

THE CONSIDERATION OF HUMAN FACTORS IN THE DESIGN OF  
A BACKING-UP WARNING SYSTEM

James C. Duchon and Linneas W. Laage  
U.S. Bureau of Mines  
Minneapolis, Minnesota

ABSTRACT

Despite the use of automatic backing-up warning systems, large mobile equipment is still involved in reversing collisions, causing injuries, fatalities, and property damage. This paper discusses specific human factors that contribute to the failure of this type of system as used on front-end loaders in the surface mining industry. The use of the backing-up automatic alarm causes the operators to lose the perception of responsibility for vigilant behavior, while the ground crew predictably become habituated to the alarm. These human factors and their interaction with the noise pollution created by the alarms sets up a potentially unsafe condition. Bureau of Mines' research into discriminating backup warning systems could provide an effective alternative to the conventional backup alarm.

INTRODUCTION

This paper discusses human factors in relation to the conventional automatic backing-up warning system. The system is intended for use on larger vehicles such as snow plows, garbage trucks, forklifts, and front-end loaders, where rear visual access by the operator is severely limited due to the design of the vehicle. Although the warning system is standard in many industrial and public settings, there are certain human factor considerations that suggest that the use of such a system in certain environments may not work as intended. It may even contribute to some collisions.

The Bureau of Mines research into collision protection systems for front-end loaders (FEL's) began in 1980 as a part of a broader research program to enhance operator visibility for large mobile mine equipment. This area of safety research was initiated because, despite Code of Federal Regulations 56.9087, 57.9087, and 77.410, which require "an automatic reverse signal alarm" or a spotter on large mobile equipment, collisions with objects in the rear blind area still occur. The Denver Safety and Health Technology Center (DSHTC), a branch of the Federal Mine Safety and Health Administration (MSHA), collects injury reports, occurring in the mining industry. Figure 1 shows incidence rates for fatal and permanent injury accidents occurring between 1980 and 1985. It is apparent that front-end loader accidents continue to occur and are quite serious in nature. From review of the narratives of accidents associated with front-end loaders, we have determined that in 1985 alone, there were approximately 55 injuries from collisions by or with front-end loaders; four of these injuries were fatalities. From these narratives it is impossible to determine with certainty whether the FEL was reversing or going forward. It is apparent from these narratives that most of the injuries are caused by the operator being thrown or jostled about in the cab, following a collision with a stationary object. A few of these accidents are actually due to collisions with other employees. Unfortunately, collisions

with machinery or other stationary objects causing damage to equipment only, are not reported.

One reason for collisions is the design compromise of the machine. FEL's are very efficient, are adaptable to many tasks, and are quite popular in the mining industry. However, due to the engine size and placement, relative to the driver, rear visual access is extremely limited. Even with rear view mirrors, there is a "blind" area extending from the rear of the machine back 15 to 25 feet, depending on the machine (see Figure 2). The difficulty of rear visual access is the primary reason automatic backing-up alarms are used. The function of these alarms is to warn ground personnel that the machine is backing up and that they should "stay clear." The alarm is automatic. It sounds whenever the vehicle backs up, whether or not an obstacle is in the way. An important aspect of this system is that while the driver has a limited rear visual field, the alarm gives the driver confidence that if someone is behind the vehicle, they will move when the alarm sounds.

Since backing-up collisions are still occurring, the following points have been considered as possible reasons for the failure of these alarms to prevent accidents:

1. The alarm system is essentially designed so that ground personnel will react to the vehicle when the alarm sounds. The operator is expected to ignore the alarm. This type of alarm then tends to put the responsibility for getting out of the way of the vehicle onto the ground personnel. A driver is expected to drive safely, which includes being aware of all obstacles. However, the alarm tends to shift much of the responsibility for vigilance onto the ground personnel. This displacement of responsibility is comparable to that of warning labels on some products such as cigarettes and household chemicals, of men-at-work signs in public areas, or of brake lights on automobiles. These warnings are intended

Figure 1. Fatal and Permanent Injury Incidence Rates (per 10,000 Workers) for Front-End Loader Collisions in Surface Mines

