Practical approach to EU Interim Railway Noise Modeling Method Adaptation

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ABSTRACT
This paper presents results of empirical approach to interim EU railway noise modeling method adaptation on Latvian Railway within the framework of “Innovative solutions for railway noise management” (LIFE11 ENV/LV/376 ISRNM) project under the EU supported LIFE+ program. Results of empirical investigation of railway noise on Latvian railway had shown that the real life train pass by noise levels can exceed those modelled with RMR method by up to 20 dB(A), pointing out on necessity of RMR methods adaptation to local railway conditions. Rolling noise, impact noise and traction noise of trains operated on Latvian Railway as well as rail roughness was evaluated and new train types for modeling with RMR method were defined. Developed open source simplified software for train pass by noise modeling with RMR method and integrated railway noise and vibration measurement system can be used to simplify RMR method adaptation to conditions of any other railway.

Keywords: Railway noise, Modeling, Adaptation

1. INTRODUCTION

Recently, the new European Directive 2015/996, published the 1st of July, replaces the Annex II of the Directive 2002/49/EC. The directive defines the new common noise assessment methods that should be used in each Member State from 31/12/2018 for each kind of noise sources (road, rail, aircraft, helicopter etc.)

Though, still the interim EU railway noise modeling method RMR (1) is recommended for the use in countries which lack their national modeling method, such as Latvia, Baltic states and some other EU member states.

Results of previous empirical investigation of railway noise on Latvian railway had shown that the real life train pass by noise levels can exceed those modelled with RMR method by up to 20 dB(A), pointing out on the necessity of RMR methods adaptation to local railway network conditions. (2)

In 2012 Latvian Railway initiated the project “Innovative solutions for railway noise management” (LIFE11 ENV/LV/376 ISRNM) under the EU supported LIFE+ program addressing the problem of interim railway noise modelling method adaptation along with development of innovative trackside noise barrier made from environmentally friendly composite materials.

This paper presents ISRNM project results related to RMR method adaptation.

2. DESCRIPTION OF ADAPTATION APPROACH

2.1 Adaptation methods

RMR method description (5) contains three methods for adaptation to local railway conditions:

- A – simplified method to assign new vehicle to existing category
- B – method to define a new rail vehicle category
- C – method to define new track type

The easiest and fastest way is to assign existing train types to the already defined in RMR method, based on propulsion type, vehicle type, brake system type, etc. However, this can only be done if it was proved that pass by noise levels are similar to those of Dutch trains. In order to verify that, simplified single channel measurements of equivalent pass by noise levels (spectra) can be done. If the pass by

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noise spectra levels in all octave bands found to be lower compared to those modeled by RMR method, train type can be assigned to the existing category.

Measurements of pass by noise spectrums of all train types operating on Latvian railway were performed. Of the most importance was the investigation of rolling noise for all train types on railway track with jointless rails, however, the traction noise, braking noise and impact noise was also additionally examined. It was discovered, that in case of all train types operating on Latvian Railway, actual pass by noise levels are higher compared to those modeled by RMR method. Measurement results are summarized in next section.

Since it was not possible to assign any of the operated on Latvian Railway train types to the defined in RMR train type categories, additional measurements were performed following method B. A dedicated measurement and measurement result postprocessing system was developed based on data acquisition hardware and software from Labview, providing useful practical tool for RMR method adaptation.

No new track types were defined using method C within the framework of this project.

2.2 Measurement system

Considerable effort has been spent at a European level to establish comprehensive methods for the experimental assessment of rolling noise emission of rail-bound vehicles and tracks. Big part of work was concentrated in the European METARAIL and STAIRRS projects. The objective of these was to improve the accuracy and the reproducibility of pass-by noise measurements compared to the standards that were current at that time. A further aim was to develop experimental methods separately to identify the contributions to rolling noise of the vehicles and the tracks (3).

