Effectiveness of non-tonal audible movement warning alarms for construction sites

Marion Burgess and Matthew McCarty

Acoustics and Vibration Unit, University of NSW at Australian Defence Force Academy, Canberra, ACT, Australia

ABSTRACT

The sound from the standard 'beeper', or pulsed tonal alarm, is used to provide a warning of vehicle or plant movement, usually reversing, for those in the vicinity to take the necessary evasive action for their safety. The pulsed tonal signal is widely and instantly acknowledged as a warning signal. However the sound from the common type of pulsed tonal alarms does not stay within the work site and can become a considerable annoyance for those in the surrounding community. The sound can also be an annoyance for those on site who, at that time, are not in danger yet hear a loud signal. There are options for alternative audible alarms including alarms that focus the signal in the area of potential danger, those that allow for the level of the alarm to be adjusted depending on the surrounding noise, alarms linked to proximity sensors and alarms with a pulsed broadband signal. To be an effective warning a movement alarm needs to provide the 'what', 'where' and 'when' of the hazard. As part of a study on these alternative alarms the authors have reviewed the literature to assess if there is evidence that the alternative alarms using a non-tonal signal do provide these three essential elements for movement warning alarms.

INTRODUCTION

The use of tonal or 'beeper' style alarms on vehicles and mobile plant is widespread across Australia and around the world as a means of providing warnings of moving plant on work sites. These alarms are referred to as 'reversing alarms' or 'backup alarms'. On plant such as hoists, cranes etc, warning such alarms are often referred to as 'travel alarms'.

The 'beeper' alarm comprises a pulsed sound comprising one or two alternating frequency tones, usually higher pitched, that are clearly louder than the background noise in the area. While the sound may have a purpose for those on the site, regulators often receive complaints from the community about noise from 'beeper' alarms, particularly during night works. Factors that may be desirable for a warning signal for those in danger but lead to it becoming an annoyance for those outside the site include:

- the pulsing signal draws attention to the sound.
- the frequencies used for the tone can be easily heard by those with normal hearing
- the sound can be heard at some distance from the site.
- the sound is an unnecessary alert for those outside the site
- the signal occurs even when there is no person in the vicinity.

There are a range of alternatives to the standard pulsed tonal reversing alarm that may reduce the environmental noise impact. These include use of:

- 'spotters';
- proximity sensors and/or reversing cameras to alert the driver;
- 'smart' alarms that adjust the level depending on the background sound level,
- alarms that focus the sound in the area of risk and
- alarms with a broadband sound.

Not all of these alternatives are suitable for all sites. Those which are being widely used are the 'smart' alarms and the broadband alarms. Most 'smart' alarms use the well accepted pulsed tonal signal, so long as they do adjust properly to be above the surrounding noise there should be little concern about them being a suitable warning for those at risk. The alarm using a broadband signal has been developed in the last decade and more recently has also become available in the form of a self adjusting or "smart' alarm. In this paper the authors present findings from a review of the literature to assess the evidence that the broadband alarms do provide the three essential elements for effective movement warning alarms, i.e. the 'what', 'where' and 'when' of the hazard, while also minimising the annoyance for the surrounding community. This paper draws upon the work undertaken for the NSW Department of Environment and Climate Change [Burgess & McCarty, 2009].

REQUIREMENTS FOR WARNING ALAMS

The aim of an acoustic motion alarm is to provide an audible warning for anyone in the area to take the necessary safety action. Such an alarm signal should provide three pieces of information about the hazard [Catchpole et al 2004]; namely:

- 'what' is the hazard;
- 'where' is the hazard; and
- 'when' is it a hazard?

In terms of objective requirements for warning alarms two different international standards could apply on construction sites:

- If the alarm is considered an 'auditory warning signals' then ISO 7731 would apply, requiring the level of the signal to be 15 dB above the background noise level in the area, not to exceed 112 dB and recommending the alarm to have dominant tones. There is no specific distance from the alarm for these levels as the definition for area is that "*in which persons are intended to recognize and react to a signal*"
- For movement alarms on earth moving equipment, then ISO 9533 would likely apply, requiring the alarm to be at least as loud as the engine under full power at the defined measurement locations around the item.

ISO7731 could be considered applicable to serious hazards, such as fires, when 100% reliability is required for all those in threat, including untrained personnel and those who may need some time to move from the area of potential risk. ISO9533, with lower requirements for noise level, apply to warnings for persons near mobile plant on worksites. Such personnel should have received a site safety induction and so be aware of the audible warnings used for the potential hazard.