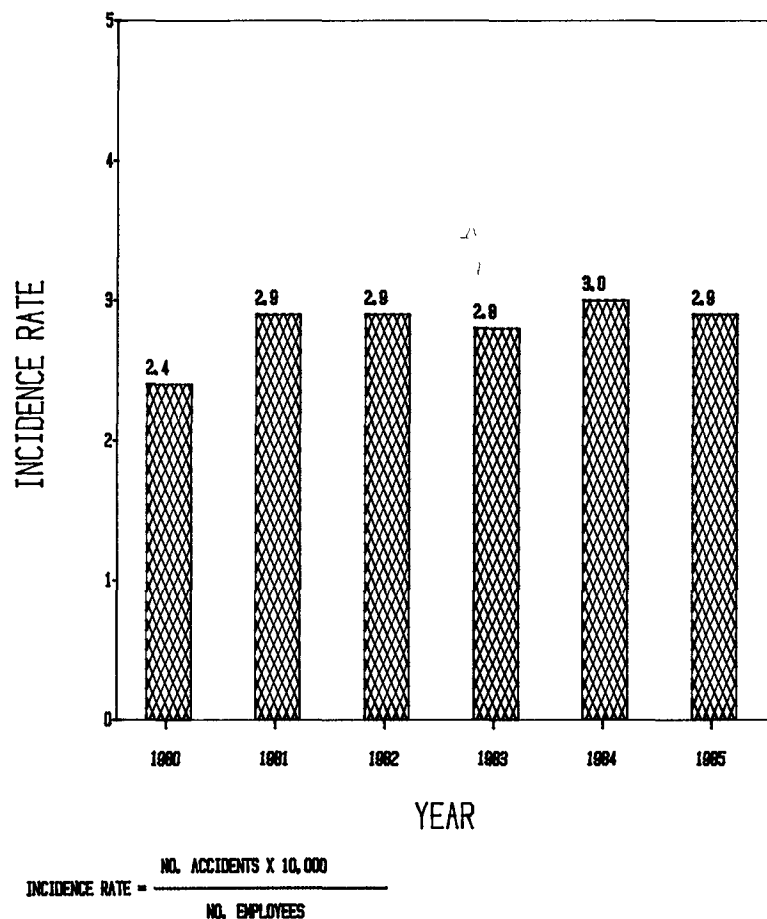
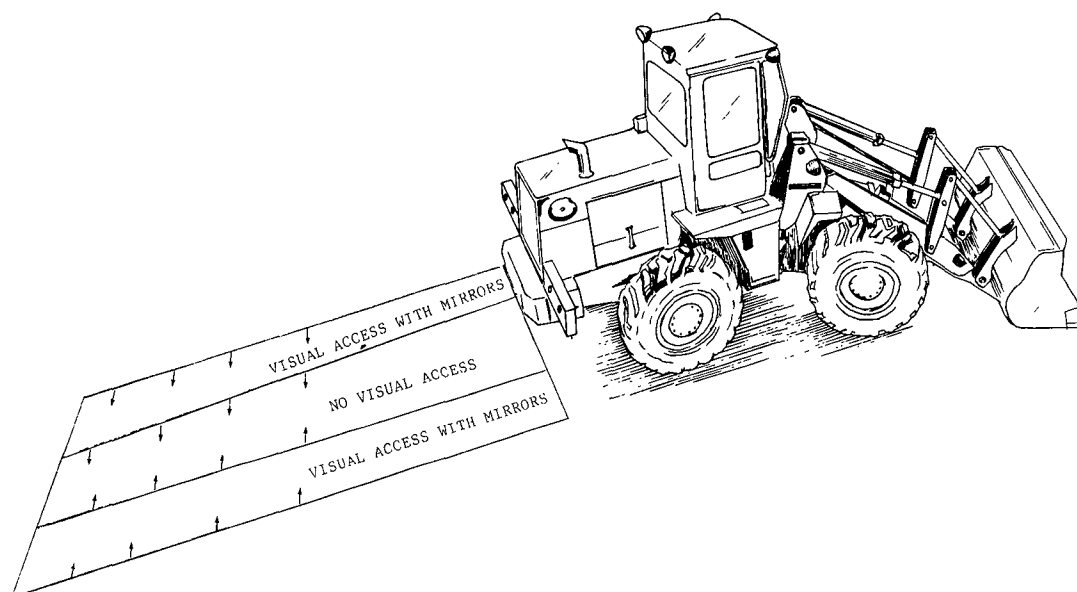


