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Warning horns—Audibility versus environmental impact

A.E.J. Hardy, R.R.K. Jones*

AEA Technology Rail, Jubilee House, Pride Park, Derby, DE24 8LY, UK

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Abstract

The original standards for the warning horns used in the UK were based on a combination of listening trials and available technology. Underlying this work was the need to provide people working on the track with an adequate warning of an approaching train. Recent changes to the way track workers are protected mean that this primary function of warning horns is no longer required. Train drivers currently use the horns either when they see someone on or near the track who may be in danger from the approaching train, or when a 'Whistle Board' is used to provide a warning for anyone using a foot crossing. At the same time as the changes to the warning procedures there have been a growing number of complaints about the noise produced by warning horns. Starting with a simulation of the original tests this paper examines the characteristics of an audible warning that would meet current requirements for audibility at some foot crossings while at the same time minimising environmental impact.

1. Introduction

The current standards for the warning horns fitted to trains in the United Kingdom originated in the 1960s. From the original trials [1,2] the specification evolved to the current Group Standard [3].

However, recently there have been a growing number of complaints from people living near the track about the noise produced by warning horns and in many cases this has coincided with the introduction of new trains. There are a number of possible reasons why this has occurred including:

(1) Some of the older trains pre-date the earliest horn specification. The horns on these trains produced sound pressure levels below the current standards. However, on many commuting routes and lines in the south of England these old trains are only just being replaced. As the new trains meet the standard there has been a large increase in the sound levels produced by the horns.
(2) At foot crossings where it is impractical to use any other form of warning the warning horn of an approaching train is sounded at a 'Whistle Board' 400 m from the crossing. Originally these crossings were in the country and frequently no one would be living very close to the 'Whistle Boards'. However, as people have moved out of the towns and cities and housing has expanded into the countryside, people have started to live in areas close to the boards.

*Corresponding author. Tel.: +44 (0) 870 190 1244; fax: +44 (0) 870 190 1125.
E-mail address: rick.jones@aeat.co.uk (R.R.K. Jones).

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(3) Because the train builders were having difficulty meeting all the requirements of the Group Standard they were using horns that were probably louder than required.

An investigation has been carried out to try and understand the issues involved. This paper examines some of the findings.

2. A brief history

In the UK one of the basic requirements, dating at least from the early 1960s, is that the horn should be clearly audible at 1/4 mile (400 m) from the source. However, this requirement did not include any mention of background noise, ground cover or meteorological conditions. A series of listening trials carried out in the late 1960s established a minimum standard for the horns installed on some locomotives of an unweighted sound pressure level of 120–125 dB measured 5 m in front of the train. With the introduction of trains with a maximum speed greater than 160 km/h (100 mph) a *C*-weighted sound pressure level (L_C) of 122–127 dB, also at 5 m in front of the train, was introduced. However, many vehicles, such as the first generation multiple units, were constructed before these standards were introduced and their horns produced L_C values below 120 dB. Interestingly, the horns on these vehicles appear to have operated satisfactorily for over 30 years.

Since the late 1980s all new vehicles have been built to have horns that produced a minimum L_C of 120 dB at 5 m. However, recently the horns fitted to some of these newer vehicles have been the subject of a number of complaints.

3. Minimum requirements

For a warning horn to be effective it needs to be clearly audible and recognisable under a range of listening conditions and at a distance from the train that allows the hearer to take appropriate action. As already stated there has been a longstanding requirement for the warning horns to be clearly audible at 1/4 mile (400 m) from the front of the train. Clearly the sound power needed to achieve this requirement will depend on the background noise, the hearing ability of the listener and the propagation conditions (e.g. ground cover and atmospheric conditions).

The problem with such variables as the background noise is that it has potentially a wide range of values. This is made worse by the fact that, because the warnings operate for a short time (typically 1–2 s), the background noise needs to be considered over that period. However, it also needs to be remembered that no practical warning horn will be audible in all background noise conditions.

Similar problems occur with meteorological conditions. For example, under some combinations of atmospheric temperature gradient, humidity, and wind speed and direction the sound can be diffracted upwards away from the listener creating a shadow zone.

