DETERMINING A NOISE-MITIGATION STRATEGY FOR NIGHT-TIME RAIL-NOISE EVENTS

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1 INTRODUCTION

Housing developments in the UK have to be designed with the noise environment in mind, to protect residents from the variety of health and quality-of-life issues that have been linked to environmental noise exposure[2,4,7,10,11]. While the regulations vary between local authorities, the WHO Night Noise Guidelines for Europe[6] and the WHO Guidelines for Community Noise[3] are used as a reference point. These guidelines specify that in order to allow restful and restorative sleep, bedrooms must achieve an average night-time internal target $L_{Aeq,8hr}$ of 30dB and an L_{Amax} of 45dB that is not exceeded more than 10-15 times per night. This is based on the recommendation in 1991 of Vallet[22] who found that reducing the number of aircraft events above 45dB to fewer than 15 per night would prevent the majority of noise-related awakenings. The numerical total stipulation for L_{Amax} is intended to minimise sleep disturbance to residents from 'event noise' such as aircraft and trains, as described in BS 8233:2014[18].

Producing a representative measure of L_{Aeq} from a single night of recording is rarely problematic. L_{Amax}, however, is subject to far more variability. For example, if a recording is made on a night when a passing car backfires or an animal disturbs the meter, then an abnormally high L_{Amax} will be recorded. Basing a planning decision on that data point would be unwise, potentially leading to unnecessarily inflated construction costs or delayed development. For this reason, a 'budget' of 10-15 events per night exceeding design criteria is often used, as recommended by the WHO Guidelines for Community Noise[3] based on the work of Vallet[22]. But to apply it without careful consideration is equally unwise and can lead to underestimation of a real, persistent source of noise, to the detriment of residents' quality of life.

2 RAIL NOISE

Historically, railway noise has been considered to be the least annoying and harmful source of noise pollution when sound pressure level is taken into account[8,9]. A growing body of research, however, is beginning to challenge this notion. It would appear that while rail noise does indeed cause less perceived annoyance to those habituated to it, it has a more pronounced effect on sleep quality and health than previously appreciated[5].

Of more concern is evidence that when individuals do become accustomed to railway noise it is only partial. In a laboratory study on subjects from both quiet and railway-exposed areas, it was found that cardiovascular response and sleep disturbance were less pronounced in those who had been exposed to it for a number of years[20]. The effect was not total, however, and later work by a related team found a very strong link between long-term railway noise exposure and chronic daytime sleepiness and poor cognitive performance[19]. The authors suggested that this was due to accumulated sleep debt. They also found that there was no difference between the railway habituated group and the un-habituated group in how they rated their sleepiness using the Karolinska Sleepiness Scale. This was different from their actual level of sleepiness, suggesting that many people may be suffering adverse effects from rail noise exposure but are simply unaware of it.

There are very few studies available on noise sources other than road, rail and air traffic. In a literature review by Omlin, *et al*.[12], only 23 studies were found, and their quality and subject matter so disparate that no meaningful conclusions could be drawn. The only study relevant to impulse noise was by Vos[24], who found impulse noise (door slamming and gunfire) was similar in its awakening effect to aircraft noise of the same A-weighted sound equivalent level (ASEL).

Additionally, there is increasing interest in the effects of freight train noise on sleep. Freight traffic in the UK is anticipated to increase in the coming years[14], and the majority of this increase will have to be scheduled during the night so as not to conflict with passenger traffic.

Saremi, *et al.*[16] compared the effects of passenger train and freight train noise. They found that while micro-arousals occurred at the same rate for both types, freight trains caused significantly more awakenings than passenger trains for the same sound pressure level – an awakening here being defined as an arousal lasting more than 10 seconds. They suggest that the longer duration of each freight train event (42s vs 20s for passenger trains) may be responsible. Tassi, *et al.*[21] used the same experiment to conclude that cardiovascular responses to noise were also more strongly affected by freight train noise, again suggesting that the duration was the primary cause. Elmenhorst *et al.*[5] found that freight train noise was significantly more disruptive than noise from passenger trains and aircraft. This might be explained by a comparison of their sound profiles. Aircraft and passenger trains typically reach their L_{Amax} values for only a brief period, whereas freight trains can remain at a high sound pressure level for an extended period, usually greater than 20 seconds. This concurs with the finding of Elmenhorst *et al.*[5] that aircraft noise and passenger train noise had similar effects on sleep, but that freight noise was more disruptive than either.