In these projects, measurement methods were developed that could determine the combined wheel/rail roughness and the ‘transfer functions’ for the vehicle and the track, that is, the separate noise contributions per unit roughness. The roughness and transfer function spectra provide a powerful basis by which vehicles and tracks can be characterized by measurement, to a high extent, independent of the running speed and site conditions. Such a description of the track and rolling stock allows the prediction of rolling noise spectra for different combinations of vehicles and track from those at which the characteristics have been measured. The measurement effort is limited; only straightforward one-third octave band measurements of pass-by sound pressure and vertical railhead vibration are needed. (3)

Within the framework of this project different rolling noise source separation techniques were analyzed, but the pass-by method published by Janssens et al. (2006) was chosen as the most straightforward and technically less demanding. Moreover, this method was already applied by number of other researchers showing accurate and reproducible results.

In order to separate train and track rolling noise components following B – measurement method, integrated noise and vibration measurement system (further measurement system) was developed based on the data acquisition and postprocessing hardware and software from National Instruments.

Few software versions were prepared with two key functional differences: with and without real time data analysis. For all necessary data collection, it is enough to use version without real time analysis and then to use post analysis application. This allows so save machine time and secures more stable operation. Real time analysis was further development of the system in order to allow real time monitoring of the train pass by noise and vibration, which can be used as an alarm system in case if any train or any dedicated wheelpair is causing too high noise or/and vibration levels. Such a system can be used for continuous monitoring and keeping noise levels under allowed limits as well as for train condition based service planning.

Data acquisition system operates under following algorithm: measurement is triggered when the first wheelset crosses the first optical sensor (connected to NI module with digital inputs) and is stopped when the optical sensor has not been crossed by the wheel for five seconds (may be adjusted). During the measurement, raw data from all sensors except the one optical used for triggering measurements is being logged. Raw data then either in real time either during postprocessing is used for all calculations. Such approach gives advantages over standardized measurement systems, where real-time processing is performed based on the presets, so later postprocessing is usually limited. Using raw data in LabView, it is possible to perform all main analysis, including third octave band and octave band spectra analysis, FFT, weighting as well as transform raw data to wav (audible) file, perform different custom math calculations, build graphs, etc.

Main measurement system interface (data logging version) is shown in Figure 1. It has basically
start/stop functions only and calibration function to provide reliable measurement results. The graph shows measured raw data just for indicative purposes (to make sure that system is alive and operational).

![Figure 1 - Measurement system interface (data logging version)](image1)

In real time processing version, it is possible to see third octave band and octave band spectra of the noise and vibration signal, as well as indication of optical sensor signals and the train speed.

Main functionality is provided by the post processing LabView virtual instrument (application), which allows to display all measurements in a convenient way along with octave and third octave band analysis, A-weighting, audible event listening and calculations following B-method.

In Figure 2 is shown main view of the measurement result postprocessing application.

![Figure 2 - Measurement result postprocessing application, main view](image2)

### Parameters tab
First, the measurement log file in *.tdms format is selected and loaded.

There is possibility to apply or not to apply A-weighting for the sound measurement results. Vibration measurement results remain unweighted.

Measurement system has two channels for sound and two channels for vibration measurements. It is possible to select which sound and vibration measurement channels will be used for calculations following B-method.

From the log file the following information is displayed: measurement date, measurement time, pass-by time and number of wheel sets in the train.

To calculate the train speed, two wheelsets of one bogie are selected (in this case wheelset 3 and 4) and the train type, in this case – electric train. Next version of the measurement system will automatically detect vehicle type and speed.

For calculations following B-method, four wheelsets are selected, in this case – wheelsets 3, 4, 5 and 6.

After the measurement log file was loaded in the application, audible event wav file is created and stored. It can be listened either in the application directly in audio tab, or opened separately with any wav file player.

In the main tab, the unprocessed measurement results can be displayed from all sensors. Signal levels and different microphones and accelerometers can be visually compared as well as registered at the measurement point moments of wheel set pass-bys can be displayed to simplify the selection of wheelsets used for calculations.
Other tabs provide other measurement results following B-method, where main are:
- rail vertical vibration spatial decay, Figure 3;
- combined effective roughness, Figure 4;
- total transfer function, Figure 5.

