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Using source separation techniques in measuring railway noise emission

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Abstract [211] In Europe, the HARMONOISE project is developing a calculation method that provides a standard for noise immission calculation of railway and road noise. It is intended that the HARMONOISE method will be used for future noise immission calculations (noise mapping after 2008). Meanwhile, a so-called interim method can be used by the Member States of the European Union. For railway noise, the interim method is based on the Dutch calculation scheme RMR. The interim method RMR as well as the HARMONOISE method require that rolling noise is separated in noise originating from the track and noise originating from the vehicle. The interim method prescribes that the so-called silent vehicle measurement technique is used for separation. The HARMONOISE method provides two more measurement techniques that allow for track and vehicle noise separation. As the concept of source separation is rather new in noise calculation schemes, the need for rolling noise source separation is discussed. The available measurement techniques are reviewed and compared, using criteria as robustness, expenses, ease of use, extent of validation. Advantages and limitations of the techniques are given. This information will help European authorities and consultancy offices to determine the effort needed to obtain new measurement data and to be ready to introduce the prescribed calculation methods.

1 INTRODUCTION

Environmental noise is a topic of growing concern in Europe, both on a central policy level and amongst European citizens. In spite of noise regulations and legislation that has existed for long time in many Member States, the number of European citizens that are annoyed by environmental noise shows an ever growing tendency. In order to assess objectively the exact size of the noise problem on a European scale and to monitor the efficiency of plans to control and reduce the effects, the European Noise Directive 2002/49/EC (short: END) has been set up [1].

The END requires strategic noise mapping to be undertaken in the Member States by 2007, followed by noise action planning one year after. In this first mapping operation, the noise within the largest agglomerations and near major roads, railways and airports is considered. The computation of L_{den} and L_{night} should be done using the existing national calculation models, or, if absent, using the so-called Interim Methods. The selected interim method for railway noise is the Netherlands “Reken en Meetvoorschrift Railverkeerslawaai ‘96” (short: RMR).

The END also expressed the need for a common approach to the production and presentation of noise data from the Member States. This need has been the starting point of the Harmonoise project, in 2000 [2]. The main objective of the Harmonoise project is to provide new harmonised

computation methods for the prediction of noise from *roads* and *railways*, which can meet the requirements of the END in that they are more accurate, more reliable and, on that basis, enjoy a general international acceptance from future users throughout the Community. The adoptation of the Harmonoise methods for *aircraft* and *industrial* sources have become tasks of the IMAGINE project, which started in December 2003 [3]. In addition, IMAGINE will provide guidelines that explain how to measure and model noise from these four types of sources.
Though the obligation to use the harmonised computation methods will come into effect no earlier than 2012, i.e. during the second strategic noise mapping operation, Member States will need to prepare this operation well before that date. Therefore, for those Member States that will use the Interim Model, i.e. the majority of the EC Members, it will be interesting to examine what data is needed to use Interim Model on the one hand and the Harmonoise model on the other hand, and to see if work can be combined in an efficient way. This paper will examine the input data for railway noise modelling, both for the Interim Model (RMR) and the Harmonoise model. We will concentrate on the source characterisation and separation techniques that are required, and will review the alternatives.

2 DESCRIPTION OF THE MODELS

2.1 Interim model RMR

According to the END, the 1996 version of RMR is the recommended Interim Model for railway noise [1]. Surprisingly, not the Dutch 1996 version but a Dutch revision of it, dated 2002, has been prepared under the authority of the Noise Steering Group of the EC [5]. In this 2002 revision, two measurement procedures for determining source parameters have been introduced:
A. a simple procedure that enables new trains (i.e. train types that are not listed) to be assigned to one of the 10 existing train categories
B. a comprehensive method for categorisation that enables new categories to be defined.
(Apart from these two procedures, there is a third measurement procedure for track characteristics, which is beyond the scope of this review.)
It is clear that these procedures are quite useful in the context of the END, as there is a great variety of (passenger) trains througout Europe: Member States should first identify the types of trains within their railway network and then assign these trains to existing or new categories, using method A or B, respectively. An outline of the prescribed measurement procedures is given here.

A. Simplified method

1. A test site with a prescribed track construction should be used: rails (type 54E1), concrete sleepers, stiff pads (300-500 kN/m).
2. The actual rail roughness at the test site should be measured (though not for all types of trains), as the measured noise levels will be corrected for differences between the actual and reference rail roughness.
3. Test runs should be carried out with the trains at a number of speeds.
4. Noise of these pass-bys is measured in octave bands at 7.5 m from the track centre.