While it seems logical to assume that the longer duration of freight trains are the cause of their greater disruption, Saremi *et al*.[16] and Tassi *et al.*[21] contended with a knowledge gap in the available literature, only being able to find prior research into noise duration effects on fully awake subjects. They recommend that noise duration effects on sleep should be investigated in future studies.

At present the guidelines simply stipulate a number of allowed exceedances of 45dB L_{Amax}.[3] While the research here is very limited, it so far does not appear to contradict the intuitive assumption that if a noise is loud enough to cause a person to wake then it is more likely to wake them if it continues for longer.

The aim of the studies reported here was to investigate the sound profiles of railway noise, particularly at night (2300 to 0700), and, given recent research findings, identify the events most likely to contribute to sleep disturbance. Most sound pressure measurements for railway noise are based on integrated 1-minute recordings, and adverse events are signalled by the L_{Amax} value for each minute. A particular concern was that not all L_{Amax} values are necessarily attributable to train noise, and a method was sought to investigate this. One possible solution would be to perform attended monitoring over several nights. This is neither practical nor economical. What is needed is a way of identifying potentially outlying data points and then determining the likelihood that they have not been caused by an identifiable, repeating event.

A more general goal was to produce a method that would only rely on the use of a single instrument using integrated recordings. In the rest of this paper we examine, in particular, the use of exceedance percentiles such as L_{A5}, L_{A10}, etc. in unravelling the pattern of individual train-passing events. In what follows we produce some simple analytical procedures that allow useful inferences to be made about night-time rail noise events.

3 METHODS

Long-duration recordings (>12h) were made of train noise at Tile Hill railway station (just west of Coventry on the Rugby to Birmingham spur of the West Coast main line).Three instruments were used:

- Norsonic 140: recording 1-min L_{Amax}, L_{Aeq}, L_{A1}, L_{A5}, L_{A10}, L_{A50}, L_{A90} and 1/3 octave band frequency. Also recorded were 1-second samples synchronised with each 1-minute sample.
- CEL 360: recording 1-min L_{Amax}, L_{Aeq}, with up to five customisable L_{Ap} values, where *p* corresponds to a percentile, as above.
- Olympus mp3 recorders.

The overall goal was to produce a method that would only rely on the use of a single sound level meter. To do this it was necessary to compare the 1-minute averaged data with the mp3 recordings and the 1-second profiles produced by the 140. The mp3 recordings were used to confirm the source of noise occurring in the sample, and the 1-second profile gave us a clearer picture of how the sound pressure measured by the meter varied throughout the sample.

Initial attempts at identifying outliers using conventional statistical methods (e.g. Grubb's and Cochran tests)[1] were not very successful as these rely on assumptions of standard probability distributions such as the normal or lognormal. L_{Amax} data did not appear to follow simple empirical probability distributions, and where outliers were identified, they often corresponded to real rail events. Scatterplots of the L_{Amax} and L_{Aeq} measured each minute suggested a high correlation between the two variables, though points with a large deviation between the two sound levels implied the presence of loud events of brief duration. A further refinement was introduced by comparing the L_{Amax} to L_{A1}, the minimum sound pressure level during the loudest 0.6 seconds of a 1-minute sample. An L_{Amax} that correlates poorly to its L_{A1} suggests an impulsive sound which is not the product of the normal operation of a car, train or aircraft. This has been corroborated by examining the noise source from mp3 recordings and looking at the profiles from 1-second data. Train passes were found to rarely exceed a 3dB discrepancy (between L_{Amax} and L_{A1}), quite distinct from the large discrepancies noted in miscellaneous events such as industrial loading incidents, gunshots and animal disturbances.