To overcome these problems a set of unfavourable conditions was defined where the warnings should be clearly audible. These conditions include:

(1) A combination of a maximum wind speed of 30 km/h blowing from the receiver towards the train, a minimum temperature of $-5\,^{\circ}$C, a minimum relative humidity of 30% and a clear sky.
(2) The listener having a hearing threshold of the best 95% of the population of 60-year-old males.
(3) A background noise spectrum as defined in Fig. 1.

In addition to the background noise spectrum, Fig. 1 also includes the effect of the limiting hearing threshold. It can be seen how the hearing threshold dominates above 4000 Hz.

In practice, this combination of conditions will be exceeded very rarely in the UK. For example, high wind speeds usually do not occur at higher temperatures and higher relative humidity. This means that a warning that is audible under these conditions would also be audible at wind speeds up to 50 km/h in more typical conditions of temperature and humidity.

Measurements of the sound pressure levels from warning horns have shown that the impedance of the ground can have a significant effect. Typically, for the types of ground found near a railway the sound

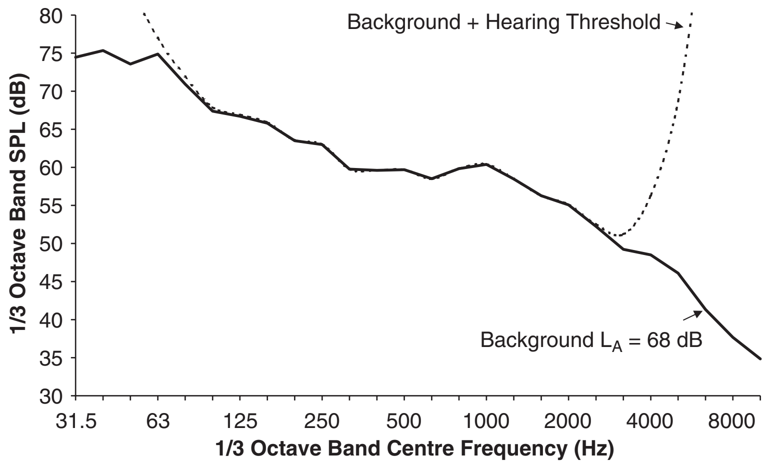

Fig. 1. Limiting background noise spectrum.

pressure level can vary at 100 m from the source by as much as 8 dB. The lowest sound pressure levels occurred when the ground cover was a fine ash material as found in some sidings. Interestingly, some of the highest sound pressure levels occurred when the ground cover was new ballast. Therefore, included in the conditions is a ground cover of fine ash.

4. Propagation of warnings

The propagation model was derived from the information given in Refs. [4,5] and is described in more detail in Ref. [6]. Measurements of the sound pressure levels produced by horns at different conditions were used to provide the information on the ground impedance, etc. From this model it was possible to predict the sound pressure levels under a wide range of propagation conditions. Typically, it was found that the difference between the predicted and measured *C*-weighted sound pressure levels was less than ± 3 dB.

5. Hearing the warnings

A typical warning horn produces a sound that comprises a fundamental frequency and a large number of harmonics. The relative sound levels of these frequencies depends on the design and installation of the horn. In Ref. [6] the effects of the characteristics of a number of horns are studied in some detail. However, for this paper the study is confined to two horns most commonly used in the UK that have nominal fundamentals of 311 and 370 Hz.

There are a number of ways of predicting if a particular warning sound is audible. For this work it was decided to use the following: at least one harmonic should be 15 dB or more above the masking threshold and at least two additional harmonics should be at least 10 dB above the masking threshold. The reasons for this are covered in more detail in Ref. [6].

In this case the masking threshold is derived from the 'Background + Hearing Threshold' curve given in Fig. 1.

6. Predicting audibility

Using the combination of the propagation model and the audibility model it is possible to predict the audibility of a particular type of warning under a range of conditions. To minimise the environmental impact it is important that the warnings produce the lowest sound pressure that is consistent with them being audible.

7. Environmental impact

The contribution to the overall noise at any location will depend on the background noise without the horns, how loud the horns are, how long they are sounded for and how often they are sounded. When assessing audibility, poor propagation conditions are assumed. For the environmental impact it is assumed that good propagation conditions occur comprising still air and a favourable ground impedance.

