forum acusticum 2023

VR DEMONSTRATION OF RAILWAY NOISE MITIGATION USING AURALISED TRAIN PASS-BYS

Reto Pieren[1*] **Fotis Georgiou**[1] **Giacomo Squicciarini**[2]
Kurt Heutschi[1] **David J. Thompson**[2]
[1] Empa, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland
[2] ISVR, University of Southampton, Southampton, UK

ABSTRACT

In the European project SILVARSTAR, a new tool for the demonstration of railway noise mitigation measures was developed. The tool allows for an interactive, immersive audio-visual experience of different train pass-by scenarios. Different train types, speeds and tracks can be simulated within different virtual environments. The user can activate a set of mitigation measures and switch in real time between variants. The tool offers nine different mitigation measures, such as barriers, dampers, acoustic rail grinding, and as well as their combinations. The train pass-by sounds are auralised using physics-based synthesis. For rolling noise, structural transfer functions for the sleepers, the rails and the wheelsets are predicted using the TWINS model. The track contributions are modelled as a combination of distributed fixed and moving equivalent sources, whereas each wheelset is represented by a series of vertically stacked moving point sources. The pass-by sound synthesis was validated by comparisons with field measurements. At public international exhibitions, the VR system consisting of the newly developed auralisation and VR software, and commercial VR hardware has been attested to have high credibility and quality.

Keywords: *Railway noise, Auralisation, VR*

**Corresponding author*: *reto.pieren@empa.ch.*

1. INTRODUCTION

To mitigate railway noise, various partially complementary and competing measures exist. Scenarios comprising such measures are typically assessed and communicated using dB values. Auralisation and VR are increasingly used for the assessment and communication of environmental noise scenarios and thus may support decision making. However, since previous auralisation and VR applications to railway noise have consisted of prototype or research tools (e.g. [1]), these methods are not yet broadly applied in the railway sector.

To enable a wider uptake of auralisation and VR for railway noise, new software tools for the demonstration of railway noise mitigation measures were developed within the European project SILVARSTAR. The newly developed VR tool allows for an interactive, immersive audio-visual experience of different train pass-by scenarios. A preliminary version of the proposed system was presented in [2]; this paper gives an overview of the final system. The processing is done in two stages, involving two software tools. First the train pass-bys are synthesized to generate the auralisation signals and then these are input to the VR system. These tools are described in Sections 2 and 3, respectively.

2. SYNTHESIS OF TRAIN PASS-BYS

2.1 Model extensions

The sound synthesis model used in the VR demonstrator is based on previous work by the authors [1–4]. Substantial improvements to the modular simulation were made to increase the applicability of the model by making it more versatile and more closely representing the physics. This allows it to realise the broad range scenarios defined in

Section 3.1. The development work in SILVARSTAR focused on a physics-based modelling of different combined mitigation measures for various track and train types.

The updated rolling noise synthesis model considers five structural transmission paths, two for the wheels and three for the track, based on TWINS calculations [4]. This distinction allows for instance the inclusion of rail shields using recent data from [5] or rail dampers with the STARDAMP approach [6]. The required wheel modes are predicted by FEM from the wheel geometry. The rolling damping was found to be relevant for auralisation and is here estimated with a semi-empirical approach considering also the increased damping provided by possible wheel dampers or wheel-mounted disc brakes. Wheel flats are modelled based on the equivalent roughness approach developed in [7] considering occasional loss of wheel-rail contact at high speeds. Further, source-specific directivities and shielding of the wheels by the train body are applied. The spatial extents of the rails and the wheel sources are taken into account, as an extension to the approach used in [3], improving the temporal behaviour of the rail contributions and the spectral representation of the wheel contributions.

The updated sound propagation model considers the combination of ground reflection and edge diffraction to account for a track embankment, different ground types [8] and shielding by different noise barriers [9].

Finally, as an interface to the VR application which performs the real-time dynamic binaural rendering, a compact multichannel audio format was defined. A compromise between accuracy and computational costs was found in a channel-based format with a total of seven channels, referred to as the *VR audio* export option, besides mono, stereo and Ambisonics.