This concept was extended to compare the L_{Amax} with other L_{Ap} values. These are percentiles of the continuous sound measurement over the sample: an L_{Ap} corresponding to a sound level that is exceeded *p*% of the sample time. Thus, for example, L_{A5} and L_{A10} correspond to values exceeded for 3 and 6 seconds, respectively, in a 1-minute interval. An analysis of the exceedance profile gives a more detailed impression of the duration of an event. Plots of how L_{Ap} declines with increasing *p* show that samples of freight trains diverge from those of express trains for L_{A20} and L_{A30}, which is primarily a function of their different lengths, and possibly, different speeds.

4 RESULTS & DISCUSSION

L_{A1} is defined as the sound pressure level that is exceeded for 1% of the sample. In the case of 1-minute samples this amounts to 0.6 seconds. Figure 1 shows a frequency plot of the ratio between L_{A1} and L_{Amax} for 282 1-minute samples in which the L_{Amax} was above 78dB. (78dB was chosen since it was the lower end of an approximate normal distribution encompassing all freight- and express-train events) The noise source for all of these events is known, having been corroborated by the simultaneous mp3 recording. The majority (71%) of these data have a very small discrepancy (1.5%) between L_{A1} and L_{Amax} (i.e. the ratio is less than 1.015) which suggests a non-impulsive event, most often a passing train. All express and freight train events fit within the 80th percentile of this dataset, having a divergence no greater than 4% (L_{A1} /L_{Amax} < 1.04). The only exception was one train that sounded its horn as it passed the meter (L_{A1} /L_{Amax} < 1.094). This occurred during the day, but had it occurred at night (2300 to 0700) would be an example of a rare event that should be discounted: trains are required to not sound their horns at night except in emergencies, so such an event is very unlikely.

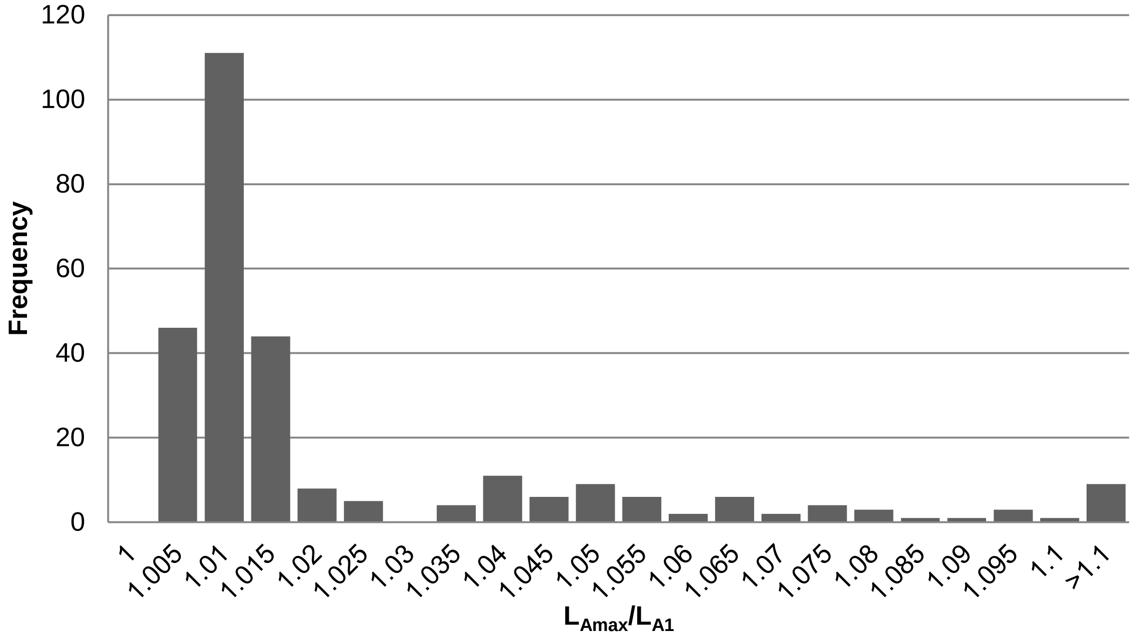

Figure 1: Bar chart showing frequencies of L_{Amax}/L_{A1} ratios.