The Australian Design Rules [ADR, 2006] which must be complied with by vehicles using the roads do not mandate the use of an audible reversing alarm but they do describe the nature of such an alarm should it be fitted. Essentially compliance means the sound level of the alarm should be no louder than necessary to warn persons near to the reversing vehicle.

Most Australian occupational health and safety (OHS) Regulations and Codes of Practice do require a reversing alarm be fitted and that it should not be modified without consultation with the manufacturer or without a risk assessment to demonstrate that the change will not reduce safety to those likely to be affected. In some, reference is made to an acoustic alarm and then the only guidance is that it should be audible. Industry guides for safe work require compliance with the Regulations and Codes of Practice and do not include anything specific about reversing alarms. Similarly guidance from industry and union groups does not specifically refer to any one type of alarm. The primary goal of these groups however is for a safe working environment; there is a general acceptance of acoustic alarms as a warning for this type of hazard.

While there is no definite or prescribed movement warning signal, the pulsed tonal alarm, or ‘beeper’, has been the universally recognised warning signal. In the majority of instances such a signal is widely considered to provide the ‘what’, ‘where’ and ‘when’ of a hazard. This implied acceptance means that a hazard risk assessment is not required for the use of such an alarm on site.

Advances in electronics have made alternative signals more readily available. These can contain more audible information than simply a warning tone. Such ‘auditory icons’ have been proposed for specific purposes, for example a sound like a crackling fire to warn of an engine fire in an aircraft. In principle these could be applied as reversing alarms however these signals are unlikely to be applicable for use on construction sites for some time.

For mobile plant on construction sites the currently available acoustic option to a ‘beeper’ alarm is a pulsed broadband alarm manufactured by Brigade Electronics. These alarms have been implemented, nationally and internationally, on many mining sites and construction sites. This indicates an acceptance of the alarm as an appropriate warning signal. The use of this type of alarm nationally and internationally, has led to a reduction in complaints from the surrounding community; especially for those sites that need to operate during the night time [Burgess McCarty, 2009]. So the use of such alarms would appear to have considerable advantage from the environmental viewpoint. Before endorsing widespread use it is essential that the pulsed broadband alarm be shown to provide the necessary safety requirements to warn of hazards. The following sections of this paper review the characteristics of broadband alarms and attempt to assess the evidence for the claims by the manufacturers that pulsed broadband alarms provide a superior warning for moving plant on construction sites as well as minimising environmental noise impact.

BROADBAND ALARM SIGNAL

Currently Brigade Electronics PLC is the sole manufacturer of these alarms, holding the patent rights [Brigade, Yamaguchi, 2001]. They are marketed as the bbs-tek range of broadband alarms which has models from as low as 62 dB to as high as 107 dB [Brigade Electronics,-]. Recently, self adjusting options for the broadband alarms have become available. The quoted noise level for the alarm is at 1 m but the actual level on the item will depend on the installation.

A comparison of the frequency spectrum for a typical pulsed tonal alarm and a pulsed broadband alarm is provided in Figure 1. From these it can be seen that the broadband alarm signal extends from around 1,000 Hz to around 5,000 Hz with none of the peaks present in the spectrum for the tonal alarm. This latter alarm signal shows the strong fundamental around 1,200 Hz and harmonics at multiples of this frequency.

A comparison of the time signals is shown in Figure 2. This shows that the repetition or pulsing rate of the two types of alarm signal are similar.

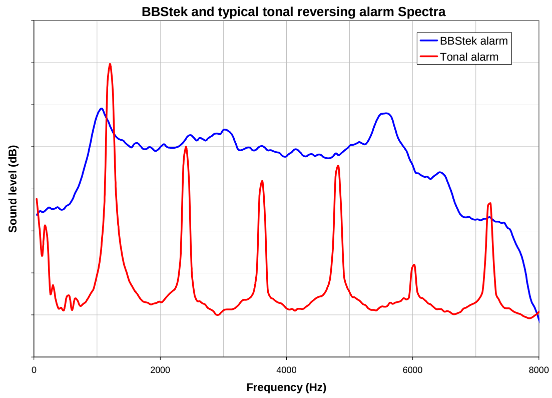

Figure 1. Frequency spectrum for a typical pulsed tonal alarm (wav file from www.federalsignal-indust.com) and a pulsed broadband alarm (wav file from www.reverseinsafety.co.uk/white-sound/white-sound.html)