2.2 Calculation concept

The auralisation follows the source–path–receiver concept where sound generation and sound propagation are separately represented [10]. The partial sound pressure time signal p at observer time t used as calibrated speaker feed for spatial sound reproduction is computed by

$$p_l(t) = \sum_m g^t_{l,m}(t) * \sum_n s_m(t') * h^{t'}_{m,n}(t') \qquad (1)$$

with the linear convolution operator $*$, time-variant reproduction and propagation filters g and h, respectively, a source signal s with source time t', and the indices m, n and l for the sources, propagation paths and reproduction channels, respectively.

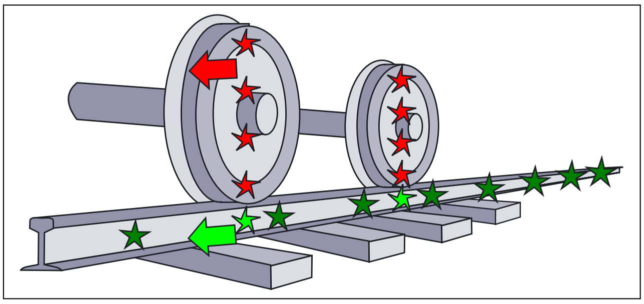

Figure 1. Distributed point sources for rolling noise synthesis with stacked moving sources for each wheelset (red), moving track sources below each wheel-rail contact (light green) and fixed track sources (dark green).

For rolling noise, the sound powers are first predicted for a unit roughness using the TWINS model [12]. Next, time domain filters are iteratively designed to match these transfer functions while reproducing the narrowband modal behaviour of the wheels and ensuring an incoherent summation of sources by randomising phase relations. Moreover, a new equivalent sources model was established. This hybrid model consists of a combination of fixed and moving point sources as illustrated in Fig. 1. The rolling noise synthesis model is illustrated by a signal flow chart in Fig. 2. For each wheelset, a time signal for the effective roughness velocity is synthesised which is processed by five transfer path filters. The contributions from the track are attributed to the moving track sources for frequencies at which and the track decay rate is high, whereas for low decay rates they are attributed to the fixed track sources. This allows the distributed nature of the rail source to be included.

The propagation filters h in Eq. (1) replicate the sound propagation effects, i.e. geometrical spreading, Doppler effect, ground reflections, edge diffraction in case of a noise barrier [9] and air absorption [13]. Meteorological propagation effects are not considered.

2.3 Validation

For model validation purposes, synthesized sound pressure signals were compared to measurements for a set of pass-bys where sufficient information about the measured situation was available, such as rail and wheel roughness

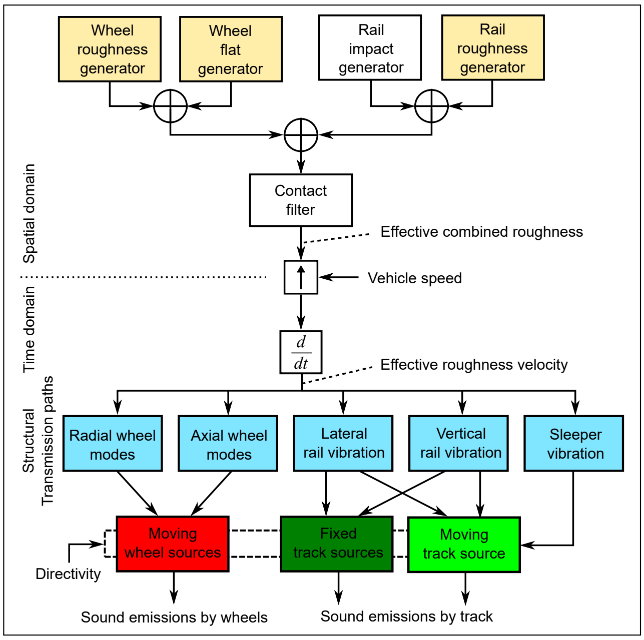

Figure 2. Signal flow chart of the rolling noise source synthesis model for one wheelset.

spectra, wheel geometries and track decay rates (TDRs). Fig. 3 shows sound level time histories of an electric multiple unit train at two speeds for two receiver distances of 7.5 and 25 m. The sound level variations with time, including the ripples during the passage for the close observer, are very well reproduced by the synthesis, in addition to the overall 1/3 octave band spectrum shown in Fig. 4.

3. VR DEMONSTRATOR

The developed VR noise demonstrator allows for an interactive, immersive audio-visual experience of virtual train pass-bys. An intuitive demonstration of railway noise mitigation measures is achieved by reproducing simulations to a user wearing a VR headset and headphones. For the hardware, state-of-the-art commercial VR equipment is used, whereas the software tools were created within the research project.