Confining the sample to train events only (198 samples) shows that 95% of train events have a discrepancy of less than 1.7% (corresponding to 1.017 on the abscissa), and 99% a discrepancy of less than 3.5%. This would suggest that if the L_{Amax} of a train event has a discrepancy beyond these bounds then it is highly unlikely that the L_{Amax} is due to the train and should therefore be discounted.

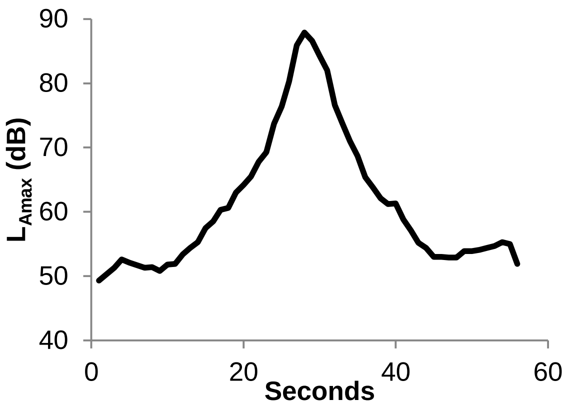

Figure 2: 1-second L_{Amax} profile of an express train 12-08-2015 @ 0941

The 1-second sampling of L_{Amax} allows the sound profile of train events to be examined. In particular, the picture produced by a freight train is quite distinct from that of an express or commuter train. Figure 2 shows the 1-second L_{Amax} profiles of a representative express train passes recorded over a 1-minute interval. The profile is characterised by a fairly sharp peak with differing slopes to and from the peak. Not included in the figure are the percentile values for the 10, 20 and 30 percent exceedance levels: 78, 69 and 64dB respectively. Recall that the LA_p value is the sound pressure value that is exceeded *p*% of the sample time, so, for example, the peak of the profile above 69 dB only occurs for 20% of the sample, i.e. 11 to 12 secs. The important factor here is essentially the length of the train, and its relatively short peak. Figures 3 and 4 show two L_{Amax} profiles for freight trains, but also includes horizontal lines for the L_{A10}, L_{A20} and L_{A30}. In both cases these are very close together. In Figure 3 the profile crosses the L_{A30} line at 10 and 28 seconds, those 18 seconds corresponding to 30% of the sample time - essentially the passing time of the train. Some freight trains have a very even profile, such as that in Figure 3, similar to that used in the experiment by Saremi, *et al*.[16]. This is referred to as the 'plateau' of the freight train profile.

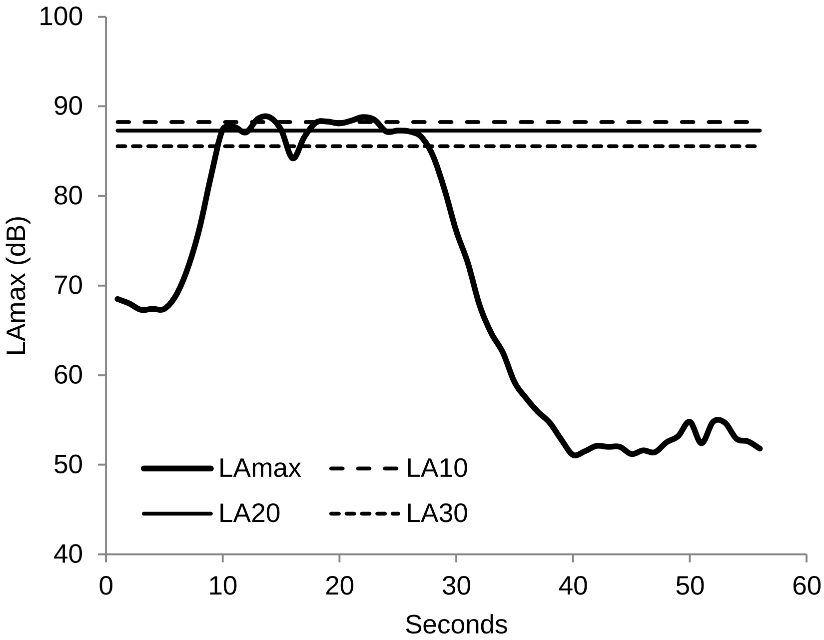

Figure 3: 1-second L_{Amax} profile of a freight train 12-08-2015 @ 1514. The L_{A10}, L_{A20} and L_{A30} values are represented by thorizontal lines.

