BACKUP ALARMS:
SOUNDS FROM THE GROUND

By Jeff A. Lancaster, John G. Casali and Khaled Alali

It would be difficult to work within any sizable construction site, especially one with any kind of operating vehicle, without hearing the ubiquitous "beep—beep—beep" of the backup alarm. Construction workers have become so accustomed to this signature sound, that it may be taken for granted. But, it is a distinct sound that is vitally important to safe operations—especially for those workers on the ground.

On the jobsite, workers must pay attention to the activities and locations of equipment and other machinery operating in their immediate vicinity. It can be difficult to hear the backup alarm with all of the other sounds or ambient noise on the jobsite such as other equipment operating nearby or the noise generated by the machine that is backing up, plus other sounds such as nearby traffic. Additionally, annunciating backup alarms may not be of sufficient sound intensity, or they may not maintain adequate pitch distinction from other operational sounds, to overcome the ambient noise. The backup alarm can be masked by other competing noise making it difficult to hear.

When any reversing vehicle is operating with a backup alarm on a construction site, workers have three critical tasks to complete quickly and automatically, in order.

The first of these is detection of the backup alarm—the worker has to be able to hear the reversing vehicle's backup alarm. The issue of detection is exacerbated by not only ambient noise and masking, but also by hearing loss. Some construction workers have been exposed to high noise levels on construction sites that may have contributed to hearing loss, making it more difficult to detect a backup alarm. Backup alarms may need to sound at levels that are considerably above the ambient noise environment, by 10 to 15 decibels more, in order for workers to adequately hear the backup alarm signal, which may pose a hearing hazard in itself.

The second critical task that construction workers must complete is recognition of the signal—that what is being heard is a backup alarm, and not something else. Steps have been taken by standards-promulgating bodies to afford spectral (pitch) distinction to the backup alarm signal. To some extent, the existing standards for backup alarms have been successful, except for those workers with tone deafness.

The third critical task that construction workers must complete is localization of the signal—determining where the backup alarm is sounding from at any given time. Localization of a backup alarm signal can be quite difficult. Most people have heard a siren from a police vehicle, fire engine, or ambulance, but when they slow down or pull to the side of the road to get out of the way, they are typically looking all around them, and in their rear-view mirror, to find the emergency vehicle. This is likely due to the inability to localize the sirens. The same occurs on construction sites.

Overshadowing all of this, however, is the issue of hearing loss amongst construction workers. Experiments are underway at Virginia Tech's Auditory Systems Laboratory to explore how various hearing protection devices (HPDs) affect the three critical tasks of detection, recognition, and localization.

Avoiding reversing vehicles with backup alarms requires consideration of both the minimum distance (d*minimum) separating the construction worker from the location and speed of the reversing construction vehicle. The determination of d*minimum and its relation to vehicle reversing speed provides one indication of accident potential with respect to a construction worker having enough time to step out of the reversing vehicle's path (see Figure 1).

The d*minimum that provides sufficient time for the construction worker to step out of the reversing vehicle's path has

$$d^*\text{minimum} \geq MRS \times \left(t + \frac{W}{HWS}\right)$$

*Figure 1. d*minimum calculation to determine time needed by a construction worker to get out of the way of a reversing vehicle's path.*

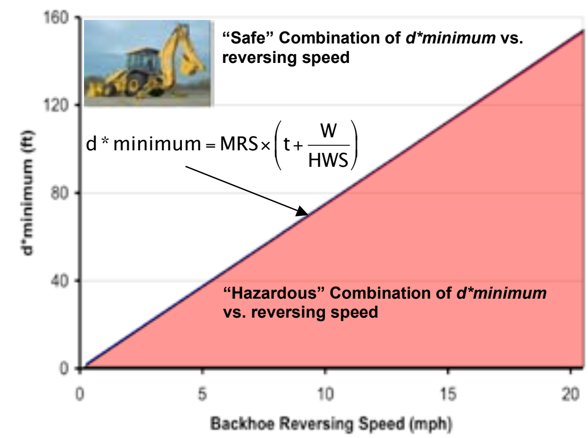

*Figure 2. d*minimum vs. reversing speed for a John Deere backhoe (Model 310 SG), used only as example.*

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been calculated for various construction vehicle types. The ascending and descending method of limits was utilized to determine the distance at which the participants could detect the backup alarm signal.

First, with the experimenter fitted earmuff in place and while facing away from the backup alarm, the participants walked slowly and continuously away from the alarm source until they no longer could hear it. At this point, the linear distance from the alarm source was measured. Participants then moved 20 feet further from this point, and walked slowly back toward the alarm source until the alarm signal was again detected. At this point, another linear distance measure was taken.

Results indicated that the average linear distance at which participants could detect the backup alarm signal was 725 feet. The next step was to determine how this distance related to the reversing speeds and widths of various construction equipment. Figure 2 depicts the d*minimum vs. reversing speed relationship as applied to a John Deere 310 SG backhoe. Note the minimum safe distance (d*minimum) is 153.4 feet. At d*minimum, the backup alarm signal should be detectable to an HPD-occluded normal-hearing worker, while allowing enough time for that worker to step out of the backhoe's path.

As shown in Figure 2, these calculations were based on different construction vehicles' widths (W) and maximum reversing speeds (MRS). The time required (t) for a construction worker to detect and recognize the reversing vehicle's backup alarm signal (estimated at approximately 3.5 seconds), as well as the average human walking speed (HWS) (3.5 mph, reduced by 0.5 to 3.0 mph for a safety margin), was included in the calculations.

Application of similar calculations to actual on-site vehicles will allow construction site safety managers and supervisors to position ground construction workers at safe distances from reversing vehicles, and alert vehicle operators of the heightened safety considerations that are needed when such workers are nearby. See Table 1, where d*minimum has been calculated for other examples of common construction vehicles based on their published maximum reversing speeds.

Follow-on experiments at Virginia Tech are now investigating backup alarm detection and localization using various HPDs of both the passive (non-electronic) and amplitude-sensitive (electronic) varieties. ◆

Table 1. *d*minimum vs. reversing speed for various John Deere construction equipment.*

Equipment	Model	Width (ft)	Max Reverse Speed (mph)	$d^*_{minimum}$ (ft)
Backhoe	310 SG	7.05	20.5	153.40
Dump Truck	400D	11.08	4	35.30
Crawler Loader	755C	8.17	6.8	53.42
Excavator	650D LC	12.25	3	27.65
4WD Loader	844J	11.46	17	152.19