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A FRAMEWORK FOR MEASUREMENT METHODS FOR RAILWAY NOISE

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ABSTRACT
In recent years a number of new techniques have been developed for measuring railway pass-by noise which enable separation of contributions from track and vehicle and independent characterisation of vehicle and track. In this paper, available methods are put into perspective and four levels of complexity are defined. The type of method best used depends on the purpose of the measurement. A single microphone measurement will generally not be reproducible at different sites due to variation in track roughness and track response properties. Independent characterisation of vehicle and track requires measurement of wheel roughness and vehicle response, rail roughness and track response.

1 - INTRODUCTION
Knowledge of railway noise control has increased substantially in the past decade. A wide variety of solutions for noise abatement at the source is available, but reliable methods for assessing noise reductions under operational conditions have only been developed more recently ([1,2]), and are still under validation ([3]). Railway noise is a key issue for the competitiveness of the European rail network. With the increasing need for reliable noise emission measurement of railway rolling stock and anticipated European regulations in this field, appropriate but practicable measurement methods are required.
Railway pass-by noise measurements are often performed with a single microphone at 25m or 7.5m distance from the track centreline. For constant speed tests the equivalent A-weighted sound pressure level is measured. The data thus obtained contains noise contributions from both the vehicle and the track. Although measured noise levels are well repeatable at the same site with the same train, additional techniques are required to be able to make such measurements reproducible between different sites. This is due to variation of rail roughness and track response properties.
In 1998 improvements have been made to international railway noise type testing standards (pr EN ISO 3095 [2] from CEN TG256/WG3 and ISO 3095), in particular in relation to rolling noise, which is a dominant source for pass-by tests. Major issues were the specification of a rail roughness limit at the test site and derivation of the contribution of track noise to the total noise. This lead to an improvement in reproducibility between measurement sites of ±5 dB(A) to ±2 dB(A) (see [4]). A further extension to the standard would be useful, to allow fully independent characterisation of tracks and rolling stock. This would then simplify the apportioning of responsibilities between train operators and track managers. It could also be stated, that without such methods, some effective noise control measures on vehicles and track will not be implemented, simply because noise reductions on only the vehicle or only the track are not quantified properly.

2 - NOISE SOURCES
Railway pass-by noise consists of a number of potential sources: wheel-rail rolling noise, which is often predominant, noise from power units and auxiliary equipment, and aerodynamic noise, in particular at high speeds (above 200 km/h). Railway noise has the particular feature that it also includes sound radiation from the track, whereas all other sources are due to sound radiation from the vehicle. As the track noise contribution can be substantial and sometimes even dominate over vehicle noise, it is useful

to be able to separate it from the total noise. The total noise level L_{ptot} is the energy sum of vehicle noise L_{pveh}, containing all vehicle noise sources, and track noise L_{ptr}, all as 1/3-octave spectra:

$$L_{ptot}(f) = 10\lg\left(10^{L_{ptr}(f)/10} + 10^{L_{pveh}(f)/10}\right) \tag{1}$$

The main influence factors of wheel-rail rolling noise are well known. Wheel and rail roughness together form the main excitation of rolling noise, resulting in a speed dependent vibration level in the contact patch. The vibro-acoustic response, or transfer function, of the vehicle and track determine the overall sound transfer to the measurement point. These are influenced amongst others by track properties such as rail geometry, pad stiffness and sleeper design for the track, as well as wheel geometry, damping and shielding for the vehicle. Site effects and measurement distance affect the sound transmission. The greater the measurement distance, the stronger the influence of ground effects becomes, which is one reason for preferring a short measurement distance of 7.5 m instead of 25 meters. For the purposes of measurement the main influence factors can be grouped as in figure 1.

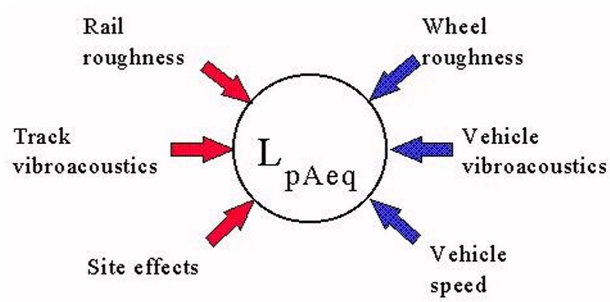

Figure 1: Main influence factors on rolling noise.