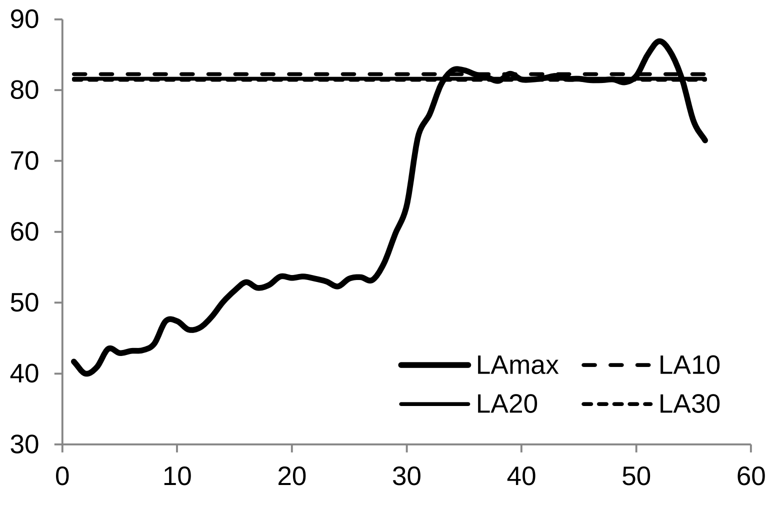

Figure 4: 1-second L_{Amax} profile of a freight train 11-08-2015 @ 2146. As Figure 3, but demonstrating a 'spike'.

Others exhibit a spike above this plateau which is likely to be the locomotive or a particularly loud carriage passing the microphone, as in Figure 4. The profile in Figure 4 is perhaps unusual with the spike occurring at the tail end, suggesting that the active locomotive was at the end of the train. This feature (the spike) is broadly similar to the profile of an express train or airliner and so treating this L_{Amax} in the usual way is perfectly valid. However, as discussed in the Rail Noise section above, the plateau is quite probably the cause of the higher incidence of annoyance[13] and sleep disturbance[16] associated with freight trains. It is therefore important that the sound pressure level of the plateau is accurately assessed without resorting to the complexity of 1-second measurement. In an effort to do this, L_{A10}, L_{A20} and L_{A30} values were compared to the arithmetic mean of the plateau.

The relative closeness of the LA_p values for freight trains suggests a possible way of differentiating between freight and passenger traffic. Plotting increasing L_{Ap} against the L_{Ap} / L_{A1} ratio clearly shows freight trains to have a distinct 'flat' profile for L_{A10}, L_{A20} and L_{A30}. L_{A1} is used rather than L_{Amax} to eliminate instantaneous noise on the basis of the argument above. Figure 5 demonstrates this for recordings of rail noise from Tile Hill, in which the freight train profiles have been highlighted. The same phenomenon has been observed at other measurement locations, and appears to be quite consistent. On one occasion the apparatus was mistakenly placed in a location where noise from the nearby road completely dominated the rail noise. Despite rail events being ~10dB lower than road noise, the freight events were identified without error. Therefore it is anticipated that this can be applied to a variety of noise environments with only a small risk of misidentifying the events. Of course, the flatness of the profile up to L_{A30} is essentially predicated on the fact that the passing time of most freight trains is greater than 18 secs, the exceedance period for an L_{A30} in a 1-minute sample.

