The need for accurate railway environmental noise prediction has grown in recent years with the emergence of many proposed high speed railway systems and the aspiration in Europe for significant increases in rail traffic. Accurate noise prediction is also important because of the European Commission’s aim to understand noise exposure across the Community through the noise mapping requirements of Directive 2002/49/EC. Rolling noise, a major element of railway noise and a function of combined surface roughness at the wheel/rail interface, can be modelled using a variety of currently available procedures. However, the majority of these do not take into account the wide range of rail head roughness that can occur on operating railways, instead assuming a rail in reasonably smooth condition. As a result, existing models could under-predict rolling noise by as much as 20 dB when the track is severely corrugated. The railway noise model emerging from the EC projects HARMONOISE and IMAGINE will overcome this failing by requiring combined wheel and rail roughness as an input but this is not yet available. As an interim measure, therefore, techniques have been developed in the UK that allow either global distributions or local characteristics of rail head roughness to be used in rolling noise models. This paper presents the UK approach and compares it with the proposed HARMONOISE/IMAGINE methodology, drawing conclusions on the improvement in accuracy that can be expected over existing models when each of these techniques is applied.
establish whether properties are entitled to retro-fitted treatment to windows and doors in the event of new or additional railways being constructed in their vicinity. As an established national method, it is a natural choice to be used for the noise mapping and action planning required under the Environmental Noise Directive. However, it has one feature that could make it unsuitable for this purpose. Being designed for new or additional railways, where the rail will tend to be in good condition, CRN’s rolling noise source terms for the various types of railway vehicle catered for in the procedure were acquired via measurements on track that was in good condition. The only measure of this condition when the data was acquired was a visual inspection of surface quality of the measurement section of track to establish whether the rail head appeared free from obvious damage, especially the periodic wear pattern known as corrugation. This latter phenomenon has wavelengths typically between 30mm and 80mm, and can increase rolling noise by more than 20 dB in situations where rail roughness dominates the combined roughness (ie where the wheels are comparatively smooth, as is the case where they are either disc-braked or composite tread-braked, rather than cast-iron tread braked).

However, any operating railway has, in reality, a wide range of surface qualities across the network of tracks, ranging from extremely smooth, with a polished and homogeneous appearance, to severely corrugated where peak-to-peak amplitude, ie the “corrugation depth”, is 120μm or more.

If the rail head roughness is not taken into account within a noise map, predicted levels could be significantly underestimated at specific locations where roughness is high. In addition, the effectiveness of an Action Plan that involves grinding to restore or retain smooth rails cannot be gauged via a model that does not take rail roughness into account. It should be noted that the recommended interim computation method for railways within Directive 2002/49/EC, the Netherlands national method of 1996 [5], is equally unable to account for variations in rail head roughness, although later versions of the procedure and associated data-acquisition protocols are attempting to rectify this [6].

In order to understand the rail head quality at specific locations and the statistical distribution of rail head roughness across the UK network, measurements of rolling noise underneath railway coaches were made across a large proportion of that network. The vehicles chosen for this data acquisition exercise were non-powered and with disc-braked wheels, ie with smooth running surfaces so that rail roughness dominates the combined roughness at the wheel/rail interface. Figure 1 illustrates the characteristics of the data thus acquired.

It can be seen from Figure 1 that at any speed there is a range of values, with the lowest representing the rolling noise on very smooth track and the highest representing the situation where the track is very rough, or corrugated. The lower bound of all the data in Figure 1 provides a relationship between level and speed that can be used to normalise the noise level to a defined reference speed. This normalisation allows the rolling noise over a specific section of track to be used to define a “single figure indicator” of rail head roughness. For the UK study, values were normalised to 160 km/h (100 miles per hour).

In order to relate this indicator to the CRN procedure, the transfer function between under floor levels and trackside levels was measured at specific locations. The CRN procedure was then used to predict the level at 160 km/h at the trackside measurement position (with the implicit level of rail roughness within CRN), which was then translated to an under floor level via the measured transfer function. By subtracting this value from the measured under floor level on any section of track, an Index named “Acoustic Track Quality” (ATQ) could be derived. Where ATQ = 0, the track is to the standard assumed in CRN. Negative values of ATQ occur where track is even smoother than CRN assumes, while positive values show that the track is rougher. A value of around +20 dB suggests that severe corrugation is present.

By amalgamating ATQ information acquired over a representative sample of the UK network, it was possible to plot its statistical distribution, as shown in Figure 2. It can be seen that the majority of track (around 90%) is rougher than CRN assumes, and that a small proportion of the track is around 20 dB noisier than CRN track.

ATQ can be acquired at a specific site either by running an instrumented vehicle over that site and measuring under floor rolling noise (the AEA Technology NoiseMon system can facilitate this), or by measuring the trackside noise from a known smooth-
wheeled vehicle. Prediction algorithms for rolling noise source sound power level (the essential starting point for any model) can then be modified as follows:

Where the wheel is smooth (ie where it has either disc brakes or composite tread brakes), the sound power emission of the wheel can simply be adjusted by adding the ATQ.

Where the wheel is comparatively rough (ie where it has cast-iron tread brakes) it can become the dominant factor in combined roughness. Therefore more detailed consideration of the implications is required by taking into account the relative contributions to the overall roughness of the wheels and the rails.