The horns on most trains in the UK are installed in such a way that they are not clearly visible from the side of the train. This usually results in the sound pressure level at the side of the train being 5 dB or more lower than at the front (the distance from the horn being the same in both cases). This is often mistaken for the horn being directional. In practice, it is simply the result of the shielding provided by the structure of the vehicle. Fig. 2 shows the directivity of a horn (as an equal sound pressure contour) assuming a point source and allowing for the shielding by using a simple barrier model. It can be seen in Fig. 2 that the barrier model predictions agree well with the measurements.

From these predictions it is clear that the sound pressure levels at the side of the train will be lower than to the front. Consequently, because the highest levels of noise will occur near to the centreline, the greatest environmental impact will occur at locations in front of the train on the outside of a curved track and this is illustrated in Fig. 3.

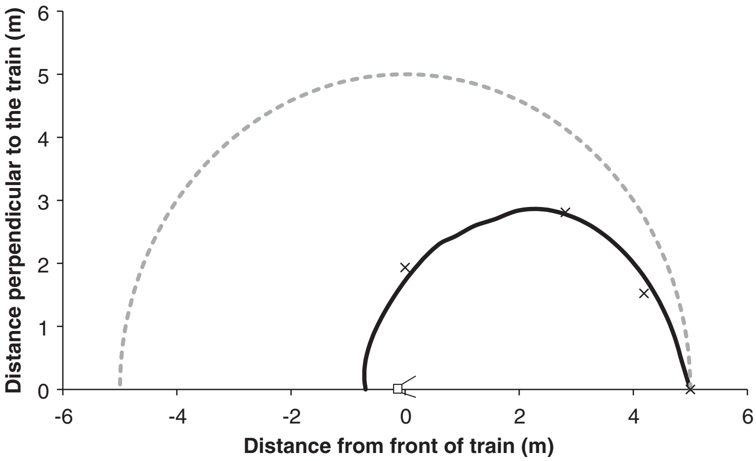

Fig. 2. Predicted and measured directivity of the *C*-weighted sound pressure level for a typical warning horn (370 Hz fundamental): —, barrier model; - - -, point source; and ×, measured.

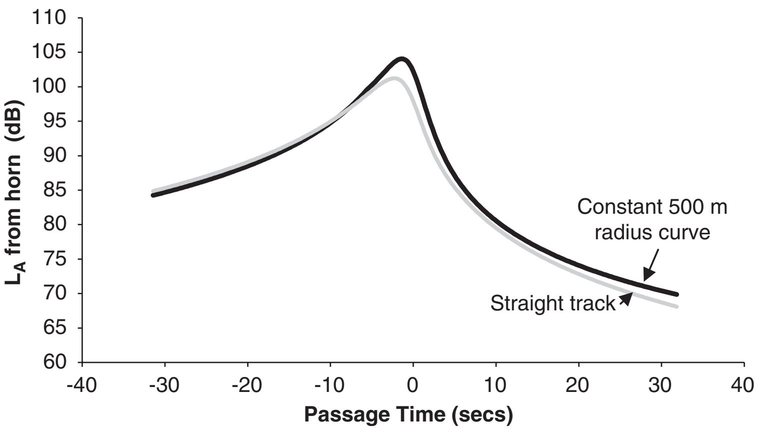

Fig. 3. Predicted *A*-weighted sound pressure level from a horn sounding continuously and passing a site 25 m from the track at 30 km/h on curved and straight track for a horn that produces 120 dBC at 5 m.

The negative times in Fig. 3 are before the front of the train passes and it can be seen that the highest noise levels occur before the train arrives. In practice the horn only sounds for a few seconds. For a 1.5 s sounding on the curved track for a single train per hour the predicted $L_{A\mathrm{eq}}$ is 70.6 dB and this sound level is within that range that is likely to produce complaints. For example, the dose response curve produced by Schulz [7] suggests that at this level over 25% of the population would be highly annoyed if the horn were sounded during the day. Sounding the horn at night increases the number of people highly annoyed to over 50% of the population.

Although the above example is only a single case, near to stations where most of the complaints occur it is close to what might arise in practice. Furthermore, increasing the number of trains/hour will have a significant impact.