Figure 2. Rear Blind Areas for Front-End Loaders



to shift the responsibility for potential accident or illness onto the potential victim. According to public law, the mere presence or absence of these warnings can shift the legal responsibility for the cause of an accident. The important point here is that while the burden of responsibility shifts to a potential victim, the other party logically becomes relieved of the same responsibility. It is, therefore, likely that the miner operating the FEL may take less precautions and expend less effort to make certain rear areas are clear. This would be especially true when driver fatigue results in more driver errors and in their taking fewer than usual safety precautions. The problem, then, is whether or not the ground crew is taking responsibility for reacting to the alarm.

2. After reviewing DSHTC reports of fatal collisions and holding informal discussions with members of certain professional safety organizations, such as the Lake Superior Mines Safety Council, the Association of Arizona Mine Safety Engineers, and

the National Sand and Gravel Association, it is apparent that the ground crew frequently stop "hearing" or "paying attention" to the sound of the backing-up alarm. Front-end loaders are designed for shuttle tasks, so that the vehicles may be backing up nearly half the time. It is also common for more than one of these vehicles to be working in the same area. It is apparent then that the sounding of the backing-up alarm is a common occurrence in surface mines. This, combined with the fact that ground crew can hear the alarm whether or not they are directly behind the vehicle, sets up an ideal condition for habituation. The alarm becomes the "boy who cried wolf." Individuals experience enough false alarms so that they begin not to respond. As the ground crew becomes accustomed to hearing the alarm coming from vehicles that present no hazard, it loses meaning. Habituation theory and the very similar filter theory (Broadbent, 1971)(Loeb, 1984) state that when individuals are repeatedly presented with a stimulus such as a tone, especially when there is little meaning associated with it, they tend to filter out this stimulus and begin "not to hear it" in favor of novel or more pertinent stimuli. This explains why miners commonly report that they stop paying attention to the backing-up alarm.

Therefore, we have a situation where the driver of the vehicle may not pay as much attention to this rear area because he believes it is the ground crew's responsibility to stay clear, while at the same time, the ground crew stops hearing the alarm. This logically leads to serious problems.

3. Finally, the prevalence of the alarm raises the level of noise pollution in the working environment. Studies have shown that sustained operations on a variety of tasks in industrial settings with noisy environments result in lowered performance levels and unsafe behavior because of increased fatigue and lowered alertness (Poulton, 1970).

In summary, although the intention of the automatic backing-up alarm system is to alert people to a backing-up front-end loader, it may be that accidents are actually caused in part by the alarm itself.