2.2 The statistical rail roughness study

Although the approach developed in Section 2.1 is applicable to predictions at specific locations, the UK Environment Ministry “Defra” were also interested to understand the implications of the true distribution of rail head roughness in the UK on the country-wide accuracy of railway noise modelling. A statistical study was therefore set up on their behalf, based on the distribution shown in Figure 2.

The study involved the definition of 18 example railway sites with typical levels of traffic during the day, evening and night. For each of these scenarios, the ATQ for each track was selected at random from the distribution, allowing the CRN source term to be derived for each type of vehicle passing the site via the considerations of Section 2.1. L_{den} and L_{night} predictions were then made in line with the requirements of Directive 2002/49/EC and compared with the levels that would have been predicted if CRN were used in its standard form (ie ATQ=0). This process was then repeated over one million times per site. The difference between CRN prediction and CRN prediction enhanced with more realistic rail roughness was then able to be examined statistically to seek correlation with a range of parameters. These included L_{den} and L_{night} predicted using CRN, average train speed at the sites, the number of wheels with cast-iron tread brakes, the number of powered wheels, the number of diesel locomotives and the number of multiple units.

None of these parameters showed a very strong correlation. The flow-weighted speed at each site was, however, the best predictor of the discrepancy between ATQ-corrected predictions and CRN predictions, as illustrated in Figure 4.

A similar result was found for L_{night}. It can be seen that the best fit line can be applied as a speed-dependent
“back-end” correction to a CRN prediction to reflect the UK-wide situation when global exposure of the population is being considered. Below approximately 40 km/h this correction is zero. The implication of this correction characteristic is that, globally, the typical distribution of rail quality characteristics in the UK will lead to an average increase in $L_{den}$ or $L_{night}$ of around 4 dB for higher speed sections, but for lower speed sections the average effect is small. However, when the true noise environment at a specific site is to be modelled, it is necessary to determine the local ATQ via an instrumented vehicle or trackside measurements of stock with known characteristics.

3 The HARMONOISE/IMAGINE methodology

The method for railway rolling noise source term quantification being developed in the EC Research Projects HARMONOISE and IMAGINE (set up to provide the common assessment methods required under Article 6.2 of Directive 2002/49/EC) takes a more fundamental approach. Here, the source terms are generated as a function of the combined roughness at the wheel rail interface, taking into account contact filter effects, via transfer functions between the combined roughness and the separate sound powers of the wheels and the track. Figure 5 illustrates this approach.

Figure 5: The HARMONOISE and IMAGINE approach to the quantification of railway rolling noise

Wheel and rail roughness may be measured directly using various devices, or indirectly by measuring track vibration and assuming the track dynamic characteristics. The transfer functions can also be derived using several alternative methods involving the measurement of trackside sound and track vibration.

The individual sound power for wheels and track enable propagation models to be applied with precision, as their heights are different. They also allow the effects on environmental noise impact of treatments applied separately to vehicle or track to be established, and help in cost benefit analyses and action planning.

4 Comparison between the UK and HARMONOISE/IMAGINE methodologies

It is obviously desirable to apply the HARMONOISE/IMAGINE scheme where possible, as this provides the ultimate level of precision in defining rolling noise source terms. However, the quality of the source term data thus derived is highly dependent on the precision of measurement of the roughnesses and the transfer functions. Although devices are now available that ensure precision in roughness measurement, there can be uncertainties associated with source separation techniques unless they are applied by the few skilled experts in this field. This may cause practical difficulties in acquiring the large amount of source data that needs to be in place in time for the second round of noise mapping under Directive 2002/49/EC.

The UK approach is, by its nature, a more generic one, especially where global “back-end” corrections are used. However, it does enable a reasonably precise indication of the local rolling noise environment to be predicted if ATQ at the site in question can be obtained either by running an instrumented vehicle over the site or by measuring the pass-by noise of stock with known noise characteristics.

Both the IMAGINE/HARMONOISE method and the UK local ATQ method will enable rolling noise to be predicted with significantly more precision than with current models such as CRN [3] or the Netherlands 1996 model [5]. An indication of this is the situation at a highly corrugated site with smooth-wheeled stock where either of these methods will predict the rolling noise around 20 dB more accurately than existing methods. The UK approach does not, however, have the level of flexibility of the IMAGINE/HARMONOISE method, as under many circumstances the vehicle transfer functions and track transfer functions can be considered independent and therefore applicable to other vehicle/track combinations. The latter method also has the advantage of enabling train and track to be considered separately in the model for improved accuracy in propagation modelling, for cost-benefit studies where the relative benefit of treating track or vehicle can be considered, and hence for action planning.
5 Conclusions

Although the high-precision railway rolling noise source definition techniques that are the aspiration of the HARMONOISE and IMAGINE projects will eventually have many advantages over current techniques, the UK methodology based on the concept of Acoustic Track Quality provides a useful interim step. By obtaining ATQ locally, prediction methods based on source terms that would otherwise assume rail head in good condition can have their accuracy improved by up to 20 dB. The UK “back-end” correction approach will also enable improved prediction of global railway noise exposure from its railway network if it is applied for the first round of mapping required in 2007 by Directive 2002/49/EC.

6 Acknowledgement

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References