A pair of Sennheiser HD650 headphones and a head-mounted display (HMD) of the type Meta Quest 2 (with integrated head-tracking) wired to a modern graphics processing unit (NVIDIA GeForce RTX 2080 or higher) is used. During the virtual train pass-by, the user can instantly switch between different scenarios using hand-held motion controllers, by pushing either real or virtual buttons, to experience and directly compare different possible mitigation solutions.

The demonstrator runs with a stand-alone VR application developed with the game engine Unity 3D. The *SILVARSTAR VR Tool* renders an animated 3D visual environment reproduced stereoscopically via the HMD. Corresponding dynamically rendered binaural sound is reproduced over the calibrated and equalised headphones. The application has a GUI allowing the operator to guide the user through different virtual scenes. The scenes and their presentation sequence can be configured to create a storyline. The corresponding required VR-ready multichannel audio files are pre-calculated with the *SILVARSTAR Auralisation Tool*. Both software tools are available on `www.empa.ch/web/silvarstar`.

The VR demonstrator has been presented to the public at international exhibitions, including the Transport Research Arena (TRA) 2022 in Lisbon and the International Trade Fair for Transport Technology (InnoTrans) 2022 in Berlin (see Fig. 5). The demonstration was attested to have high credibility and quality, and will likely be further used.

3.1 Scenarios

Table 1. Input parameters related to vehicles and their operation.

Parameter	Values
Train type	Regional, Intercity, Freight
Train length	Short, Long
Speed	80–200 km/h for passenger 60–100 km/h for freight
Driving direction	RL, LR
Used track	Close, Far
Start position	50–200 m

In contrast to a previous prototype demonstrator [1], with the presented system a large variety of different scenarios can be created by the user. A scenario is characterised by a list of input parameters describing an outdoor train pass-by situation. Different types of rolling stock, operation, tracks, environments and observer loca-