Criterion: Trains are assigned to a certain category if the measured noise level at 7.5 m is below the category value at all speeds and all octave bands. Small exceedances in some bands are allowed, provided that the dB(A) values at 25 m from the track are below the category dB(A) value.

Comments: A number of practical difficulties with this procedure are envisaged. For instance, the prescribed track construction is common in the Netherlands, but the combination of 54E1 rails and stiff pads are rare elsewhere.

Also, rail roughness should be measured with specific instruments (using prEN ISO 3095:2001). To my knowledge, there are only three types of instruments that are suitable for this task. These are the CAT trolley, the RM1200E ruler and the TRM02 ruler. Apart from technical concerns about the accuracy and comparability of the results of these instruments, there may also be economical thresholds: the purchase price is considerable (25-80 kEUR), and the owners of the few available copies are found only in western Europe.
Last but not least, the criterion of acceptance is tight, even tighter than the original Dutch guideline. This is not only because of the extra margin L_{diff} of 1 dB(A), but also due to the fact that at low speeds the two coefficients that relate speed to noise emission will probably not fit well.
Because of the tight criterion, it is therefore likely that procedure B will required for many trains in the Member States.

B. Comprehensive method

While procedure A takes 5 pages, about 25 pages are used for a procedure B aiming at the creation of new categories for trains.

1. Test track: it is preferred to build a silent test track. A track with rail dampers is proposed as an alternative.
2. Four source heights are defined above railhead level: 0 m, 0.5 m, 2 m, 4 m and 5 m. The contributions of four types of noise (traction, rolling, aerodynamic, braking) to these heights is determined by measurement.

We will concentrate here on the measurement of <u>rolling noise</u>, as this is mostly the pre-dominant type of railway noise, and as rolling noise is treated in a both fundamental and innovative way which requires understanding of its excitation, transmission and radiation.
The measurement of rolling noise in Procedure B requires the following:

3. Rail roughness, wheel roughness and total roughness are measured (excitation).
4. The contribution of the track sources (sleepers, rails) and vehicle sources (wheels) to rolling noise is determined (separation).
5. The transfer functions from total roughness to track noise and to vehicle noise are calculated (characterisation).

Comments:
A large number of the quantities that should be determined for rolling noise are shared between the Interim Model ad the Harmonoise model. In fact, the quantities mentioned under items 3, 4 and 5 are also required for the Harmonoise source model, except that the Harmonoise model uses <u>source power</u> instead of source pressure as input. This will become clear in the next Chapter. The main difference between RMR and Harmonoise, with respect to rolling noise characterisation and separation, is that Harmonoise provides several alternative methods where RMR prescribes one method: the silent (or reference) vehicle method.
The main disadvantage of this method is that it is impractical. The method requires pass-by measurements with silent reference vehicles. Citing RMR: *The main property of these vehicles is that they radiate substantially less sound (10-20 dB) than the track. Wagons with small massive wheels with 40 cm diameter or less and massive webs are suitable.* The availability of these wagons can be a problem for some Member States, or, if available from elsewhere, access to railway network may be difficult. For example, vehicles with such small wheels would caused safety problems at switches in the Netherlands.

Before we will have a closer look at the Harmonoise source model and the alternative measurement methods provided therein, it is remarked here that the Netherlands have decided recently to remove

Procedure A and B from their Dutch 2002 version of the RMR. These procedures have therefore never been in force in the Netherlands, as the 2002 version was only a draft and the procedures were absent in the 1996 version.

2.2 Harmonoise railway source model

Source model and parameters

The rolling noise part of the Harmonoise source model for railways [17] has its roots in the STAIRRS project [4]. Figure 1 gives an overview of the source model for rolling noise, adopted in Harmonoise.

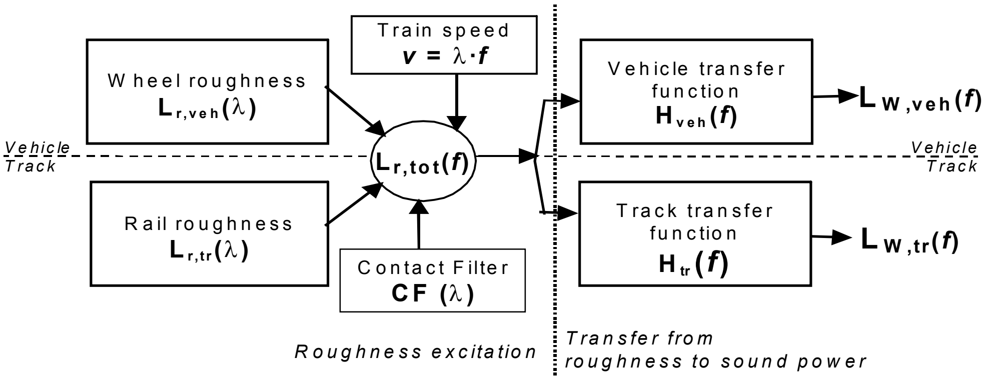

Figure 1. Rolling noise source model (Harmonoise), see also [17].

