Noise Exposure Assessment for Nationwide Infrastructures

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ABSTRACT

When predicting the macro economic impact of infrastructural planning, noise-impact on population and nature is part of the consideration. Such assessment was undertaken by the German Department of Transport when planning the railway infrastructure for the time horizon of 2030. The department entered a research & development agreement with the authors of this paper.

A fast noise impact assessment for German-wide scenarios was required. The simulation model covers a railway network of some 30000 km of tracks and related barriers plus about 30 million buildings with inhabitant data and nature reserve zones.

To achieve fast processing times a "Settlement based Infrastructural Noise Assessment" method was developed, which treats entire Germany in 500 x 500 (m) cells. For each cell various geometric parameters of the housing structure were determined and from this a limited number of representative settlement structure types was retrieved. For each type a range of impact scenarios was pre-calculated.

The final assessment looks at all affected railway tracks, estimates demand for barriers, accumulates effects on settlements in up to 1000 m by-pass distance of railway tracks as well as nearby nature reserves and compares this to the existing situation.

Keywords: Exposure Assessment, Infrastructure   I-INCE Classification of Subjects Number(s): 68.3

1. INTRODUCTION

The long term planning for the transport infrastructure in Germany in 2030 is based on cost-benefits logics covering a large range of aspects amongst them "population noise exposure". A range of different scenarios are compared against each other after monetarizing each aspect. Scenarios may include new tracks, closing down of existing tracks, changes in track quality, speed limits, traffic volume and vehicle types. The definition of future scenarios is typically based on traffic simulation models, which cover the whole German railway network of some 30000 km. Traffic simulation with focus on changes in one region will regularly result in small changes of traffic volumes all over the whole network.

The study discussed in this paper refers to railway noise but the principle approach might as well be applied for trunk road networks.

There is no existing regulation which will give advice on how the perform a population noise exposure assessment of the give scale to compare different scenarios with economically justifiable effort.

When setting up a new scheme for such large scaled projects the main aspects were:

- Use of up to date source emission models, which enables a realistic outlook into 2030, i.e. German railway noise regulation "SCHALL03-2014"
- Use of a simple propagation logic, supporting LDEN, i.e. German railway noise regulation "VBSUCH"

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- Interest in exposure noise levels ≥ 45 dB on residential building facades at different floor levels in regions where a changes in noise levels of ≥ 2.1 dB (rounded to 3 dB) can be anticipated
- Fast assessment time for comparing existing situation against a future scenario, e.g. less than 6 h
- Use of model data ad hoc available to the client, the German "Bundesministerium für Verkehr und digitale Infrastruktur" (Department of Transport)
- Limited complexity of the chosen method

Judgement on environmental impact of new roads or railway tracks is covered by German regulation of 16.BImSchV (16. Verkehrslärmschutzverordnung). As the regulation focusses on the increase of noise levels (rounded differences in receiver levels of 3 dB) considerable simplifications in the assessment can be justified.
Furthermore a cost-benefit analysis of noise exposure is also part of the judgement. This will look at all people exposed to a noise level above 45 dB and will use none linear rating of the noise exposure levels. Therefore the chose method chosen for exposure analysis ought to be reasonably accurate.

It shall be noted that all data management and geometric analysis as well as acoustic calculations described in this paper have been performed with help of the LimA software suit for environmental noise assessment. The actual method has been defined within macros, enabling the user to calculate a scenario assessment and create the final CSV output table comparing given situation and planned scenario by a single button press.

2. THE CHOSEN METHOD

2.1 Available data

The basic data used for the project is widely identical to the kind of data used for EU Environmental Noise Mapping purposed. The data instantly available also influenced the design of the method.

- Traffic per track ID as CSV file
- Railway net in 2-d (see Figure 1)
- Tunnels
- Screens next to railway tracks
- Highway network
- Address-points for residential buildings
- Inhabitant census data per 100 x 100 (m) cells.
- Buildings, 2-d
- Nature reserve zones

The use of a digital terrain model (DGM) would have been feasible with respect to accuracy. However any German-wide DGM of required accuracy was not available within the given timeframe of the project. Using a DGM will increase the complexity of any chosen method.
With future applications under consideration the method presented in this paper is subject to ongoing developments.

