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Input data complexity in railway traffic noise modeling: Case Study of Railway line M604 Oštarije – Gospić – Knin – Split

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Summary

Many sources of error can influence traffic noise modeling results: choice of calculation method, applied software, and input data complexity. In addition, when large areas need to be analyzed, noise calculations usually get time-consuming and costly very fast. At the same time, the required input data needed for these calculations might not be available. In the Republic of Croatia, a uniform database for noise models preparation and the analysis of railway noise emission is not yet developed. In order to prepare a sufficiently accurate model of the area under study, a large quantity of data obtained from various sources must be used for each analysis. Therefore, the designer must be aware that a trade-off between the required accuracy of the results and the time and cost needed to perform the analysis will always be present in this process.

In this paper, the influence of input data complexity in railway traffic noise modeling will be presented on an example of a railway line M604 Oštarije – Gospić – Knin – Split in Croatia. In order to upgrade the track structure for train speed of up to 160 km/h, approximately 62 km long section of this railway line was reconstructed. As a part of the reconstruction project, railway noise analysis was conducted. Because a large part of the analyzed area is contaminated with landmines, noise levels were defined by means of several field measurements in the close proximity of the tracks, and noise modeling. The purpose of the analysis presented in this paper was to determine which adjustments of available input data can be made in order to reduce model preparation and noise calculation time, without influencing the accuracy of the results.

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1. Introduction

The first step in railway noise management is the definition of noise levels generated by traffic operations, either by field measurements or by noise calculations conducted via specialized software packages. Noise calculations require the production of noise calculation models, comprised of geometric and acoustic data. Quality of these models significantly depends on the quality of input data and the effort to create the precise and accurate representation of the area for which the calculation is conducted [1].

Unfortunately, a uniform database for railway noise modeling is still not developed in the Republic of Croatia. Because of that, input data gathering and modeling is the most resource and time-demanding phase in railway noise management [2, 3]. Often a compromise must be made between data accuracy and detail, and cost and time required to collect and systemize it: some simplification of inputs or missing data should be accounted for in every noise management project.

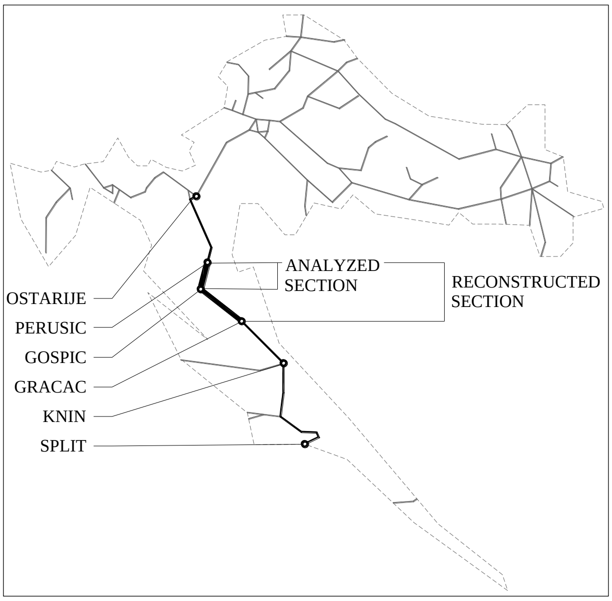

Figure 1. Reconstructed and analyzed track section.

Influence of input data complexity in noise modeling of railway traffic will be presented on an example of a railway line M604 Oštarije – Gospić – Knin – Split in Croatia (Figure 1). In order to upgrade the track structure for train speed of 160 km/h, approximately 62 kilometers long section of this railway line was reconstructed in 2008 [4]. As a part of the reconstruction project, railway noise analysis was conducted, which included several field measurements in the proximity of the track, and noise modeling.

In this paper, the process of calibration and validation of five railway noise models with different levels of detail will be presented. Model calibration for the section of the aforementioned railway line was conducted on the basis of available input data from various sources. Validation was carried out by comparing the calculated noise levels with field measurements. The purpose of this analysis was to determine which simplifications of input data could be made in order to reduce the time for model preparation and noise calculation without considerable effect on the modeling results.

2. Input data and model calibration

Town councils and railway authorities are normally responsible for gathering and entering traffic noise input data into widely accessible databases. However, in the Republic of Croatia, these bodies neither collect nor systemize input data needed for the preparation of prediction models for railway noise. In order to prepare a sufficiently accurate model of the area under study, a large quantity of data obtained from various sources must be used for each analysis. In this section, a procedure of noise model preparation usually applied in Croatia is described. In addition, the calibration process of five models with various levels of detail concerning input parameters is presented.