Figure 3 - Measurement result postprocessing application, Spatial Decay tab

Figure 4 - Measurement result postprocessing application, Combined roughness tab

In the tab Rail Roughness, the measured rail roughness can be inputted and then the wheel roughness is calculated as energetic difference of combined and rail roughness and is displayed in Wheel Roughness tab.

Figure 5 - Measurement result postprocessing application, Total Transfer Function tab

Figure 6 - Measurement result postprocessing application, By Frequency (TOS) tab
In *By Frequency (TOS) and (FOS) tabs*, Figure 6, are correspondingly displayed third octave band and octave band measurement results of sound and vibration in time and frequency domains (frequencies to be displayed can be selected).

In *Equivalent Spectra* tab, Figure 7, equivalent spectra for the whole train pass by are displayed for all measurement channels in order to verify whether there is any considerable difference in sound and vibration radiation levels between two sides of the track. In the *Help tab*, basic help notes are provided.

![Figure 7 - Measurement result postprocessing application, Equivalent Spectra tab](image1)

The measurement system was first tested in laboratory conditions, Figure 8, however later it was modified and upgraded few times after testing in the field.

![Figure 8 - Measurement system testing in laboratory](image2)

Installation of the measurement system in the field is shown in Figure 9: vibration measurement of two rails of one track, sound measurements at both sides. Additionally, standardized sound meter for reference at one sound measurement point and two standardized sound meters close to the rail at different heights for traction noise source height estimation. By adding two more optical sensors to the measurement system it will be possible to perform measurements at both tracks simultaneously (one vibration and sound measurement point by track).

NI data acquisition system offers modular design for cost effective system sizing and measurement system can be easily upgraded for simultaneous measurements at multiple tracks / rails / crossections.
3. MEASUREMENT RESULTS

3.1 Rail roughness measurement results
Within this project the first rail roughness measurements were performed on Latvian railway using direct method and laser roughness measuring device Salamander, produced by Meas Prog. Measurements were performed on two tracks and both rails. Measured area consisted from 16 linked measured sections with length over 10.3 m. Each section was measured in the middle of rolling surface mirror. Joints (all joints were welded and visually hardly noticeable) were not excluded to obtain continual roughness diagram along whole testing area. Rail head had clean surface. Corrosion of rail mirror was not visible. Track had some local defects, Figure 10. Roughness of each section was evaluated and spectra for each section were estimated. Average roughness spectra for each rail were calculated. Roughness for all rails was compared at one diagram, Figure 11. One segment was measured 2 times and results compared for device repeatability test. One segment was measured in the morning and in the evening and results compared for track surface stability test. Averaged over all rails roughness spectrum is below TSI limits defined by EN15610. Only several individual segments and only in one third octave bands were over TSI limits.

Figure 10 – Local rail surface defects

![Figure 10](image1.png)

Figure 11 - Roughness measurement results both tracks and TSI limiting line

![Figure 11](image2.png)

3.2 B – method measurement results for rolling noise
Using measurement system described in previous subsection a number of measurements were performed for all train types operational on Latvian railway. Unfortunately, nor the reference train, nor the reference track were available during this project to separate the transfer functions of train and track using the B – measurement method, therefore only total transfer functions were estimated and during RMR adaptation the original distribution of noise radiation between track and train is kept. Measurement results had shown that wheel roughness estimated following B – measurement method is dominant over rail roughness for every train type. Directly measured rail roughness levels at measurement site, Figure 11, are below ISO limiting levels and below average for Dutch Railway used in RMR, therefore defined in RMR levels can be used, unless it will be proved by more measurements on Latvian railway, that corrections are essential.
**Electric trains**

In Figure 12 is shown equivalent pass by noise spectrum of electric train at the speed of 84 km/h.

![Figure 12 - Equivalent electric train pass by noise spectrum, 84 km/h](image1)

In Figure 13 are shown roughness levels in frequency domain. Rail roughness levels out of the range of measurements where extrapolated. It can be seen, that wheel roughness levels are dominant in whole frequency (wavelength) range.

In Figure 14 is shown total transfer function, estimated following B – measurement method.