Traffic data, i.e. quantity, category, speed was available for day, evening, night (EU terms) as well as for 16 h day time (German requirement) was provided in separate CSV files for the existing reference status as well as for various scenarios in 2030. Emission data was aggregated per track ID, summing up emission levels at different heights and assigning the total value to a representative emission height at 0.6 m above railhead.
The railway network comprises some 39000 km of tracks. Tracks in tunnels were marked and could be ignored.
The position of existing noise abatement screens next to the railway tracks was given in 2-d and a height of 2 m above railhead was assumed as default.
The network of motorways (highways) was used to suppress any evaluation of costs for noise pollution of nature reserve zones in the premises of motorways.

Address-points of residential buildings helped to recognize residential buildings and to distribute the number of inhabitants defined for 100 x 100 (m) grid-cells in a German-wide census.
The total 2-d building data covered more than 30 Mio. buildings.
Once the number of inhabitants was known, a realistic building height could be estimated on statistical data for average floor space size per inhabitant. For none residential buildings default heights were used depending on shape size, i.e. 4, 8 or 9 (m) height for A<100, <1000 ≥ 1000 (m²).
Nature reserve zones were supplied in high resolution as shown in Figure 2.

Figure 1 - Relevant railway network of Germany

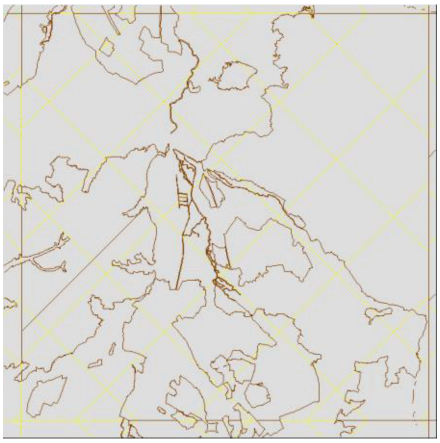

Figure 2 – Nature protection zones in 10 x 10 (km) area

2.2 Grid cell approach

The initial idea of rolling up the assessment along individual railway tracks, i.e. integrating effects in orthogonal position to the track and finally sum up the total effect of all tracks, was soon discarded. It cannot be seen how the logarithmic superposition of several source contributions could be solved and even a single track passing a settlement in a bend is problematic.
Superposing the influence of several sources in different locations on the same settlement needed to be solved for 4 reasons:

- Background noise from existing other tracks need to be accounted for
- Bended tracks shall show a different effect than straight tracks
- Effects of adjacent tracks shall be bundled
- Any change in traffic, speed etc. along the same physical track results in a logical split up of tracks. So the combined effect of several tracks is not only subject for parallel tracks.

The considerations above led to the development of a "Settlement based Infrastructural Noise Assessment" method (SINA).
The required exposure analysis for nature zones can still be treated along individual tracks, using a 100 m track segmentation. Also the principle analysis deciding on the need for extra abatement screens can be handled track related for these 100 m segments. After this initial step is done the infrastructure is completely defined and the settlement based noise exposure of inhabitants can be calculated.
To achieve a fast processing time and with the project related demands on accuracy in mind, population exposure was pre-calculated for different settlement types and different source constellations.

2.3 Settlement types

A limited number of 24 settlement types, each describing typical arrangements of residential buildings within 500 x 500 (m) cells, was defined out of the total number of 488965 populated cells in Germany. 4 criteria were used to distinguish settlement types.

1) Average building heights
   Buildings are sorted into 3 sub-classes according to their height.
   Quantile values for 33 and 66 (%) were used to find the threshold value for each class.
   Quantile values for 16.5, 49.5 and 82.5 (%) were used to define the "ideal" condition of a class.
   When any settlement falls into a certain height class, according to its average height of buildings, the difference between its average height and the ideal condition of the related class is used to create a "matching-rate" factor.

2) Total volume of residential buildings – indicating density of population
   For all cells within one of the 3 height sub-classes the 50% quantile is used as class threshold for 2 sub-classes. Values of the 25% and 75% quantile describe the ideal condition. "Matching-rate" factor is calculated as described above.

3) Proportion of residential building volume in relation to total building volume -
   indicating predominantly living or mixed areas
   For all cells within one of the 6 classes defined by criteria 1) and 2) the 50% quantile is used as class threshold for 2 sub-classes. Values of the 25% and 75% quantile describe the ideal condition. "Matching-rate" factor is calculated as described above.