2.1. Geometrical data

The main sources of terrain model data are official cartography services. Unfortunately, the level of detail in commonly available digital terrain model (DTM) usually does not include important information that affects noise propagation. This is because the spatial interpolation of scattered elevation points used in the creation of DTM usually filters out much of the details needed for accurate noise mapping: the shape of embankments, railway platforms, cuttings and other significant relief close to the noise source [1]. Because of that, substantial effort must be directed towards the enhancement of information in DTM. This additional information is usually collected via field measurements and observations, which is a costly and time-consuming process. This process was also inevitable in the case of the rail traffic noise modeling of a single-track railway line M604, which passes through the mostly uninhabited areas of County Ličko-Senjska.

The main challenge in the creation of the geometric model of the analyzed area was the lack of access to the railway. Namely, more than 50 % of the analyzed track section passes through a very inaccessible terrain with a poorly developed and unmaintained local road network. Also, as many as 15 % of the analyzed track section (about 9 kilometers) passes through the mine suspected area [5]. Because of that, a DTM created and applied in this analysis was composed of the 3D model of reconstructed railway and relief model of the narrow belt along the track (from 25 to 75 meters on each side of the track), provided by the railway authorities. The plan view of the buildings was acquired from the existing cadastral plans of the cities and municipalities, through which the analyzed track section passes, with the assumed low level of accuracy. The function (economic or residential) and the condition of the objects (inhabited objects, undisturbed objects, ruins), and the number of floors were estimated based on available orthophotographic maps of the area and video clips recorded from the train.

Along 62 kilometers of the reconstructed railway section, 9 short subsections were defined, with an

Table I. Geometric characteristics of analyzed subsections.

Subsection	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Area [km2]	0.12	0.10	0.13	0.12	0.10	0.12	0.12	0.13	0.14
Length [m]	655	598	669	660	595	600	590	595	615
Max. elevation distance [m]	27.0	13.0	7.5	25.0	17.0	9.5	24.0	9.5	4.0
Measuring points	1	2	3	4 5	6	7	8	9 10	11
Distance to the source [m]	53	52	13	18 29	73	41	61	47 52	72
Cut									
Share of subsection length [%]	21	31	42	23	0	36	46	31	0
Max. height [m]	0.7	2.0	2.5	2.2	0.0	2.5	2.3	1.8	0.0
Average height [m]	0.6	0.8	1.8	1.7	0.0	0.9	1.5	1.0	0.0
Fill									
Share of subsection length [%]	57	46	42	38	0	29	23	54	100
Max. height [m]	2.8	1.8	2.0	2.5	0.0	1.0	5.5	3.1	5.0
Average height [m]	1.7	1.1	1.5	1.9	0.0	0.7	1.4	1.6	2.9
Buildings									
Residential [-]	6	9	8	30	6	9	0	7	20
Other [-]	12	9	25	43	3	10	0	15	22
Min. distance to source [m]	12	30	10	10	43	10	-	35	10
Average distance to the source [m]	50	50	50	30	75	30	-	55	80
Bridge length [m]	0	0	0	0	0	0	150	0	0

average length of 620 meters and an average area of 0.12 km2. Detailed geometric characteristics of these subsections are given in Table I. Location of each subsection was defined based on the locations of noise level measurement points [6].

Measurement point locations were defined outside train station zones, at different distances to the track, where access was possible. Another requirement in the selection of subsections was the shape of their relief. On the selected subsections relief is represented in the same proportions as the relief along the entire reconstructed track section. Subsections 3, 6, 8 and 9 have flat relief, on subsections 1, 2 and 4 the relief is rolling, on subsection 5 the railroad is on a hillside, while on the subsection 7 railroad crosses the riverbed.

In the calibration process of the geometric models, three digital terrain models with different levels of detail were created.

In the first model (DTM1), the relief was represented by contours without elevation data, the embankments were neglected (cut and fill embankments were modeled as brake lines without elevation data), and noise propagation barriers in the form of residential and commercial buildings were not considered.

In the second model (DTM2), the relief was represented by contours without elevation data, the embankments were neglected, and buildings were modeled with their plan view and the number of floors, as buildings with a flat roof.

In the third, most detailed model (DTM3), the relief was represented by contours with 0.5 meter equidistance, the embankments were modeled with break lines with corresponding 3D coordinates, buildings were modeled with their plan view and the number of floors, as buildings with a flat roof. In this model, bridges, overpasses, and water surfaces were also modeled.