![Figure 13 - Roughness levels in frequency domain, dB re 1μm. Electric train, 84 km/h](image2)

![Figure 14 - Total transfer function of rail vibration to sound pressure for electric train at the speed of 84 km/h](image3)
Passenger trains

In Figure 15 is shown equivalent pass by noise spectrum of passenger train at the speed of 86 km/h.

Figure 15 - Equivalent diesel passenger train pass by noise spectrum, 86 km/h

In Figure 16 are shown roughness levels in frequency domain. Rail roughness levels out of the range of measurements where extrapolated. It can be seen, that wheel roughness levels are dominant in whole frequency (wavelength) range.

Figure 16 - Roughness levels in frequency domain, dB re 1μm. Passenger train, 86 km/h
  blue – combined effective roughness estimated from pass by rail vibration measurements;
  red – measured using direct method rail roughness levels;
  green – calculated wheel roughness

In Figure 17 is shown total transfer function, estimated following B – measurement method. Levels are lower compared to Electric train transfer function.

Figure 17 - Total transfer function of rail vibration to sound pressure for passenger train at the speed of 86 km/h
**Freight trains**

In Figure 18 is shown equivalent pass by noise spectrum of freight train at the speed of 42 km/h.

![Figure 18](image1.png)

**Figure 18 - Equivalent freight train pass by noise spectrum, 42 km/h**

In Figure 19 are shown roughness levels in frequency domain. Rail roughness levels out of the range of measurements where extrapolated. It can be seen, that wheel roughness levels are dominant in whole frequency (wavelength) range, except 6300 Hz, where levels are comparable.

![Figure 19](image2.png)

**Figure 19 - Roughness levels in frequency domain, dB re 1μm. freight train, 42 km/h**

In Figure 20 is shown total transfer function, estimated following B - measurement method. Levels are considerably higher compared to Electric and Passenger train transfer functions.

![Figure 20](image3.png)

**Figure 20 - Total transfer function of rail vibration to sound pressure for freight train at the speed of 42 km/h**
3.3 **Traction, braking, impact and curve squeal noise**

**Traction noise**

Locomotive and electric train traction noise was evaluated from the pass by noise measurements. An example of the diesel passenger A-weighted total pass by noise levels with well visible locomotive traction noise is shown in Figure 21. Locomotive traction noise is dominant noise source in the frequency range up to 1600 Hz, except the 630 Hz and 800 Hz third octave bands. Based on measurements at different heights, it was approved that the 0.5 m above rail surface level is the correct height for diesel locomotive traction noise source.

![Figure 21 - Total A-weighted pass by noise levels of diesel passenger train](image1)

Freight train locomotive traction noise levels are dominant in the frequency range up to 1250 Hz. Locomotive idling noise can also be important noise source especially at the areas close to shunting yards. In Figure 22 is shown locomotive idling noise measured at the distance of 7.5 m from the track central line and at the height of 1.2 m above the rail surface. Highest levels are observed at 630 Hz, 800 Hz, 1000 Hz and 1250 Hz bands.

![Figure 22 - Third octave band locomotive idling noise levels](image2)

Electric train traction noise when present is dominant at 1000 Hz, 1250 Hz and 1600 Hz third octave bands (third octave band center frequencies).

**Braking noise**

The braking noise was measured for electric passenger trains stopping at the train station. It was discovered, that the occurrence of high level tonal squeal noise is strongly dependent on the braking intensity. It is possible to stop the train without any noticeable increase in the noise levels if low braking force is applied in a due time. Though, in case of “unsuccessful” braking the high level tonal braking squeal noise is seen in the 8 kHz octave band and sometimes even in the 16 kHz octave band, increasing the total noise level by about 10 dB(A). For Latvian railway rolling stock the dominating braking noise frequency found to be higher than 4 kHz as in case with standard European rolling stock.