For the above predictions it is assumed that the vehicle structure modifies the radiation pattern of the horn in the way illustrated in Fig. 2. However, on some vehicles it has been found that the sound pressure levels at the side are unusually high. Clearly if the horn radiates more sound to the side the $L_{A\mathrm{eq}}$ will increase.

8. Reducing the impact

The options for reducing the environmental impact of the warning horns include sounding the horns less often, reducing the sounding time, making the horns more directional, using a horn that is more audible at a lower L_A and reducing the level of sound.

The UK railway industry through the Rail Safety and Standards Board has reduced the number of situations in which it is required to sound horns. However, there are still many situations where not using the horns would lead to an increased risk of an accident.

The train driver currently determines the sounding durations of the horns. Although they are typically 1–2 s they do vary according to the situation. If a driver perceives a higher level of risk he will generally sound the horns for longer. However, in some higher risk situations he will use a series of short soundings. As the only practical way of reducing the sounding time of the horns is to take away the control of it from the driver this would remove his ability to respond to such risks. Therefore, it is impractical to shorten the sounding times.

Several attempts have been made to make horns more directional. However, based on current technology it seems likely that the current horns will continue to be used for some time. It has already been demonstrated that the vehicle body often provides some shielding to the side of the train. It might be possible to optimise this modified directivity so as to reduce the amount of sound radiated to the side. It certainly should be possible to identify those vehicles that radiate high levels of sound to the side and modify them accordingly.

In Ref. [6] the audibility of several alternative warning devices is examined. It is found that the current pneumatic warning horns used in the UK are close to the optimum in terms of being clearly audible at the lowest A-weighted sound pressure level.

Because the distance varies less with time, the greatest environmental impact from warning horns occurs at the lowest speeds. However, for the people being warned of the approaching train the performance is defined by the distance from the receiver that the horn needs to be sounded to provide an adequate warning time at the maximum speed of the train. Therefore, by varying the sound pressure level from the horn with speed it should be possible to reduce the environmental impact at the most sensitive locations.

By using the defined conditions under which horns are likely to be effective, Ref. [6] recommends the minimum C-weighted sound pressure levels measured 5 m in front of a train for different speed ranges shown in Table 1.

The levels in Table 1 were derived by determining the minimum sound pressure level that is required for a warning horn to be just clearly audible under the adverse listening conditions defined earlier.

In common with current standards the levels are the minimum sound pressure levels. To minimise environmental impact Ref. [6] also recommends that these levels should not be exceeded by more than 5 dB. Furthermore, to ensure that the horns do not radiate significant amounts of noise to the side of the train, Ref. [6] also recommends that the C-weighted sound pressure level measured 5 m to the side of the trains and opposite the horns is 5 dB or more lower than the level 5 m in front of the train.

Table 1
Recommended horn levels as a function of train maximum speed

Maximum speed, v (km/h)	C-weighted sound pressure level, 5 m in front of train (dB)
$v \leqslant 30$	95
$30 < v \leqslant 80$	105
$80 < v \leqslant 160$	112
$v > 160$	115

Table 2
Approximate reduction in trackside L_{Aeq} resulting from the recommended horn levels

Maximum speed (km/h)	Approximate reduction in trackside L_{Aeq} (dB)
30	25
80	15
160	8
200	7

These recommendations, depending on the actual sound pressure levels produced by the horns, will provide the approximate reductions in trackside L_{Aeq} from the horns shown in Table 2 when compared with the current standard [3].

It can be seen that the greatest reduction occurs when trains operate at lower speeds, which is when the environmental impact is greatest. Furthermore, on high speed lines people are less likely to live close to the track and so the number of people who are affected will be lower.

9. Conclusions

It has been shown that under some conditions warning horns can have a significant detrimental impact on the environment. However, by defining the conditions under which warning horns provide a useful safety system and then setting levels that are appropriate for these conditions and for the speed of the train, it is possible to provide a significant reduction in the overall environmental impact. In particular the largest improvement is achieved when the trains are running at low speed which is the condition where the current impact is greatest.

Acknowledgements

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Note added in proof

Since the presentation of this study at the International Workshop on Railway Noise in 2004, the Rail Safety and Standards Board has issued a new Group Standard "GM/RT2484 Audibility Requirements for Trains, April 2005", which implements the recommendations in Table 1.

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