2.2. Noise source input data

According to the Croatian traffic noise regulation, The Netherlands national computation method published in document "Rekenen Meetvoorschrift Railverkeerslawaai '96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer" should be used in the calculation of the rail traffic noise levels [7]. According to this method, noise emission points are located in the track axes at the height of 0 and 0.5 meters above the rail running surface.

The vehicles operating on the observed section are classified into categories by type of propulsion and

braking system, and the section of the track is divided into categories according to the sleeper type, track type (ballasted or slab), rail fastening system and running surface discontinuities, design and train running speed.
The above-mentioned parameters applied in the modeling of noise levels at the analyzed railway subsections are described below.

2.2.1. Number and type of trains

As in most rail traffic noise calculations, railway authorities provided only the information on total train volumes in operation on the reconstructed railway section in a 24-hour period and a summary classification on freight and passenger trains. Since this data is not sufficient for the production of a reliable calculation model, it was supplemented with information on the number and type of trains that were observed during 24-hour noise measurements at 11 measuring points along the analyzed railway subsections. On these locations, the number of trains of a certain type differs, because measurements were performed in six different 24-hour periods [6]. Three different train types were observed and included in the models: diesel freight trains with brakes (type 5D), disc braked and brake blocks passenger trains (type 2), traveling exclusively in the night period, and Intercity trains with disc brakes (type 8) that operate exclusively in the daytime period (Table II).

2.2.2. Rail track superstructure

Data on the track superstructure, required to calculate rail noise levels according to the RMR method, has been gathered from the railway line reconstruction project documentation. Track superstructure characteristics are homogeneous along observed subsections: single track line is constructed with concrete transverse sleepers in ballast bed, and continuously welded rails without switches or crossings.

2.2.3. Train speed

As mentioned earlier, one of the rail line M604 reconstruction goals was to upgrade the track alignment and structure for train speed from 80 to 160 km/h, depending on track section. However, during noise measurements (conducted in spring 2009) it was observed that train speed along different track sections was lower than one given in official reconstruction project documentation. Because of that, values from the Network statement document published by the network's manager HŽ Infrastruktura were used as input speed for each train type. According to this document, maximum permitted train speed on this rail line during measurements was 100 km/h for passenger and 80 km/h for freight traffic [8].
Using the average speed of a traffic fleet instead of the speed distribution will generally lead to an underestimation of the corresponding sound power levels [1]. Because of that, as an input parameter in noise modeling equivalent speed was used. In the model calibration process, two methods of defining the equivalent train speed were used, which resulted in two speed models. In the first model (V1), the maximum permissible speed at the considered rail section, which depends on the train type, was used as the equivalent speed. This resulted in the division of the reconstructed track section into 4 segments with homogeneous speed conditions. In the second model (V2) the equivalent train speed for noise modeling was defined by aggregating maximum permitted and limit speed values [8]. Track segments along which train speed increases or decreases, from limit to maximum permitted values, were defined for speed interval of

Table II. Number and type of trains observed during noise measurements.

Subsection	*Day*			*Night*			*Evening*		
	5D	2	8	5D	2	8	5D	2	8
1	4	0	3	6	5	0	1	0	0
2	4	0	3	6	5	0	1	0	0
3	8	0	4	6	5	0	2	0	0
4	6	0	2	6	5	0	2	0	0
5	4	0	6	4	5	0	2	0	0
6	4	0	6	4	5	0	2	0	0
7	5	0	5	4	5	0	2	0	0
8	4	0	3	5	5	0	1	0	0
9	4	0	2	5	5	0	1	0	0

10 km/h and acceleration and deceleration values of 0.55 m/s2 for tilting passenger trains (type 8), 0.35 m/s2 for conventional passenger trains (type 2) and 0.15 m/s2 for freight trains (type 5D). This resulted in the division of the reconstructed track section into segments with homogeneous speed conditions as follows: 24 segments for passenger trains (type 2 and 8), and 13 segments for freight trains. Equivalent speed for each of the nine analyzed track subsections and train type is given in Table III.

Table III. Equivalent speed models and train type.

