sonRAIL - the new Swiss railway noise calculation model

1 Introduction

sonRAIL is the new Swiss calculation model for railway noise. It is designed to set new standards in the accuracy of the prognosis of sound immission. The sound propagation model as well as the emission model are aiming at simulating the physical processes of sound generation and propagation. Therefore they not only allow a reproduction of current situations but also a prognosis of the effects of different mitigation measures. sonRAIL was funded by the Swiss federal office for the environment FOEN. The project was accomplished in three years, from 2007 until 2009. It was conducted by an interdisciplinary project team composed of several enterprises and institutions:

- Empa, Swiss Federal Laboratories for Material Testing and Research, Laboratory of Acoustics: Development and programming of the sound propagation model, participation in the measurement campaign.
- Technical University of Berlin, dept. of rail vehicles: Development of the sound emission model, participation in the measurement campaign.
- PROSE AG, measuring and testing: Organization of and participation in the measurement campaign.
- LCC Consulting: Programming of the Graphical User Interface, the emission model and the database application.
- SISE – Swiss Institute for Systems Engineering: Support of the project management.
- IFV BAHNTECHNIK e.V.: Public relations and supporting services (Internet, Intranet).
- Sulzer Innotec: Microphone array measurements and source identification, participation in the measurement campaign.
- PSIA Austria: Participation in the measurement campaign.

2 Emission model

The calculation model of sonRAIL is composed of an emission model that describes the generation of railway sound and a propagation model. Both are defined in one-third-octave bands from 100 Hz to 8 kHz. The emission model yields sound power levels for five predefined source heights along the vehicle surface for each vehicle in dependence of infrastructure and operation conditions. Track sections with constant properties, i.e. track superstructure, travelling speed, traffic volume and composition, are combined to line sources that can be described by their total sound power.

The emission model describes rolling noise as the primary sound source based on roughness spectra of wheel and rail. First an effective roughness spectrum is derived using a contact patch filter that takes into account the contact area of wheel and rail. In combination with train speed and type-dependent transfer-

functions for wheel and track the total rolling noise can then be calculated. Special solutions are implemented for switches, several types of bridges and curved tracks.
For secondary sound sources such as traction noise, gear noise or aerodynamic noise sound power spectra have been gathered and are stored in database together with a speed dependency factor.

3 Measurement campaign

Extensive measurements have been performed with the goal of collecting model data for the majority of vehicles and track systems that are currently in use in Switzerland. Pass-by-measurements of totally 14'500 vehicles with train speeds ranging from 50 to 200 km/h were performed at 18 measurement sites. The situation at each measurement site was described by the decay rate, the local rail roughness and the local sound propagation conditions, determined with loudspeaker experiments. Pass-bys of trains were measured using sound pressure microphones at 4 positions and acceleration meters at each rail. At two measurement sites additionally a line array was used to gather information on secondary sound sources. Additionally two test trains were assembled for the purpose of this measurement campaign with known wheel roughnesses. Figure 1 shows one of the two test trains passing the line array and Figure 2 results of the microphone array.

Figure 1: Picture of one measurement site, showing the line array and a test train passing.

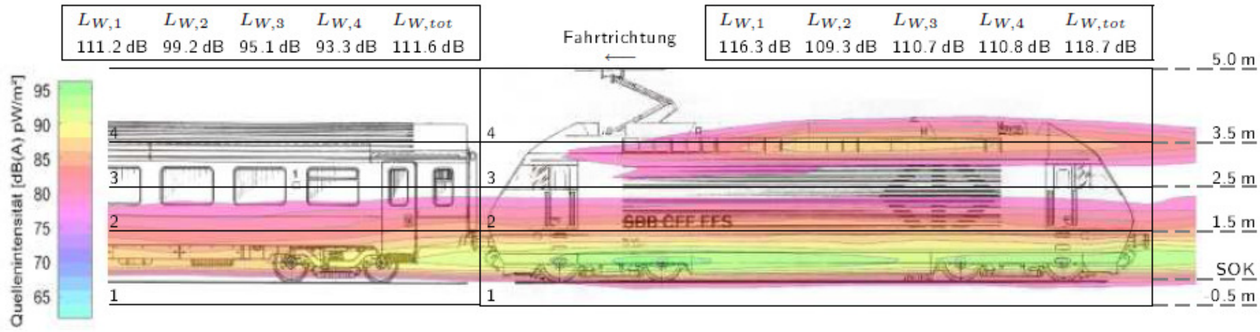

Figure 2: *Distribution of sound intensity in the one-third-octave-band of 1 kHz for a locomotive type Lok 2000 and a coach type EW IV at 100 km/h. On top the resulting sound power for four ranges of height is given.*