The physical excitation mechanism for rolling noise is found in the left-hand side of this diagram. The rail roughness $L_{r,tr}$ and wheel roughness $L_{r,veh}$ as a function of wavelength are added logarithmically. The total effective roughness $L_{r,veh}$ is found from this by applying a contact filter CF. The actual train speed will convert roughness from the wavelength to the frequency domain.
In the right-hand side, two functions $H(f)$ are defined transferring total effective roughness to the sound power of the track sources $L_{W,tr}$ and vehicle sources $L_{W,veh}$. These sound power values, calculated per axle of the vehicle and positioned at 0 m height and 0.5 m height above the railhead, respectively, are finally fed into the Harmonoise propagation model.

The parameters that govern this rolling noise source model are listed in Table 1. This table explains the main dependences of the parameters, and provides a first impression how to obtain values for different rolling stock and tracks. The Harmonoise project, being aware that some applications of the model require much less accuracy than others (e.g. noise mapping versus assessment of source measures), have planned to provide a database with default values. Using these values, where choices can be based on a small number of network-related, traffic-related and rolling stock features, a fair level of accuracy can be reached e.g. for noise mapping.
The highest level of accuracy, however, can only be reached if these parameters are measured for the rolling stock and network of the Member States. For this purpose, the Harmonoise project provides a list of (combinations of) measurement and calculation methods and analysis techniques that can be applied in certain situations. These methods are reviewed in the following two sections on roughness measurements and source separation. These reviews reflect the point of view of the author, based on experience with those methods during participation in the European project Metarail, STAIRRS and Harmonoise, and a number of Dutch research projects.

quantity		value depends mainly on	how to obtain value
$L_{r,tr}$	*rail roughness*	grinding regime	network or line average (measured or default)
$L_{r,veh}$	*wheel roughness*	braking system	train category average (measured or default)
CF	*contact filter*	axle load and wheel size	default value
v	*train speed*	operational data	average (traffic data or measured)
H_{tr}	*track transfer function*	type of track superstructure	measured, calculated or default
H_{veh}	*vehicle transfer function*	type of vehicle	measured, calculated or default

Table 1. Parameters in the source model

Roughness measurement methods

Roughness can be assessed in a direct and indirect way [6, 7, 8]. Direct roughness measurements make use of a sensor that measures the irregularities on the rail or wheel surface. The rail roughness instruments mentioned earlier all belong to the direct class of measurement. Indirect roughness measurements make use of rail vibrations during train pass-bys (wayside measurements, [9]) or wheel vibrations on board a measuring coach (e.g. via telemetry or axle-box). It is important to realise that indirect measurements (only) yield the total effective roughness.

The following table gives an overview of combinations of direct and/or indirect measurement methods that are able to provide the roughness spectra of rail and wheel as well as the total effective roughness. A rating from – – (unfavourable) to ++ (favourable) is given for 4 aspects: 'accuracy', 'robustness', 'economy' and 'ease of use'. These are defined as follows:

'Accuracy': accuracy of the result, in terms of deviation from the 'true' value.
'Robustness': consistency of results between different sites and different trains
'Economy': economical aspects of using these methods (including hardware and software)
'Ease of use': likeliness to obtain useful results without much experience

ROUGHNESS	**accuracy**			**robustness**	**economy**	**ease of use**
	$L_{r,veh}$	$L_{r,tr}$	$L_{r,tot}$			
direct wheel roughness + direct rail roughness	++	++	+	++	– –	+
indirect roughness measurement + direct wheel roughness	++	±	++	+	–	±
indirect roughness measurement + direct rail roughness	±	++	++	+	–	±
using default values from literature	–	–	–	n.a.	++	++

Table 2. Review of roughness measurement methods.

Note that the direct methods provide good accuracy for rail and wheel, but the constructed total effective roughness (by summing in the energy sense) appear sometimes to deviate slightly from what is expected by inspection of noise data. If direct and indirect methods are combined, the missing roughness quantity (either $L_{r,veh}$ or $L_{r,tr}$) is obtained by subtraction of roughness levels, which may, however, lead to poor accuracy.