Subsection	*V1 [km/h]*			*V2 [km/h]*		
	5D	*2*	*8*	*5D*	*2*	*8*
1	80	100	100	80	100	100
2	80	100	100	80	100	100
3	80	100	100	80 75 65	100 95 85	100
4	80	100	100 50	65 55 50	75 65 55 50	95 85 75 65 55 50
5	80	100	60	60	60	60
6	80	100	100	80	100	100
7	80	100	100	80	100	100
8	80	100	100	80	100 95	100
9	80	80	95	80	80	95

3. Model validation

By combining the different levels of detail of the geometric and acoustic input data, five noise calculation models were generated:

- Model 1, the simplest model, obtained by joining the geometric model DTM1 and the speed model V1;
- Model 2, obtained by joining the geometric model DTM2 and the speed model V1;
- Model 3, obtained by joining the geometric model DTM2 and the speed model V2;
- Model 4, obtained by joining the geometric model DTM3 and the speed model V1;
- Model 5, the most complex model, obtained by joining the geometric model DTM3 and the speed model V2.

These models were validated by comparing calculated and measured noise levels. Noise level measurements were carried out at 11 measuring points at different distances from the track axis, depending on the possible access to the track (Table I). At all measuring points, the microphone was positioned at a height (4.0 ± 0.1) meters above the ground. Measurements were performed in six different 24-hour periods [6]. Below are the results of the analysis for the time period Day (Table IV).

As shown in Table IV, the greatest deviation between measured and modeled noise levels was obtained using model 1 on the subsection 2 (at measuring point 2). After the introduction of the buildings in model 2, this deviation was reduced to the permissible level (≤ 3 dB). It then remained unaltered regardless of the extent to which the detail of the noise calculation model was increased. Furthermore, deviations greater than 3 dB were reported at measuring point 6 at subsection 5 in all calculation models. By introducing detailed models this deviation has not diminished. It was concluded that the reason for this was

- the negligible difference between the geometry of model 1 and the real world shown in model 5 (Table I)
- the fact that there are no significant differences in the speed model (Table III) on this subsection, and
- that the measuring point is far from the noise source (73 m from the track axis, Table I).

The difference in the deviations at the measuring points between models 1 and 5 ranged from 0 to 0.7 dB, with the largest difference being recorded in subsection 7 (measuring point 8). This result was expected because the difference in the geometry of the simplest and most complex model in that subsection is significant (Table I). Due to the above, it was concluded that the relief of the observed subsections has the biggest impact on the calculation results accuracy. Since it is not justified to neglect the influence of the remaining noise calculation parameters on the accuracy of the model based on a small number of analyzed data (noise level in 11 measuring points), a more detailed study was conducted on the simplest and most complex calculation model (models 1 and 5).

4. Analysis of input data complexity influence

When examining the impact of the complexity of the calculation model, which was based on the deviation between the results of the most complex model (model 5) and the simplest model (model 1), the number of trains of a certain type was equalized on all nine subsections. As the relevant number of trains, the maximum value recorded for a period Day was adopted (Table II). Noise levels were calculated in 1890 receptors modeled on every 50 meters of tracks at altitudes of 1.6, 2.8 and 4.0 meters above the ground level, and at distances of 10, 25 and 50 meters from the track axis. The results of the analysis are shown in Table V.

According to the analysis results, the increase of the average deviation between the models is proportional to the increase of the distance of the receptor from the axis and inversely proportional to the increase of the receptor height. At distances smaller than 25 meters from the axis the average deviation of the model results is less than 1 decibel, and the upper fence is less than 3 decibels. However, the highest individual value of deviation was observed at the smallest distance from the axis (10 meters), at the lowest receptor altitude (1.6 meters). Due to such calculation outcomes, the outliers of the calculated deviations were investigated. The outlier shares in the total observed sample were less than 10 % (a relatively low value), but their values differ significantly above the upper fence of the interquartile range.

By analyzing the locations of the receptors in which outliers were reported, the following was concluded. The biggest difference was recorded on the subsubsection where the difference in the geometry of the analyzed models is most significant (subsection 7). Significant deviations also occurred at the locations where shadow zones were created due to the introduction of residential and commercial buildings near the modeled receptors (subsections 4, 6 and 9). Some deviations also occurred in subsections where fill embankments are higher than 4 meters, and in locations where the buildings and the cut embankments higher than 10 meters caused the sound reflection (subsection 1).

5. Conclusion

Because of the fact that uniform database for rail traffic noise modeling is not developed in the Republic of Croatia, input data gathering is the most resource and time-demanding phase in rail

Table IV. Validation results: values and statistics of deviations between measured and modeled noise levels (in dB).