4) Position of centre of gravity for residential building volume -
   2 classes are distinguished, with the centre being within +/- 125 of the cell centre in x/y or outside. The knowledge of this x,y-position for each cell will also be used to select appropriate combination between source and settlement out of the pre-calculated constellations.

The Index of the best matching settlement type needed to be defined for each populated cell in the German-wide data. For each cell and its assigned settlement type the overall congruence for criteria 1, 2 and 3 is described by a "matching rate". The matching rate is given in % as the product of the 3 matching-rate factors multiplied by 100.
Each matching rate factor (MRF) describes the parameter deviation with respect to one criteria.

$$MRF = 1. - 0.5 * \left(VAL_C - C\_VAL_{ST}\right)/(L\_VAL_{ST} - C\_VAL_{ST}) \quad (1)$$

with

VAL_C the parameter for the considered cell
C_VAL_{ST} the centre value of the relevant class of the considered criteria
L_VAL_{ST} the upper or lower limit value of the relevant class of the considered criteria, depending on VAL_C being above or below the centre value

For criteria 4) MRF is always 1.0 as it just represents a logical grouping. Each other MRF ranges from 0.5 to 1.0 and combined matching rate will range from 0.125 to 1. The average matching rate over all settlement cells in Germany is about 37%. This value could perhaps be improved by further differentiation of settlement types. The limitation to 24 types was initially agreed upon, having in mind a potentially manual application of “SINA”.

Considerations for further differentiation have been made at an early phase of the project, including:

- Orientation of main building facade towards nearest railway line
- Distance of next building opposite to main building façade
- Nearest distance of next residential or other major building
- Distinguishing of different average distances of residential buildings next to railways
- Differentiate between average distances to nearby buildings where railway tracks run through settlements.

2.4 Exposure classes

For each settlement type a number of different source line constellations were pre-calculated and related population exposure was stored in 1 dB noise level classes as XLS file. Population was always set to 100 inhabitants per cell and the population was distributed on the facades of residential buildings in line with the German VBEB regulation (Noise exposure analysis in END). These tables can potentially be used in a manual application of the method.
Within a settlement cell the gradients in noise level distribution will vary depending on the distance of the source line and the presence of any near source screens. To roughly care for this effect and still limit the number of pre-calculated constellations, calculation was performed at 4 different distances. When assessing any real scenario, the actual track distance needs to be shifted to match the nearest of the 4 distances. Emission data is then adapted to result in an equivalent receiver level in the middle of the settlement cell.

32 cases per settlement type result from combining a few principle constellations. In all cases sources are represented by 5000 m long straight tracks.

- 1 transit situation, represented by by-pass at 30 m distance to edge of cell on all 4 sides - This approach helps to avoid potential geometric conflicts when new tracks are planned.
- 5 by-pass situations
    - East, North, West, South
      This distinction is used in combination with centre of gravity of residential buildings
    - On all 4 sides to represent situations of multiple tracks in multiple directions
- 3 distances for each by-pass situation, taken from cell centre
    - by-pass in 500 m
    - by-pass in 1000 m
    - by-pass in 2000 m
- 2 propagation conditions
    - Free field
    - Near track screen, 2 m above railhead

In case of 30 m distance only building within the settlement cell area were taken into account.
For all other distances a buffer area of 250 m included the buildings of the neighbourhood, to represent a more realistic screening/reflection for the settlement cell area, shown as read frame in Figure **3** .

Figure 3 - Settlement cell exposed to railway track in the South at 1000 m distance

For each settlement type 10 different example cases were extracted from the German wide model. To ensure the selection of a representative subset out of the existing 488965 cells, the cells were separately ordered for each settlement type from best to worth match. Within one settlement type the samples were taken at equidistant intervals covering the whole dataset.

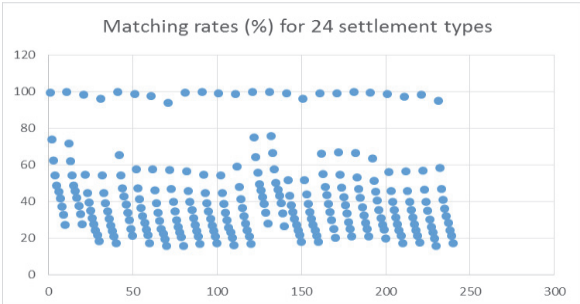

Figure 4 - Matching rates for 24 settlement types with 10 samples each

The figure above shows the distribution of matching rates (%) within the quantity of taken samples. For most settlement types an ideal real geometry could be found, for which the matching rate was almost 100%. A rate of 60% or better could be found for 10 – 30 (%) of the samples, depending on the settlement type.