#### DISCRIMINATING BACK-UP ALARM

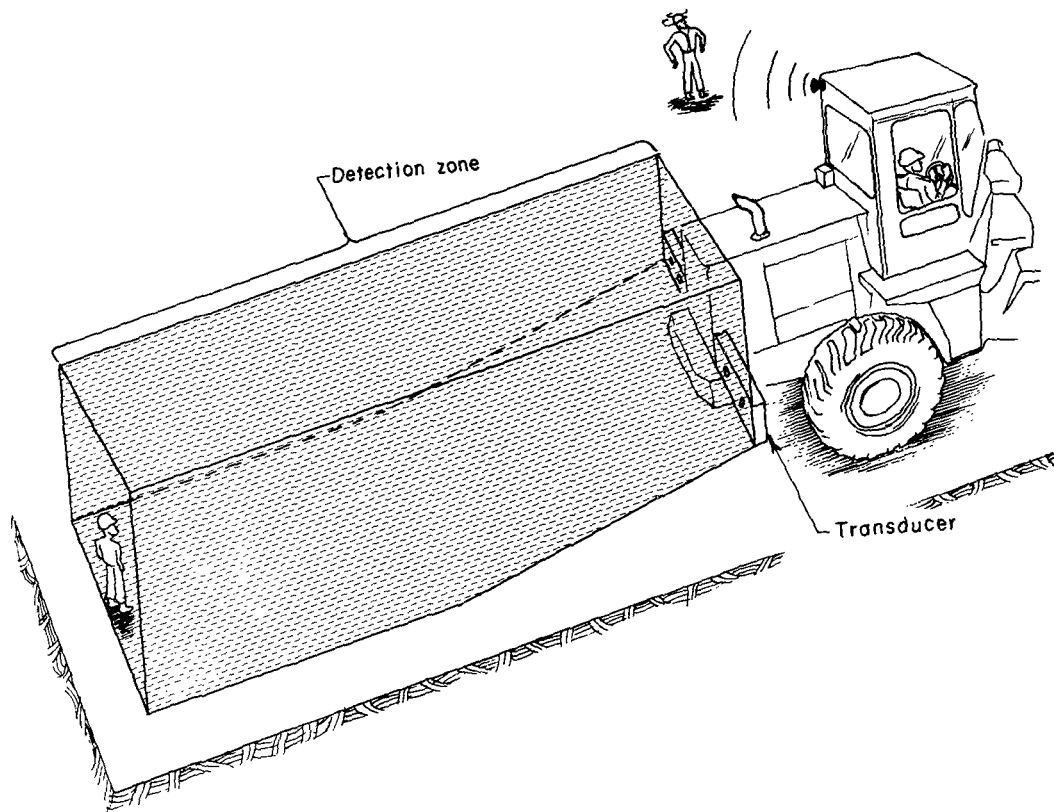
A possible solution would be the use of a newly developed discriminating backing-up alarm. This alarm system sounds only when an obstacle is detected in the rear of the reversing vehicle (see Figure 3). The alarm is activated by an object sensing system utilizing infrared light, ultrasonic waves, or Doppler radar. Mines must petition to use these systems in place of conventional backup alarms. Several models suitable for mining applications are commercially available, utilizing Doppler radar and ultrasonic technology. The alarm is intended to alert both the driver and ground crew that some object is in the way of the vehicle. This system has several desirable features:

1. Assuming that both ground crew and operator are motivated to avoid a collision, both will be aroused by the alarm. Logically, the perception of responsibility for responding to the warning signal is shared by the operator and ground crew. That is, both are motivated to respond. When a collision is imminent, as when the warning alarm sounds, both parties will respond to the serious situation.
2. The condition of habituation would not exist with this type of alarm. Since the warning signal would sound less often and would take on increased meaning to the workers, the alarm should, in fact, alert the crew.
3. Finally, the problem of noise pollution and its negative effect on human alertness is partially alleviated, since the alarm would sound less frequently. The infrequent warning sound may actually serve to arouse workers in the area to a state of higher alertness.

#### CONCLUSION

Much of this paper is based more on logical inference, than on actual research. Therefore, it is essential to test the assumptions cited above. It is also important to note that many of the problems with the automatic backing-up

Figure 3. Detection Zone for Discriminating Backup Alarm for Front-End Loader



alarms may be relevant only under certain conditions, such as those found in surface mines. By the same token the benefits of the discriminating backup alarm may exist only under particular environmental conditions. In conclusion, it may be pointed out how a seemingly reasonable solution to a safety problem, such as the automatic backing-up warning system, can lead to further problems and complications when human reactions and behaviors are not well considered.

#### REFERENCES

- Broadbent, D. E. Decision & Stress. New York: Academic Press, 1971.
- Loeb, M. and E. A. Alluis. Theories of Vigilance in Sustained Attention in Human Performance. Ed. by J. S. Warm, John Wiley & Sons, 1984.
- Poulton, E. C. Environment and Human Efficiency. Charles C. Thomas, Springfield, IL, 1970.