Separation of vehicle and track noise is not sufficient to characterise vehicle and track independently. A quiet wagon with smooth wheels might produce a high noise level on a rough track, and similarly, on a quiet and smooth track, a wagon with rough wheels may produce high sound radiation from the track. A better way to characterise vehicle and track independently is by measuring wheel roughness and vehicle response for the vehicle, and track roughness and track response for the track. 'Track Response' refers to the vibro-acoustic transfer function between roughness and sound pressure due to the track L_{Htr}, or a similar quantity for the vehicle L_{Hveh}:

$$L_{Htr}(f) = L_{ptr}(f) - L_r(f) \tag{2}$$

$$L_{Hveh}(f) = L_{pveh}(f) - L_r(f) \tag{3}$$

where L_{pveh} is the sound pressure level due to the vehicle and $L_r(f)$ is speed-dependent total roughness. The total roughness $L_r(f)$ is the energy sum of wheel and rail roughness.

$$L_r(f) = 10\mathrm{l\ g}\left(10^{L_{r,veh}(f)/10} + 10^{L_{r,tr}(f)/10}\right) \tag{4}$$

3 - A FRAMEWORK FOR MEASUREMENT METHODS

A framework for measurement methods for railway noise is put forward here, which can help select the most appropriate approach depending on the purpose of the measurement. Firstly, the following general distinction can be made between types of noise measurement:

Type testing and periodic monitoring: these are standardised methods for measuring noise emission of rolling stock, used for acceptance testing and performed under fully controlled conditions, i.e. a test train with prescribed speeds at a well-defined test site.

Continuous monitoring: Measurement of normal rail traffic at a given site, for evaluating overall traffic noise emission or immission at a given location or picking out noisy vehicles.

Diagnostic measurements: These are measurements for special purposes such as source location, for example antenna measurements, and characterisation of components, for example railpad properties, track input mobility and many others.

Whichever of these methods are being used, it can be beneficial to know beforehand which quantities are relevant for particular purposes. For this reason four levels are defined for measuring railway noise, illustrated in the table below.

	Obtained Quantities			
	Total	Vehicle	Track	Applications and notes
Level 0 (No separation)	L_{ptot}			Overall levels, large spread
Level 1 (Sound Separation)	L_{ptot}	L_{pveh}	L_{ptr}	For assessing track or vehicle noise control measures
Level 2 (Sound and roughness separation)	L_{ptot}	L_{rveh}, L_{Hveh}, L_{pveh}	L_{rtr}, L_{Htr}, L_{ptr}	For independent characterisation of tracks and vehicle
Level 3 (Sound, roughness and dynamics separation)	L_{ptot}	L_{rveh}, L_{Hveh}, L_{pveh}	L_{rtr}, L_{Htr}, L_{ptr}	Partly using calculation, when vehicle not available
		Mobilities and others	Mobilities and others	

Table 1: Framework for measurement methods for railway noise; all level quantities are 1/3-octave spectra and corresponding overall levels.

Level 0 is the simplest method using a single microphone, resulting in only the overall noise level L_{ptot}. Data obtained by this method will not reproduce well from one site to another, and is not reliable to assess the noise reduction of noise control measures on track or vehicle. To do this, at least Level 1 is required, which results in separate vehicle and track noise contributions L_{pveh} and L_{ptr}. Level 2 results in wheel roughness L_{rveh} and vehicle response L_{Htr}, as well as rail roughness L_{rtr} and track response L_{Htr}. These independent quantities can be used for comparing data measured at different sites. Level 3 is most complex, fully taking coupled wheel-rail dynamics into account, and can provide any of the results of the other levels, but makes use of partial input data and calculation models such as TWINS [6]. At this level it is possible to separate and combine dynamics of wheel and track.
The type of method best used depends on the purpose of the measurement. For example, proper assessment of performance of bogie shrouds on rail vehicles requires at least Level 1, as the total noise may show little change due to the contribution from the track. Level 2 data would be required to predict the noise level of a vehicle at another site; level 3 might be used if a vehicle is not yet available for measurement, or for special vehicle-track configurations.

4 - LEVEL 1 AND LEVEL 2 METHODS

Methods for levels 1 and 2 have been developed in recent years in the METARAIL project [1], and are currently being validated and formalised in follow-up projects (STAIRRS [3] and others). One example of a level 1 method is the 'reference vehicle method', which uses a quiet vehicle to characterise the track response function during pass-by (see [1], [5]). The 'quiet vehicle' typically has small and massive wheels. Once this track response function is obtained, the track contribution of any other vehicle pass-by can be derived from the rail vibration level. A similar approach can be taken to characterise the vehicle contribution by using a quiet test track. Also, reciprocal methods [7,8] have been developed which allow determination of response functions under stationary conditions by irradiating the vehicle or track with a sound field and measuring the vibration response. Track roughness can be measured directly using procedures described in [2], or indirectly by axlebox vibration or onboard noise monitoring, which have limited accuracy. Wheel roughness can be either measured directly (not practical for type testing) or indirectly by railhead vibration [1], [5].

5 - CONCLUSIONS AND RECOMMENDATIONS

A framework for measurement methods for railway noise has been described which can help select the most appropriate method for particular purposes. The levels described are only partially incorporated in the current pr EN ISO 3095 preliminary standard. A future improvement to this standard could be the formulation of separate standards for track and rail vehicles based on level 2 methods.

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