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Train Passing Synthesis in Environments Based on Geospatial Data

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ABSTRACT

The planning process for railway infrastructure projects is often lengthy and requires acceleration. One way to achieve this is by enhancing acceptance through mediation efforts that allow affected individuals to experience the impacts of new or revised plans in virtual environments. Beyond this communicative purpose, synthesized train passings can be utilized for psychoacoustic assessments, providing a better match of human perception of the acoustic impact compared to standard SPL predictions. As part of the EAV-Infra research project, a geometric sound propagation algorithm was implemented to calculate the phenomena of reflection, diffraction, and scattering at surface structures. This algorithm relies on digital terrain models (DTM), 3D building models, and digital surface models (DSM), as part of a comprehensive BIM model. The calculation process is divided into three stages: geometric pre-processing, calculation of sound propagation paths, and translating these paths into impulse responses for moving partial sound source positions of a train pass-by. A key feature of the algorithm is its ability to handle large spatial models with careful simplification.

Keywords: *railway noise, sound propagation, eav-infra*

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1. INTRODUCTION

Planning processes for railway infrastructure in Germany are lengthy compared to international standards. This is due to both structural factors, such as the distributed and multi-level organization of the planning processes, and technical reasons. The introduction of Building Information Modelling (BIM) is seen as having great potential to accelerate these processes and has already been implemented in pilot projects.
BIM allows for the early calculation of acoustic immissions along planned routes, which is crucial for communication with decision-makers and citizens' initiatives. Additionally, immission planning can be quickly updated at each stage of the planning process.
The railway infrastructure planning process is divided into several planning phases. Time-consuming immission calculations must be repeated whenever changes occur. The main benefits of BIM include significant acceleration of work by integrating geometric and design data into a comprehensive model, and simplified communication between designers and stakeholders by discussing a unified model.
The existence of a BIM model also enables the creation of a virtual audio-visual environment, or digital twin, of a track section and its surroundings. This model can inform residents along a proposed railway line at an early stage in the planning process. Current communication methods, which rely on isobars of equivalent sound pressure levels, do not

adequately convey the acoustic perception of train passages or noise reduction measures.

Using Virtual Acoustic (VA) simulation, it is possible to listen to train passings and evaluate different noise abatement measures at any immission point of interest, such as residents' windows. The proposed application of VA is based on acoustic source and propagation models. On the reproduction side, immersive synthesis methods are available for both socially shared and individual perception.

Furthermore, a VA environment captures acoustics with relevant information content at immission locations according to psychoacoustic criteria. The EAV-Infra project includes a sub-project that developed a psychoacoustic metric for railway noise, presented at Euronoise 2025 under the title “An Approach For Evaluating Time-Varying Annoyance Caused By Railway Noise.”

2. 3D MODELLING

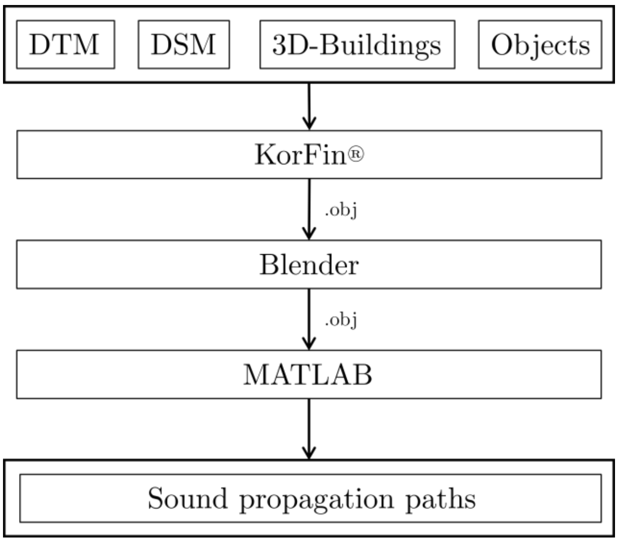

Figure 1: Toolchain for calculating sound propagation based on BIM models integrating geospatial data

Figure 1 schematically visualizes the geometric modelling process. A BIM digital twin is created from openly available geodata and track data. Details on that are presented at Euronoise 2025 in the contribution “BIM-Based Noise Protection Planning in Railway Infrastructure.”

In the first step, geodata is processed in KorFin®. The aim is a 3D meshing of the terrain model, vegetation and buildings. DTM, DSM and 3D-Building data serve as a basis. Manual data optimization is particularly necessary in the DSM data, since overlap with 3D-Buildings data can occur in the area of houses and these have to be cut out in the DSM model. Once the data has been consolidated, it is imported into the free software Blender. An object group is created for each of the DTM, DSM and 3D-Buildings. The mesh resolution is reduced via a decimation process, since the computational complexity increases exponentially with the number of faces. After completion in Blender, the next step is to export the data in .obj-format. The track and the scene, consisting of the DTM, DSM and 3D-Building model are then transferred to MATLAB®. A parser script transforms the mesh into a half-edge data structure which allows for efficient geometric calculations.