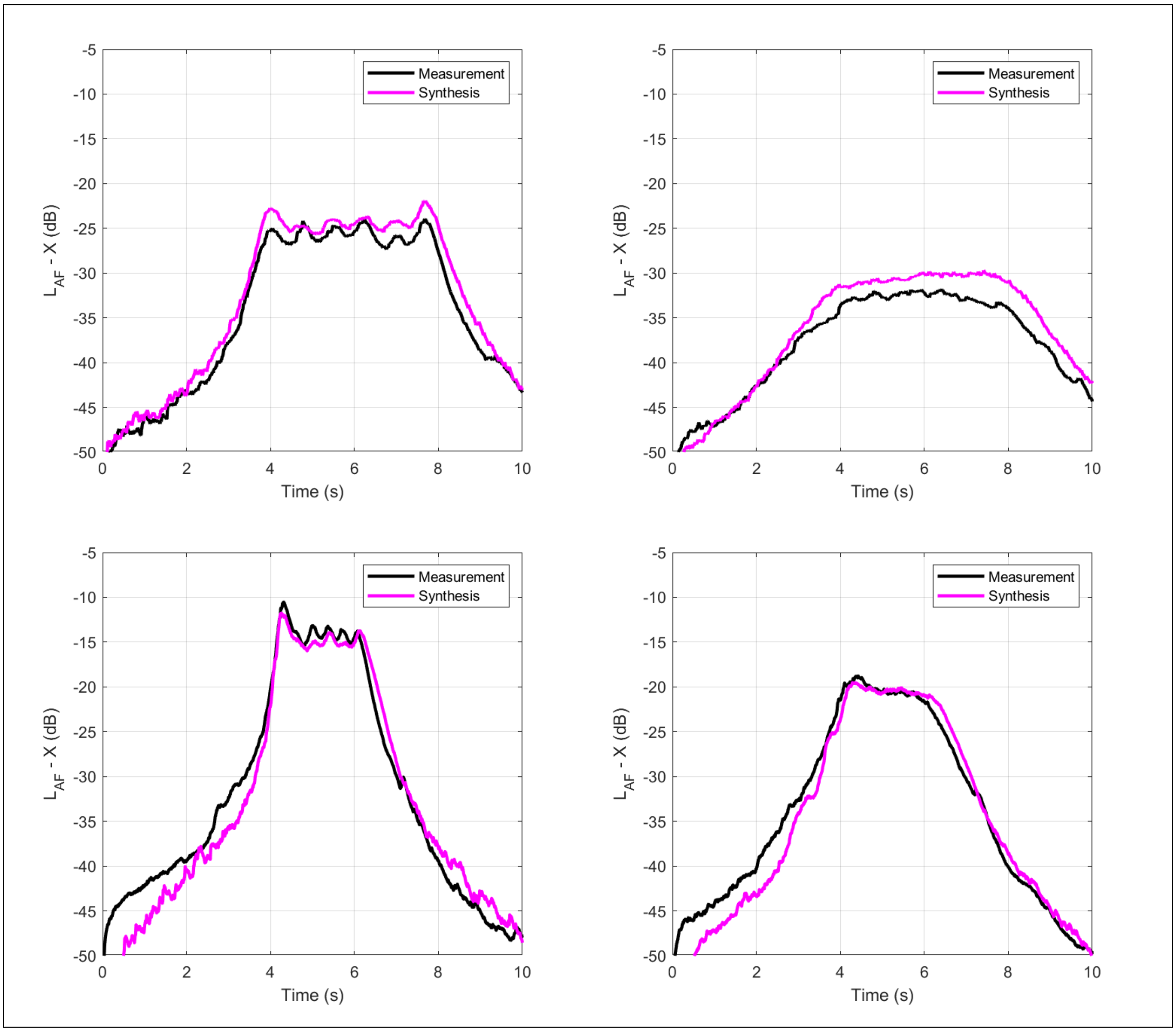

Figure 3. Measured and simulated A-weighted FAST-time weighted level time histories of an electric multiple unit train with 80 km/h (top) and 160 km/h (bottom) on a ballasted track at the position 'A' (left) and 'C' (right) according to ISO 3095 [11]. The levels are shifted by an arbitrary value X for confidentiality reasons.

tions can be chosen, as well as different noise mitigation measures. A total of six different trains, seven tracks and ten mitigation measures can be selected. Some continuous parameters such as the travelling speed, the observer distance, or the barrier height can be selected within a given value range—offering a very large number of possible scenarios.

Figure 6 illustrates the geometrical situation of the railway. It is based on a double track which is assumed to be translation-invariant along the track. Input parameters related to the train and its operation are listed in Tab. 1. Three different train types (Regional, Inter city, Freight) are considered, each in two lengths. The travelling speed can be selected within a given range of 80–200 km/h for the passenger, and 60–100 km/h for the freight trains. The track used, the driving direction and the starting position

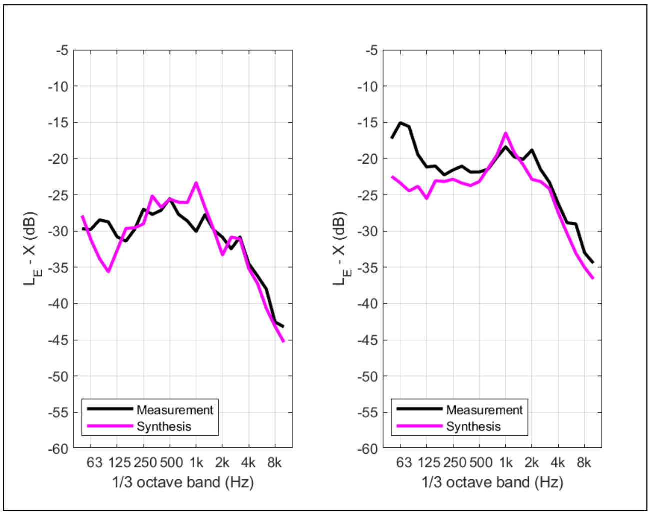

Figure 4. Measured and simulated sound exposure spectra of the two pass-bys from Fig. 3 (left column). The levels are shifted by an arbitrary value X for confidentiality reasons.

Figure 5. Live demonstration of the new SILVARSTAR auralisation and VR tools at InnoTrans 2022 in Berlin at the Europe's Rail exhibition booth, with the EU Directorate-General for Mobility and Transport Henrik Hololei using the VR system (photo provided by Europe's Rail).

along the track can be chosen.