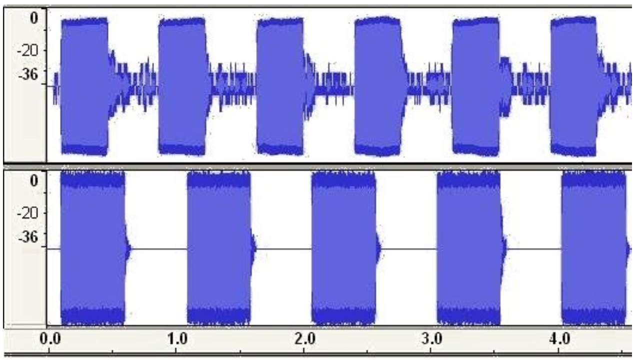

Figure 2. Time signal for a typical pulsed tonal alarm (wav file from www.federalsignal-indust.com) and a pulsed broadband alarm (wav file from www.reverseinsafety.co.uk/white-sound/white-sound.html)

BROADBAND ALARM AS A WARNING SIGNAL

The aim of an acoustic motion alarm is to provide an audible warning to anyone in the area to take the necessary safety action. The pulsed tonal alarm, or ‘beeper’, has been the universally recognised warning signal and as long as properly installed is considered to provide the ‘what’, ‘when’ and 'where' of a hazard. In this section the evidence that a broadband signal can provide these important characteristics is reviewed.

Loudness

The loudness provides the 'what' and 'when' for an acoustic warning signal. Regulations and Codes do not clearly prescribe a required loudness for movement alarms but simply require the subjective assessment that the alarm is 'audible'. There is a range of noise levels for the broadband alarm and the verbal advice from the Australian supplier [private communication] is that the 102 and 107 dB alarms are suitable for mining equipment while the 92 and 97 dB are generally suitable for mobile plant,

A paper by Leventhall [2007] has the results of listening tests, sponsored by Brigade, for the broadband alarm on a number of items of construction plant. These tests involved 30 subjects presented with the sound of a vehicle and a broadband alarm for which the level was gradually increased from 59.4 dB to 82.8 dB. Five vehicles that would typically be found on a construction site were used. The stated outcome of these listening tests was that the noise level of the alarm only needed to be between 6 and 1 dB *below* the noise level of the machine to be considered as a good warning signal. Various other documents prompting the use of the broadband alarm refer to active listening tests or on site demonstrations and repeat the statement that the broadband alarm is effective at a '*Lower dB(A) rating*'.

No independent studies on the assessment of audibility of the loudness of the alarm for subjects in a normal working environment, or focussed on a work task, have been found as part of this review.

Character of sound

The character, or the information content, of the sound contributes to the 'what' and 'when' for an acoustic warning signal. Regulations and Codes again do not clearly prescribe a required sound character but simply require the subjective assessment that the alarm is 'audible'. Studies have been carried out by various researchers on the design of alarms to create a sense of urgency. One such study found that alarms of high frequency, rapid pulse rate and a high level of loudness produced the highest ratings of perceived urgency in the tested subjects [Hass et al, 1996].

The frequency of occurrence of an alarm signal also has a large effect on the response of people. It has been shown that alarm signals audible where there is no hazard for the listener (for example at distance from the mobile plant) not only pollute the sound environment and distract people from their tasks but also generate a 'false alarm' effect. People tend to match their reaction to an alarm to the perceived rate of false alarms for the system [Edworthy & Hellier, 2005]. This means that if a person perceives an alarm to be 90% reliable in warning of a hazard, they will respond 90% of the time whereas if an alarm is perceived to be 10% reliable, then people will only respond 10% of the time. The same paper noted that the design of an alarm signal is critical because if a less than ideal alarm signal is used too often, people's hearing as the primary warning sense becomes overused and again the reaction will not be as good when there is a real hazard associated with the signal.

A broadband noise is not a classic alarm signal and Catchpole et al [2004] states that

> *A broadband noise will generally provide the best location cues but alone will not make a suitable alarm sound*

and further suggest that

> *..... a broad band noise to guide the listener to the location of the sound source, and tones and/or sweeps to provide the usual what and when alarm information*.

However as long as the signal stands out from the background noise and appropriate training is provided, people can associate an unfamiliar alarm noise with the hazard. On construction sites such training can be part of the usual OHS induction for all entering the site.

Localisation of the hazard

Identification of hazard location is promoted by the suppliers as an advantage of a broadband alarm over a tonal alarm thus better satisfying the 'where' for a hazard warning signal.