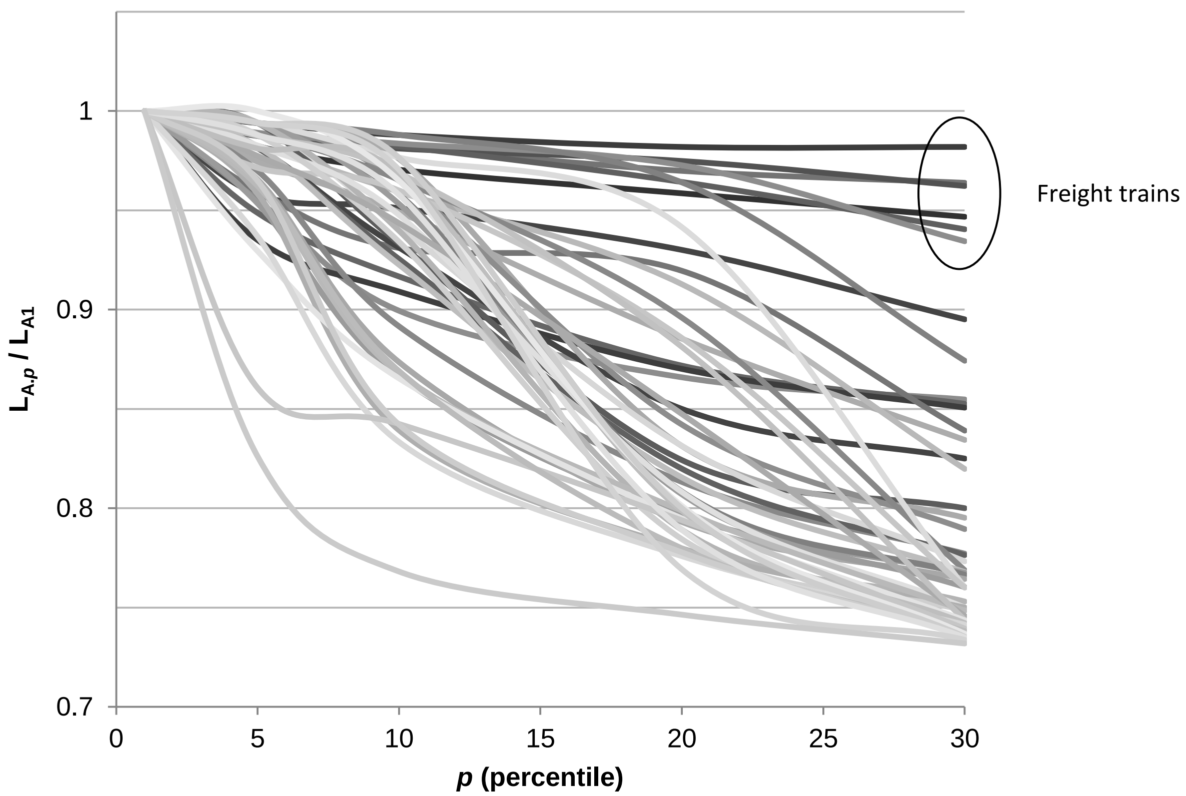

Figure 5: Decrease in $L_{A,p}$ with increasing p. All freight events are found to decline minimally, grouping as indicated.

One final comment: if we assume that the average passage time (i.e. the plateau time) for a freight train is about 30 seconds, then only about half of the sampled trains will fall into a 1-minute sampling period. Clearly, it is possible to combine the data from two consecutive periods but there are difficulties integrating the data from 1-minute samples. In general it is better to take the sample with the longer passage time.

5 CONCLUSION

Where we see a large discrepancy between the L_{A1} and L_{Amax}, the event is either impulsive (e.g. a loading yard incident) or a meteorological event (e.g. rain or wind buffeting the microphone). As sleep disturbance research has shown, single impulsive events have a negligible effect on sleep. Therefore, they should probably be discounted and are not necessarily the feature on which to base a noise mitigation strategy for residential dwellings.

As has been shown, the L_{A20} is a good proxy for the plateau of a freight train, and it is therefore proposed that the L_{A20} be used as an additional test statistic for designing sound mitigation for freight train noise. Allowing the L_{A20} in a bedroom to exceed 45dB in a night-time period has the potential to be highly disruptive to residents' sleep and wellbeing. Reasonable steps should be taken to minimise the occurrence of such exceedances.

Where events can be clearly identified, e.g. train movements, their number and type over the night-time period can be estimated. Using sleep disturbance research the event numbers and type of freight trains can be used to inform the noise mitigation strategy for a proposed residential development.

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