**Impact noise**

Measurements of impact noise were made at three points along single track at 7.5 m distance from the track central line and 1.2 m height above the rail surface. Measurement point 1 was selected in front of jointless segment of the track, measurement point 2 was selected in front of rail joint with 10 mm wide gap and measurement point 3 was selected in front of rail joint with 16 mm wide gap. It can be seen that the joints cause about 10 dB(A) pulsed noise level increase due to impact noise, Figure 23. Impact noise causes noise level increase in whole frequency range with total equivalent A-weighted pass by noise level increased by about 3 dB(A). Similar situation is with diesel passenger and freight trains.
The curve squeal noise is hardly predictable noise source which appears at track turns with relatively small radius, hence is generally considered as unimportant noise source. Though, at some places this noise type being high frequency (4000 Hz – 5000 Hz) and highly tonal can cause considerable disturbance. An example of curve squeal noise which appeared during electric train pass by at the speed of 55 km/h is shown in Figure 24. Measurements were made at 7.5 m distance from the track central line and 1.2 m height above the rail surface.

4. ADAPTATION OF RMR METHOD

Comparable analysis of measurement and modeling results had shown that application of the RMR method for railway noise modeling on Latvian railway without appropriate improvement will result in significant underestimation of pass by noise levels in all octave bands of all train type categories and in any conditions.

Here, the improvement means the definition of new radiation index and correction coefficient tables for new train types and tracks. Unfortunately, nor the reference track, nor the reference train was available during this project to separate the transfer functions of train and track using the B – measurement method, therefore new parameters to be used in RMR for Latvian tracks and trains were defined statistically using statistically averaged A – method measurement results.

Unfortunately, none of the currently available on the market noise mapping software packages known by author offers user the possibility of new train and track definition for RMR method. To define new train and track categories for Latvian railway, the software, hereafter regarded as Train Noise Software (TNS) for train pass by noise spectrum calculation in the point of reception using RMR method was developed (in C#).

The application has a simple and user friendly interface with three main options: noise spectra calculation in the point of reception, Figure 25; radiation spectra calculation and noise level speed dependency visualization in all octave bands. Calculations are based on input data defined in RMR:
train type, train speed, number of passing trains per hour, braking or non-braking operation, track type and rail disconnection class. All radiation indexes, correction coefficients and other required data is stored in the excel table where the application takes it from. The used data can be viewed within the application. If any data should be changed or added it can be done easily updating the excel table.

Using TNS five new train type categories were defined for modeling with RMR in Latvian railway conditions, Table 1.

<table>
<thead>
<tr>
<th>RMR Train category c</th>
<th>Radiation index</th>
<th>Octave band center frequency, Hz and number i</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a 29 80 95 72 49 50 52 43</td>
<td>63 125 250 500 1000 2000 4000 8000</td>
</tr>
<tr>
<td>4 (mixed)</td>
<td>a 88 98 97 93 94 80 76 90</td>
<td>b 0 0 7 10 10 17 17 6</td>
</tr>
<tr>
<td>4 (tanks)</td>
<td>a 90 100 98 94 95 81 77 91</td>
<td>b 0 0 7 10 10 17 17 6</td>
</tr>
<tr>
<td>4 (wagons)</td>
<td>a 83 99 87 79 80 61 55 62</td>
<td>b 0 0 12 17 17 27 27 19</td>
</tr>
<tr>
<td>6</td>
<td>a 66 80 87 53 43 40 21 15</td>
<td>b 0 0 0 22 30 30 38 36</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

Based on measurement results, five new train types were defined for more accurate application of RMR method in Latvian railway conditions. Developed open source simplified software for train pass by noise modeling with RMR method and integrated railway noise and vibration measurement system can be used to simplify RMR method adaptation to conditions of any other railway.

The new European Directive 2015/996, published the 1st of July, replaces the Annex II of the Directive 2002/49/EC and defines the new common noise assessment methods that should be used in each Member State from 31/12/2018 for each kind of noise sources (road, rail, aircraft, helicopter etc.).

Results of recent project provide valuable input in update of the data base with required parameters for CNOSSOS application on Latvian railway, but more detailed research is still required, i.e. separation of track / wheel and bogie / superstructure transfer functions; more measurements of rail and wheel roughness, more statistics on impact and curve squeal noise, braking noise. Availability of reference train and possibility to perform measurement in controlled conditions is essential.

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