It is widely accepted that the mechanism for perception of the direction of sound varies across the frequency range. In the low frequencies, considered to be up to around 1,500 Hz, the perception of direction is based on the time difference between the arrival of the sound at one ear and then the other ear (referred to as the inter-aural time difference, ITD). There can be some confusion for this detection as there are a number of locations for the sound source that would give the same time difference in arrival at the ear. In the middle frequency range the perception of direction is based on the difference in sound level at each ear (referred to as the inter-aural intensity difference, IID). The frequency cross-over between the time-difference technique and the sound level technique begins at 700 Hz and is complete at 2800 Hz [Howard & Angus,2006]. In the higher frequencies the perception is based on detection of the modification of the sound wave as it passes around the head, around the ear and down the ear canal; ie the head transfer function. The outer ear, or pinea, plays an important role in perception of direction in these higher frequencies. Localisation of acoustic signals with a frequency range spanning the three methods is considered to be accurate to within 5 degrees [Withington, D. 2000]. This would indicate that a wider band signal would lead to better localisation than a narrow band signal that only used one or two of the methods of perception.

As well as these mechanisms in the hearing process, simple head movement is often used sub-consciously to resolve an ambiguous direction cue. [Howard & Angus,2006].

It is also relevant to note that much of the work supporting the benefit of a broadband alarm is based on studies on the perception by drivers of emergency signals. There is one study on perception of broadband reversing alarms [Withington 2004], which involved 1477 vehicles of which 313 were fitted with broadband alarms. 80% reported that they could "always tell which vehicle is reversing" for the broadband alarm, compared with only 10% for a tonal alarm.

Directionality of the alarm

The goal for an effective alarm signal is that the sound provides the information on the 'where' and so is heard primarily by those who need to take evasive action and not by others on the site or in the neighbourhood. The distribution of sound from any alarm depends on the design of the alarm and its enclosure, the placement of the alarm on a vehicle and the frequency spectrum of the alarm signal. For most loudspeakers (one of the main components of an acoustic alarm), the higher frequencies tend to beam forward while lower frequencies are more broadly distributed. The design of the loudspeaker enclosure (the alarm casing) can modify the effective distribution of the sound. The positioning of the alarm in a suitably recessed location on the item of plant can also provide shielding and hence more directionality for an alarm.

There is data from Brigade showing a drop of up to 10 dB between positions directly in front and those at 90 degrees to the side. Bassett, 2009, have undertaken measurements around items of plant fitted with broadband alarms. Using the data from the Bassett report, the authors of this paper have been able to compare the data or a broadband alarm with that for focussed tonal alarms. This has shown that that the directionality of the sound from the broadband alarm does appear to be well focussed at the rear of the item and supports the comments in the promotional material.

DISCUSSION

There is considerable evidence that the use of broadband alarms has been successful on construction and mining sites both within Australia and internationally. The broadband alarm has become very popular for use on mining sites but it should be noted that such work sites operate differently to construction sites. At a mining site the range of equipment and the workforce is relatively stable. In contrast, on most construction sites there can be a greater diversity of personnel and plant during the project. Hence understanding and acceptance of a different type of warning signal may be easier to achieve on a mining site than for a construction site.

Industry experience to date has shown that with the appropriate selection of the loudness of the alarm and with suitable training/induction on the nature of the alarm, the broadband alarm can be used safely on construction projects. In particular the case studies demonstrate that where there is a justified need to undertake construction work outside the standard (daytime) hours, alternatives to reversing 'beeper' alarms, such as broadband alarms can greatly reduce complaints from the community about noise from alarms.

While the promotional material from the supplier states that the broadband alarm sound level can be 5 dB lower and provides for a better localisation of the hazard than a tonal alarm, there is to date little supporting evidence from documented studies carried out by independent organisations. Independent studies however do indicate that the broadband alarm has a similar horizontal sound distribution to a focussed tonal alarm, thus limiting the spread of sound to those areas where there is not a hazard. The reduced spread of sound coupled with the character of the signal is suggested to remove some of the confusion that arises when there are many tonal alarm signals on the site.

Where a risk assessment is required as part of the project approval, the person responsible for undertaking this assessment may use a variety of means to support their decision making. This review has highlighted that guidance material is needed for those undertaking the risk assessment when considering the use of any audible movement warning alarm that is different to the common pulsed tonal or 'beeper' signal.

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