Model	*Subsections and Measuring points*											*Mean*	*Quartiles*				
	1	*2*	*3*	*4*	*4*	*5*	*6*	*7*	*8*	*8*	*9*						
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*		*100*	*75*	*50*	*25*	*0*
1	1.2	3.9	1.9	0.5	0.7	3.1	1.4	1.5	2.2	1.8	0.2	1.7	3.9	2.0	1.5	0.9	0.2
2	0.9	2.8	1.8	0.6	0.4	3.1	1.4	1.4	2.2	1.8	0.2	1.5	3.1	2.0	1.4	0.7	0.2
3	0.9	2.8	1.9	0.2	0.7	3.1	1.4	1.4	2.2	1.8	0.2	1.5	3.1	2.0	1.4	0.8	0.2
4	0.8	2.9	1.8	0.5	0.0	3.1	1.6	0.8	2.2	1.8	0.3	1.4	3.1	2.0	1.6	0.7	0.0
5	0.8	2.9	1.9	0.1	0.3	3.1	1.6	0.8	2.2	1.7	0.3	1.4	3.1	2.0	1.6	0.6	0.1
1-5	0.4	1.0	0.0	0.4	0.4	0.0	0.2	0.7	0.0	0.1	0.1	0.3	1.0	0.4	0.2	0.1	0.0

Table V. Simulation results: statistics of deviations between noise calculation models 1 and 5 (in dB).

Distance [m]	*Level [m]*	*Count*	*Quartiles*					*IQR*	*Upper fence*	*Lower fence*	*Mean*	*% outliers*
			100	*75*	*50*	*25*	*0*					
10	1.6	209	19.4	1.1	0.3	0.1	0.0	1.0	2.6	-1.4	1.0	5
	2.8	209	18.6	0.6	0.2	0.1	0.0	0.5	1.4	-0.6	0.8	8
	4.0	209	17.6	0.5	0.2	0.1	0.0	0.4	1.1	-0.5	0.6	6
25	1.6	206	13.1	1.1	0.4	0.1	0.0	1.0	2.6	-1.4	0.9	7
	2.8	206	12.6	0.9	0.3	0.1	0.0	0.7	2.0	-1.0	0.7	6
	4.0	209	13.1	0.8	0.2	0.1	0.0	0.7	1.8	-0.9	0.7	8
50	1.6	200	17.4	2.2	0.7	0.2	0.0	2.0	5.2	-2.8	1.7	9
	2.8	200	16.3	1.8	0.5	0.1	0.0	1.7	4.4	-2.5	1.3	8
	4.0	205	16.2	1.3	0.4	0.1	0.0	1.2	3.1	-1.7	1.1	9

noise management. The purpose of the analysis presented in this paper was to determine which simplifications of noise modeling input data for rail line M604 Oštarije – Gospić – Knin – Split could be made in order to reduce model preparation and noise calculation time without significantly affecting the modeling results.

Based on the analysis of the calculation results for the five noise models with different levels of detail it was concluded that for the largest part of the analyzed 62 kilometers long rail track section a satisfactory level of results accuracy can be achieved by application of noise model 2. This model consists of geometric model in which the relief is represented by contours without elevation data, the embankments are neglected, and buildings are modeled with their plan view and the number of floors, as buildings with a flat roof. The speed for each train type included in the model is the maximum permissible speed at the considered rail section, which depends on the train type.

A detailed calculation model 5 should be applied to track segment where any of following geometric characteristics appear:

- fill embankments higher than 4 meters,
- cut embankments higher than 10 meters,
- height differences in relief in the proximity of tracks over 15 meters (at a distance less than 25 meters from the track),
- objects that affect propagation closer than 20 meters from the track.

This model consists of geometric model in which the relief is represented by contours with 0.5-meter equidistance, the embankments are modeled with break lines with corresponding 3D coordinates, buildings are modeled with their plan view and the number of floors, as buildings with a flat roof. In this model, bridges, overpasses, and water surfaces, if any, should also be modeled. The equivalent train speed for this model is defined by aggregating maximum permitted and limit speed values. Track segments along which train speed increases or decreases, from limit to maximum permitted values, should be defined for speed interval of 10 km/h, and acceleration and deceleration values that depend on train type.

The relief that could demand the use of detailed noise calculation model 5 is specific for the mountainous and rolling terrain, with predominantly uninhabited areas of Croatia, through which around 51 % of, mostly local and regional, rail lines pass. The rest of the existing rail network is situated mostly in lowland terrain. On these lines, specifically for the track sections outside urban agglomerations, simpler noise calculation model 2 could be used for the purpose of rail noise management, which would significantly reduce time and funds spent on rail traffic noise model preparation.

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