Input parameters related to the track, the environment and the observer are listed in Tab. 2. The user can select a slab track or a ballasted track. For the latter, monoblock or biblock concrete sleepers and three classes of rail pads with different stiffness can be selected. The track can be situated at-level or on an embankment, and either in a rural or urban environment. The observer is at a fixed location and outdoors. The horizontal distance from the observer to the centre of the nearest track is limited to 7.5–50 m, due to source and propagation model assumptions. The observer is either standing on the ground or at an elevated position on a balcony, with the ear level being between 1.65 and 10 m above the terrain.

Tab. 3 lists the input parameters related to the nine mitigation measures considered. Four of them are related to the vehicles, and five to the track. Seven measures mainly affect rolling noise. The first three measures are related to the roughness excitation: i) Acoustic rail grinding can be simulated by setting the rail roughness to 'Smooth'. ii) The freight train wagons can be partially or fully retrofitted by composite K brake blocks. iii) Wheel flats with an occurrence of 2% of the wheelsets can be included or omitted. Further, the wheels and the rails can separately or both be equipped with dampers. In place of rail dampers, rail shields can be activated.

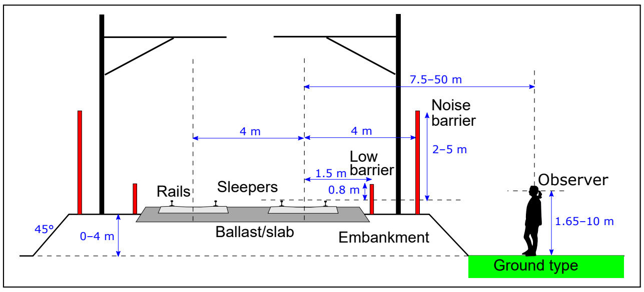

Figure 6. Sketch illustrating the double track geometry in a vertical cross-section.

Secondary sources such as equipment, traction and aerodynamic noise sources can globally be attenuated. Finally, either low height barriers with fixed geometry, or a conventional sound-absorbing noise barrier of selectable height can be enabled.

3.2 Calculation times

Using the *SILVARSTAR Auralisation Tool*, the sound synthesis of one train pass-by takes between five minutes and three hours of computation on a modern PC (Intel Core i9-12900KS), depending on the train length, the train speed and its start position along the track. The binaural sound and the visualisation is rendered with the *SILVARSTAR*

Table 2. Input parameters related to track, environment and observer.

Parameter	Values
Track type	Ballasted, Slab
Sleeper type	Monoblock, Biblock
Rail pad type	Soft, Medium, Hard
Embankment height	0–4 m
Environment	Rural, Urban
Observer distance	7.5–50 m
Observer height	1.65–10 m

Table 3. Input parameters related to mitigation measures.

Parameter	Values
Rail roughness	Poor, Medium, Smooth
Freight wagon brake block CI to K rate	0, 50, 100 %
Wheel flats	Yes, No
Wheel dampers	No, Yes
Rail treatment	No, Dampers, Shields
Attenuation of secondary sources	0–99 dB
Barrier type	No, Standard, Low
Barrier height	2–5 m

VR Tool in real-time on a modern VR-ready PC (with a NVIDIA GeForce RTX 3090 Ti).

4. CONCLUSIONS

New software tools for the demonstration of railway noise mitigation measures have been developed. The presented VR system allows for an interactive, immersive audio-visual experience of different train pass-by scenarios where different train types, speeds and tracks can be simulated within different virtual environments. The user can activate a set of mitigation measures and switch in real time between precomputed variants. The simulation offers nine different mitigation measures, such as barriers, dampers, acoustic rail grinding, and as well as their combinations. At public international exhibitions, the VR system consisting of the newly developed auralisation and VR software, and commercial VR hardware was attested to have high credibility and quality. The newly developed software is made available to the railway industry and academia.

The new tools will open up new possibilities in understanding or assessing noise control measures and will be applied in further public demonstrations, psychoacoustic studies and in the communication to decision-makers and residents of existing or future railway lines. Future developments could aim at extending the modelling capabilities towards more complex scenarios, such as curves, bridges, rail joints, accelerating vehicles, uneven terrain or buildings, as well as speeding up the calculations.

5. FUNDING

The work presented in this paper has received funding from the Europe's Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 101015442). The contents of this publication only reflect the authors' views; the Joint Undertaking is not responsible for any use that may be made of the information contained in the paper.

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