSHA, Beaver, WV (September 1996).
2. Federal Register: Safety Standards for Surface Haulage. 30 CFR Parts 56, 57, 77, Dept. of Labor, Mine Safety and Health Administration, Proposed Rule (1998).
3. Ruff, T.M.: Test Results of Collision Warning Systems for Surface Mining Dump Trucks, DHHS (NIOSH) Pub. No. 2000-120 (Report of Investigations 9652), NIOSH, Spokane, WA (2000).
4. Society of Automotive Engineers: Discriminating Back-Up Alarm System Standard. Surface Vehicle Standard J1741. SAE, Warrendale, PA (June 1999).
5. Boldt, C.M.K.; Backer, R.R.: Surface Mine Truck Safety—Where Are We? Proceedings of the 28th Annual Institute on Mining Health, Safety and Research, Salt Lake City (1997).