Source separation methods

Several methods for seperation of vehicle and track sources have been developed in the STAIRRS project. The VTN method [10] as well as the MISO method [11] separate the measured pass-by sound pressure into $L_{p,veh}$ and $L_{p,tr}$. The PBA software tool [12] applies an indirect roughness method [9] and recommends the silent vehicle method for source separation. Though the VTN, MISO and PBA tools are quite different in how they tackle the separation problem, it is of great practical interest that these tools all make use of the same 8-channel measurement set-up and input file format [13].
It has been mentioned earlier that Harmonoise, unlike STAIRRS and the RMR model, uses the source sound power instead of the source sound pressure. As the above separation methods are based on sound pressure, a small adaptation is necessary to serve the Harmonoise requirements. At present, it is proposed to apply a post-processing procedure called L_p-to-L_W [14] that transfers the output noise spectra of the separation tools into sound power.

Besides the above three measurement methods, Harmonoise proposes a calculation method (TWINS [15,16]) and the use of defaults as alternatives. All in all, five options are available to obtain the transfer functions, each with their own features.

1. Total effective roughness + VTN (+ L_p-to-L_W)
2. Total effective roughness + MISO (+ L_p-to-L_W)
3. PBA + silent vehicle method (+ L_p-to-L_W)
4. TWINS calculations
5. Using default values from literature

Again, the author permits himself a subjective review, see Table 3. The meaning of the aspects 'accuracy', 'robustness', 'economy' and 'ease of use' is as given in the previous section. Instead of ratings, remarks are given.

option no., see above	Accuracy		robustness	economy	ease of use
	H_{veh}	H_{tr}			
1.	fair, but dependent on track noise	Good	reasonable, tested in STAIRRS WP2 validation campaign	mainly measuring and analysis costs, trains can be measured in normal operation, no test runs	measuring reliable track acceleration signals needs some practising
2.	fair, but dependent on track noise	good, but dependent on vehicle noise	reasonable, tested in STAIRRS WP2 validation campaign	similar as for option 1	success depends on degree of coherence between track acceleration and nearby noise
3.	fair, but dependent on track noise	good	reasonable, tested in STAIRRS WP2 validation campaign	only once, a silent vehicle measurement campaign needs to be arranged; thereafter costs similar as for option 1	depends on organisational effort for silent vehicle; measuring reliable acceleration signals needs practising
4.	good	good	excellent, many years of validation and refining	a new TWINS model requires thorough measurement effort, unless a validated reference model and library is available	obtaining reliable TWINS results requires engineering knowledge and careful checking of each model
5.	varying, dependent on difference between actual and default tracks and vehicles		unknown	no direct costs, but indirect costs may arise from inaccurate noise calculations	fairly easy

Table 3. Review of source separation methods.

Table 3 is not meant to be used as a decision tool, but it can help to develop an idea of what is required to obtain more accuracy than by using default values. It also shows that methods are equivalent in some aspects, and different in others. It must be noted that the table reflects the state of development of these methods by 2002/2003. Some of these methods are being improved continuously, for example during the IMAGINE project [3].

3 CONCLUSIONS

It has been shown that there is a large degree of similarity between the railway noise parameters needed for the Interim Model (RMR) and for the Harmonoise source model. The only difference is that the transfer functions (H_{tr} and H_{veh}) are defined in a slightly different way. This difference, however, does not necessarily have impact on the measurement set-up, as it can be dealt with in post-processing.

Furthermore, it has been explained that Procedure B of the RMR measurement guideline will probably be the only option for many Member States, as their rolling stock and their track system will probably be too different from the Dutch situation. Procedure B, which produces new rolling stock categories, requires much more measurement and analysis effort than Procedure A.

However, the measurement set-up of Procedure B is one of the alternatives that Harmonoise offers. In view of these considerations, it will be worthwhile for Member States that (have to) adopt the RMR model, to consider the Harmonoise alternatives for the measurement set-up. The advantages are obvious:

- Some of the four alternatives may be more appropriate (quicker to arrange, less expensive) than Procedure B
- If Harmonoise becomes the prescribed method in the EC, these Member States are ready

It can be questioned whether it is legitimate to use one of the Harmonoise alternatives, that has no official status yet. It should then be realised that there is a good scientific basis in the STAIRRS project where the three measurement methods and the calculation method have been tested and compared. The alternatives are equivalent, or better, in their output quality.

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