3. PATHFINDER

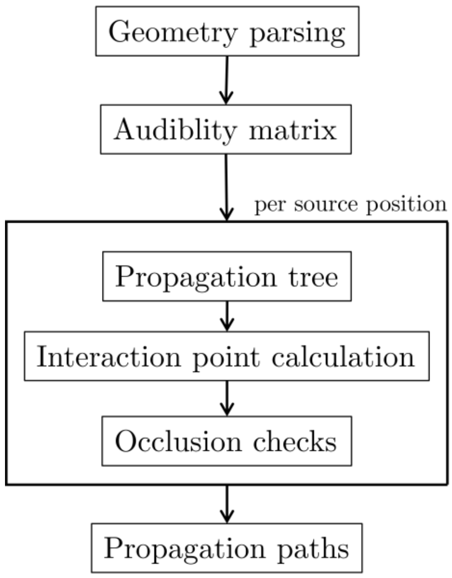

Figure 2: Propagation path calculation with the ISM/IEM Method

The geometric pathfinding algorithm combines the Image Source Method (ISM) and the Image Edge Method (IEM), which proved to be effective for sound propagation calculation in complex scenarios [1,2,3]. In our specific use case, paths are calculated for a moving source on rastered positions and a fixed receiver position.

Figure 2 shows a rough sketch of the pathfinding algorithm. The pathfinder loads the geometric structure of the scene and the track and, in a first step, creates an audibility matrix which represents the mutual visibility of the faces and edges in the scene. The pre-calculation of the audibility matrix reduces the computational complexity of the further pathfinding process as it limits the amount of possible path candidates before the time-consuming interaction point calculations and occlusion checks. Next, the propagation tree is created containing all possible interaction point combinations. These can be arbitrary combinations of reflection or scattering points on faces and diffraction points on edges up to the specified maximum order, which is the main advantage of the IEM. The size of the tree grows exponentially with the order of diffraction and reflection interactions. In the next step, the interaction points on surfaces (reflections) and edges (diffractions) are first calculated in the mirror space, then projected back into the real space and paths are linked. Finally, paths which are blocked by obstacles that were not already considered in the audibility matrix are dismissed. The valid paths are stored in a fixed scheme for each location step of partial sources of a train passing. The complete path list is stored as a MAT-file to be handed over to the following calculation of sound propagation. Figure 3 shows the sound propagation paths for our demonstrator scenario "Wutike train station" for one source position in front of the train station building and a receiver position on the court behind the train station. In this example, reflection interactions are limited to first order, diffraction interactions are limited to second order and scattering interactions of first order are only calculated for the DSM (green trees).

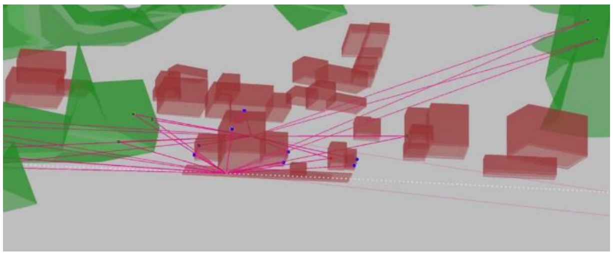

Figure 3: Simulation of sound propagation paths at Wutike train station (route number 6938, track km 19.4)

4. SOUND PROPAGATION

Sound propagation is calculated from a partial sound source, e.g. the wheel-rail contact or the turbulence points at different train positions, to the immission points, i.e. residential windows along the train route or freely selectable listening positions. Partial sound source signals of a train passings were recorded by the project partner Fraunhofer Heinrich-Hertz Institute with microphone arrays for different train types under real conditions. Various synthesis methods were used to extend the partial source signals, for which only a short recording is available due to the train passing by, into stationary signals. Details on the sound source modelling are presented in the Euronoise 2025 contribution "Measurement-based Sound Source Modelling of Moving Vehicles for Auralizations Utilizing Acoustic Beamforming".

A partial impulse response is generated for each calculated acoustic path per train location. These impulse responses contain the acoustic effects along the propagation path and are complemented by atmospheric damping (ISO 9613-1), damping through foliage (ISO 9613-2), diffraction (Maekawa) and scattering (Lambert's cosine law and cluster-based noise shaping [4,5]). Reflection properties are differentiated according to the type of material as soil, buildings and objects such as trees own different absorption properties.

The propagation effects are calculated in octave bands and finally summarized in a broadband impulse response. The propagation delay for each path is an essential parameter and stored externally to limit the storage space required for the partial impulse responses.

To generate a binaural signal, the partial impulse responses are spatialized with the head transfer function for the respective direction of the propagation path to the listening position before being combined into an overall impulse response.

5. SUMMARY

An approach to model the sound propagation of railway noise in large spatial models is presented, demonstrating the potential of using BIM models for immission calculation and auralisation in VA systems. The approach first integrates BIM data of tracks and multi-layer earth surface data in the BIM software KorFin®. The data is subsequently reduced using 3D modelling software to facilitate the computation of geometric acoustics. A pathfinder then constructs sound propagation paths between rastered source positions along a railway track and receiver points based on the geometric methods of ISM and IEM. Finally, a sound propagation algorithm calculates acoustic phenomena and stores them in impulse responses, which are then available for multichannel reproduction in VA systems.

A challenge was the simplification of the geospatial data for speeding up the pathfinding algorithm, which was done in the 3D modelling software Blender. The parsing and sound propagation algorithms were trimmed for computational efficiency. For scaling the algorithmic load, a set of parameters, for example the radius within acoustic interaction are calculated as well as orders of reflection and diffraction can be set. A significant benefit in terms of acceleration is expected by further reducing the acoustic information, such as the spatial resolution, to the space-time resolution of the auditory system.

6. ACKNOWLEDGMENTS

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