4 Propagation model

The propagation model is organized in four different modules that are operated independently from each other. The module 'Basic' is mandatory for each calculation as it performs a calculation of direct sound propagation under the assumption of a homogenous atmosphere. It basically represents an implementation of the ISO Standard 9613. The most important deviation from the standard concerns ground effect calculation. Ground reflections are calculated for spherical waves over flat and homogenous ground. The solution is extended to uneven terrain and varying ground properties using a Fresnel-zone-approach and accounts for the coherence loss between direct and reflected sound in dependence of frequency and propagation distance.

In the second module meteorological effects on sound propagation are accounted for. As additional input data vertical profiles of wind speed, temperature and humidity are used. While temperature and humidity influence air absorption, wind and temperature gradients with height in combination with a wind direction are used to derive effective sound speed profiles. Based on these sound speed profiles a ray tracing algorithm is applied to estimate changes in shielding effect and the evolution of acoustical shadow zones as a consequence of sound propagation along curved rays (see Figure 3).

The third and fourth module yield independent contributions, one for reflections at buildings, walls and other rigid surfaces and one for diffuse reflections at forest edges and cliffs. The model for reflections at buildings, walls and other rigid surfaces is designed for sound fields in urban environments. The calculation procedure is based on two analytical solutions of the reflection problem, one for coherent reflections (mirror-reflections) and one for scattering.

In principle sound propagation is independent of the type of sound source. Nevertheless there are phenomena that are specific for a certain source type. For railway noise this is for example the case for the ground effect close to the source that shows a distinct behaviour as a consequence of the specific properties of the ballast bed. Therefore an extended ground effect model is implemented for this situation. Also typical for railway noise are situations with hard surfaces in close vicinity of the vehicles that lead to additional reflections. This is for example the case for tunnel openings or railway line cuttings (see Figure 4). In order to reduce the calculation effort, these multiple reflections are not dealt with within the reflection module but are treated based on empirical formulas.

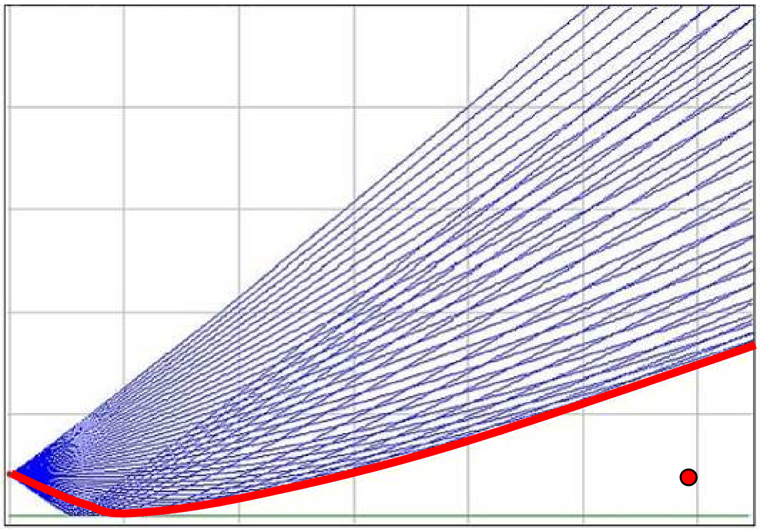

Figure 3: Meteorological effect in shadow zones. The ray that comes closest to the receiver is highlighted. Together with few geometry parameters it determines the attenuation to the receiver.

