Statistical analysis of railway noise: how long-term monitoring helps improving short-term measurements

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Introduction

Rolling noise of trains is a well-understood phenomenon for which very detailed source models have been developed (e.g. [1], [2]). The knowledge of rolling noise is based on a large number of measurement campaigns and research projects in which various parameters have been identified. Nevertheless, sometimes the measurements reveal effects that cannot be explained in terms of existing knowledge. In this paper we will focus on events and effects that may influence the representativity of the short-term manned measurements typically used for type approval (ISO 3095) and determination of the effect of noise reduction measures. How reliable are single pass-by measurements? How can we use long-term monitoring results to improve short-term manned measurements?

The noise monitoring stations developed by ProRail have yielded a large amount of statistical information in a few years time. The system lay-out is discussed in [3] and how these measurements compare to calculations is treated in [4].

As the monitoring stations are able to identify individual trains and even single vehicles, very refined variation analysis is possible. This includes weather conditions and the state of maintenance. Some of the results give reason to adjust the measurement conditions of the noise type testing standard (ISO 3095).

Manned versus unmanned

Manned short-term measurements are used in many situations, for example to assess the effect wheel or rail dampers or different kinds of braking blocks, but also for type testing in accordance with ISO 3095. Either test trains or in-service trains are applied. As time and resources are limited, the research team will have to find a balance between the number of measurements needed to obtain a representative average and the number of parameters to be varied. In practice this means that just three measurements are made for each measuring condition, as this is commonly regarded as a minimum. However, circumstances sometimes force the research team to draw conclusions on just two pass-bys. Occasionally, this number drops to one valid pass-by, for instance if the weather conditions were extremely unfavourable. Even if three valid pass-bys are available, the eventual signals may reveal unexpected differences which cause troubles during interpreting and reporting. Therefore often the representativity of these measurements can be questionable. Also, because only a relatively short period is involved, the sustainability of the effects that are studied is uncertain.

With long-term measurements such problems can be avoided. This, however, will only be affordable if unmanned measuring systems are used. Typically hundreds of pass-bys can be measured with track-side monitoring stations during just a few days. Effects can easily be studied over a few months time. If automated vehicle recognition is available, or if pass-bys results can be connected afterwards to databases with detailed service information, new opportunities to carry out railway noise analysis become possible. Although setting up a dedicated system will require an investment, the results have certainly shown to be worthwhile, see also [5,6]. Besides gaining knowledge, monitoring systems are very useful to convince the public that the noise computation results for their dwellings are reliable. However, as such monitoring systems are completely automated, manual quality control afterwards remains necessary to sort out measurement errors.

Spread of measurements

From an analysis of 27 selected passenger trains of two different types, the standard deviations of **Error! Reference source not found.** were found using the ProRail monitoring stations at 8 different sites. The microphone positions at these stations are 7.5 m from the track centre, 1.2 m above the railhead. A more detailed description of this analysis is given in [7]. The results are in reasonable agreement with manned measurements of situations where much more than three pass-bys are available.

situation	σ (st.dev.)	attributed to
1 train, 1 site (many pass-bys)	± 0.5 dB	Reproducibility of the track-vehicle system
1 train, many sites	± 1.3 dB	variation between sites
many train, 1 site	± 1.1 dB	variation between trains
many trains, many sites	± 1.4 dB	combination

Table 1: Typical variation in rolling noise levels of passenger trains. The standard deviations were calculated after correction for speed and rail roughness differences.

The table shows that the reproducibility is limited to about 0.5 dB. This implies that if a set of three measurements for one measuring condition shows a larger spread than 0.5 dB, it can be questioned if a representative average can be estimated. This will however generally not be problematic as long as the effects to be studied are larger than 0.5 dB.

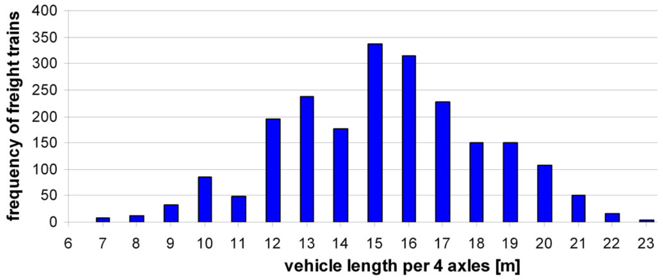

Figure 1: Distribution of average vehicle length of freight trains in the Netherlands. Lengths refer to 4 axles, so not necessarily from buffer to buffer.

Freight trains exhibit generally much larger variations than passenger trains due to differences in APL (number of axles per unit length), load conditions, wheel maintenance conditions, wheel size, (often unknown) braking systems, et cetera. With the ProRail monitoring systems it is fairly easy to yield the APL-distribution of freight vehicles, see Figure 1. This distribution appears not to vary much between the four railway lines where the stations are placed.

The axle load of freight vehicles may influence the noise emission up to 1.2 dB according to Annex E of ISO 3095. An attempt was made to verify the effect of axle load using data from the Gotcha / QuoVadis database [8] in connection with noise monitoring results. The problem with in-service freight trains is that they usually run loaded on one track and unloaded on the opposite track. Because site differences are greater than the expected load effect, see Table 1, the effect must be studied on one track, preferably even within one pass-by. For this purpose, the rolling noise of a freight train with large differences in axle loads was examined. However, there appeared to be no correlation at all between the noise emission of each vehicle and its load. Probably other effects, like wheel flats and variation in wagon types are much stronger than axle load. Obviously, test trains are more suitable to investigate load effects.