For calibration purpose the number of inhabitants is always kept at 100. Relevant façade positions are set in line with VBEB apart from being 0.5 m in front of the façade and 3.5 m above terrain from bottom floor. Also extra floor levels are calculated every 2.8 m of height.
Calculated exposure values for the 10 different examples per settlement type are averaged to generate one set of pre-calculated distribution of inhabitants per noise level classes at 1dB intervals.

2.5 Processing a scenario

When processing a scenario the key processing results are:

- Necessary noise abatement screens, based on national 16 h daytime and 8 h night time noise levels and related limit values, in any situation of significant noise increase or high initial noise levels

- "Virtual" screen heights and costs for noise pollution of nature protection zones
- Number of inhabitants exposed to noise level classes at 1 dB interval
- Number of inhabitants exposed to significant change of noise levels
- Comparison of key indicators above for the existing and the planned infrastructure

The CSV file containing the information described above is the final output of an automated macro process designed for LimA, which comprises several steps as described in the next paragraphs.

2.5.1 Treating railway tracks

While processing a project data railway tracks are automatically treated in several steps:

- Break down all railway tracks in 100 m elements.
- Find existing screens next to the tracks. Link information of screens to parallel tracks nearby.
- For each segment the need of potential abatement screening for the purpose of settlement protection is estimated. Potential screens will already by regarded in population exposure assessment.
- For track segments which will not be assessed for population exposure due to distances, the noise impact on nature reservation areas will be checked.

2.5.2 Exposure of Nature

Nature reservation areas are regarded as "affected by noise", where relevant railway tracks are placed within 100 m of the zone and the noise level in 100 m distance to the track reaches values above 55 dB at daytime. In such cases a "fictive" screen is designed to keep noise levels within the threshold level and potential screen costs are accumulated to monetarize the effect of noise impact on nature. With railway tracks being split up in 100 m segments, the base length of screens was 100 m.
The need for screening is separately investigated for each side of the track.

2.5.3 Exposure of population per cell and in total

Per settlement cell

- Find out whether a settlement cell needs to be considered as "affected by railway noise". This is the case when any newly planned or repositioned track or any track with significant change in emission level is by-passing with a distance of 1000 m to the edge of the settlement cell.
- Find all other tracks in the 1000 m neighbourhood of a relevant settlement cell, which will be used to estimate background noise.
- Find out whether the majority of noise influx in cell centre derives from railway with or without screens. Accordingly different sets of pre-calculated exposure data are used.
- Recognize the most relevant track per cell and define the substitute emission level for a long straight track at the corresponding distance of the pre-calculated exposure data.
- Increase emission for this substitute track to account for all other tracks in the neighbourhood, based on individual distances of track segments to the centre of the cell.
- Recognize whether railway sources are concentrated on one side of the settlement cell or we deal with influx from multiple directions. This will also influence which dataset for noise exposure is chosen.
- Extract the relevant exposure data set and calibrate number of inhabitants to match the number given for the settlement cell. Also the pre-calculated distribution needs to be shifted in the dB-scale to reflect the total emission level of the substitute track.

The Exposure data retrieved from the procedure described above is summed up for the whole project.

3. EXAMPLE CASES

We will check data property right issues and if conceded we will show example test cases during the presentation including a comparison of results created by the described method and alternatively created from conventional analytic calculation for limited track length in the range of 100 km. Our expectation is that population exposure can be forecasted within an accuracy of 2 dB for the vast majority of population.

4. CONCLUSIONS

The “Settlement based Infrastructural Noise Assessment” method provides an opportunity to quickly determine an estimate of population exposure to noise with accuracy fit for the purpose. The approach of pre-calculated exposure values for defined settlement types allows to handle large scale infrastructural projects covering the area of whole nations. The method is open for fine tuning by increasing the number of supported settlement types or further distinguishing with respect to other parameters. Such changes can easily be integrated by the project engineers as the method had been implemented in LimA macro technology.

Due to the efforts undertaken in the past in the context of EU Environmental Noise Mapping, it can be assumed that in many countries most of the required data for the acoustic simulation model will already be in place or easy to organize.