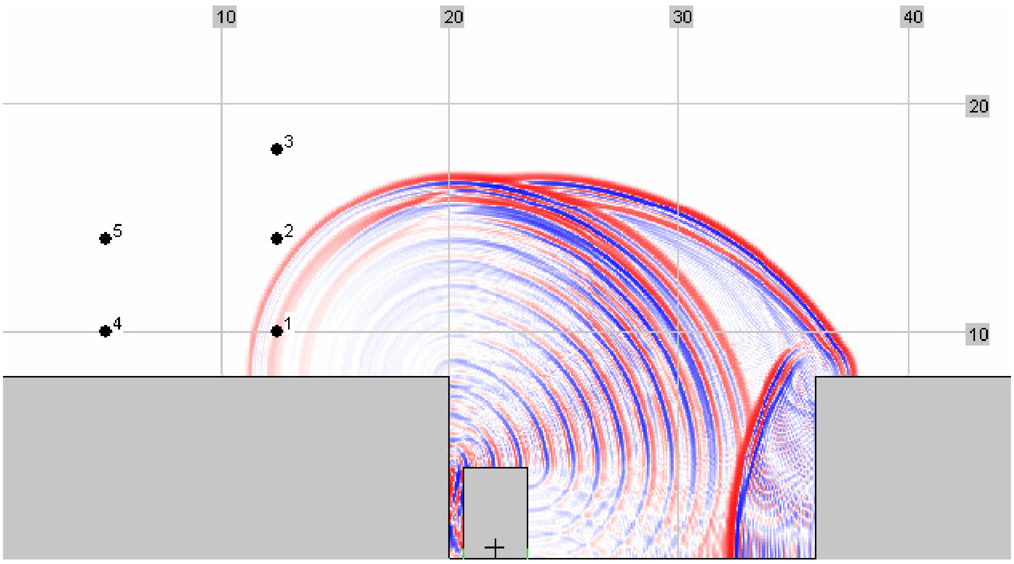

Figure 4: Sound propagation in a railway line cutting showing multiple reflections between lateral walls and the vehicle body, reflections on the opposite wall and diffractions on the edges.

5 Implementation

The propagation model can be operated entirely autonomous from the emission model with only the geometrical properties of the line sources as interface. The resulting sound exposure can then be calculated as a simple division between the sound power of a source and its corresponding attenuation. This clear distinction between sound emission and propagation is important as it allows separating the time consuming

propagation calculation from the less laborious steps.
As the quality of calculation results not only depends on the correctness of the applied algorithms but also on the accuracy of the input data, great attention was also paid to the latter. Most of the necessary data is geo-referenced and geographical information systems yield potent tools to prepare the data and to present and analyze the results. Therefore it was decided to attach the calculation model to a GIS-platform called EnvGDB (Environmental GeoDataBase), which is working on the Basis of ESRI-products and an Oracle database. While the emission model was directly implemented in the GIS-system, the sound propagation model is designed as a separate application that is started and controlled by the main program but works independently from the rest (see Figure 5). The multi-processor-structure allows splitting up big projects into several calculation tasks and permits to do noise mapping even for greater areas within reasonable time. The propagation calculations are performed on a computing system at Empa called Ipazia. Ipazia is a Linux-based, water-cooled cluster that currently consists of 46 partly infiniband-interconnected compute nodes, a total of 248 processors with overall of 768 GB RAM and 24 TB diskspace.

6 Application

The model is designed to yield calculation results of high accuracy for open-track railway situations. It can be used to assess existing situations or to evaluate different mitigation measures. Projects from single receiver positions up to noise mapping for greater areas can be handled. As a first broad application of the model the sound exposure along the north-south-corridors through Switzerland will be calculated.

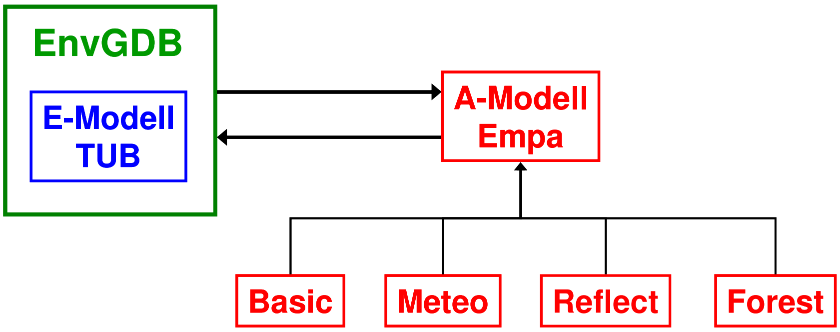

Figure 5: Implementation of sonRAIL with the emission model directly integrated in the Environmental GeoDataBase and the propagation model as a separate application with four modi of operation.

7 Contact

A full documentation of the model (in German) can be downloaded under:
http://www.bafu.admin.ch/laerm/01148/06762/07079/index.html?lang=en

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8 References

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