Long-term effects

Long-term variations can seriously affect the understanding of results from measurements taken at just two or three moments in time, like with manned campaigns. For instance, rail roughness is known to vary over periods of months [9].

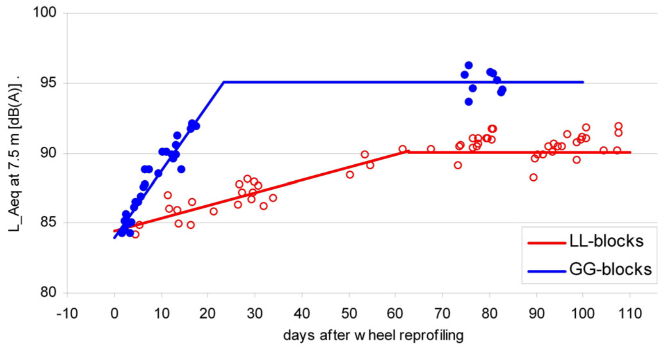

Figure 2: Increase of rolling noise due to growth of wheel roughness after reprofiling. Results for passenger trains (ICR type) with cast-iron blocks (GG) and LL-blocks. Each colour represents a fixed set of ICR vehicles followed in time at one site.

Similarly, wheel roughness may vary due to reprofiling. Recent measurements (Figure 2) show that it can take much more time before the noise level is stable than reported elsewhere [10]. With 1500 km (and about 90 train stops) per day, a mileage of 20,000 to 40,000 km is required, depending on the type of braking blocks. This is much more than the 1000 km mentioned in ISO 3095. Also, seasonal effects attributed to bad adhesion in autumn have been reported [3], leading to a sudden increase of 2.5 dB for all IRM rolling stock in November 2006. If this rolling stock would have been used in two one-day campaigns in October (reference condition) and November (test condition), proper interpretation of the results would have been problematic.

A remarkably strong long-term effect has been observed by the monitoring stations with one EMU of which the motor unit had enormous wheel defects (according to information of the Gotcha / QuoVadis database). After a treatment at the workshop the level dropped by 8 dB, but this appeared not to last long, as Figure 3 points out.

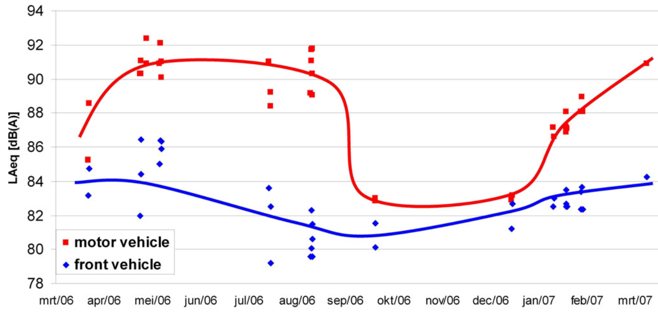

Figure 3: Long-term variations for the two outer vehicles of an EMU of type mDDM with serious wheel defects at the motor unit. After a maintenance action around September 2006 the problem occured again in February 2007. The measurements were taken at different sites and where not corrected for rail roughness differences.

On a shorter time basis, temperature effects can influence measurement sessions. Variation of air temperature will generally not be problematic in the North Sea climate – ISO 3095 estimates an effect of only 0.2 dB for a temperature difference of 20 °C. However, in summer the temperature of the rail can be much higher than that of the air. It may then affect the pad stiffness and thereby the track response. An analysis of the consecutive pas-bys of one train at one site during a heat wave in July 2006 learns that the effect is still rather small. The pass-by noise at 4 PM in the afternoon, with an estimated rail and pad temperature over 40 °C, showed no significant higher noise level than around 4 AM at night (under 20 °C).

To prevent wind effects from disturbing measurements, ISO 3095 uses a rather safe margin: wind speeds above 5 m/s are not allowed. In the Dutch climate, this means that 30% of the planned manned measurements cannot take place. The monitoring stations made it possible to detect the wind speed at which significant deviations occurred from wind still conditions. For this purpose, two selected trains were monitored at one site during a few days in which the wind varried between 1 and 11 m/s. Only above 8 m/s deviations due to wind became noticeable. This maximum wind speed of 8 m/s may depend on the wind screen used, but it seems fair to allow larger wind speeds than 5 m/s at relatively short distance between track and microphone. Allowing 8 m/s as maximum wind speed, means that only 7% of the planned measurements in the Netherlands would be cancelled. With this maximum, unnecessary costs and delays in measurement campaigns can be avoided.

Conclusions

By detailed analysis of data from noise monitoring stations along the track, it appeared possible to confirm or increase the knowledge of railway noise assessment on some selected topics. The following recommendations are proposed for manned measurements.

In manned measurements, attention should be paid to the uncertainty due to too few pass-bys (esp. freight trains). The results in this article show that trains with freshly reprofiled wheels may need much greater mileages than the 1000 km stated in ISO 3095. Ignoring this fact may seriously affect the representativity of test approval measurements. Furthermore, caution is needed if reference measurements are carried out in a different period of the year than the test measurements. At least for one type of passenger rolling stock, seasonal effects of 2.5 dB were found.

The maximum wind speed of 5 m/s in ISO 3095 leads to unnecessary costs and delays in windy countries like the Netherlands. Measurements imply that 8 m/s can still be a safe value with current wind screens. In the Dutch climate, this increases the likelihood that planned measurements can go on from 70% to 93%.

Finally, it is demonstrated that there is a large variation in the number of axles per unit length for freight vehicle (APL). Considering the APL in noise computation models would improve the predictability of freight train noise. Unfortunately, the APL is not yet incorporated in the Dutch computation model.

Acknowledgements

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