On the importance of accuracy of geographic model data for noise impact studies

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Summary

Since 1 July 2012, ProRail has to work with a new legal system of noise production ceilings (NPCs) to control the noise impact of the railway traffic on its network. The new system requires that ProRail computes the noise impact of the yearly traffic on about 60.000 reference points and has to demonstrate that the noise stays below the NPC at each point.

ProRail has to compute the noise at each reference point using the Dutch computation method SRMII (which is the recommended European interim computation method for railway noise). This model has to be updated yearly to reflect all changes in the network and surroundings. The data for the model comes from different sources. It is possible that small changes in the model are introduced by small inaccuracies in the data collection process. A source of small changes is the collection of geographic data with photogrammetric measurements with its inherent measurement and processing (in)accuracy.

To investigate the sensitivity of the calculations to small data collection inaccuracies, we have done an extensive parameter study. We performed parameter variations in the nation-scale model and analyzed the resulting change in noise level on a statistical basis. This paper presents the results of this study and shows that the accuracty of the height information is crucial.

1 Introduction

Since 1 July 2012, the Dutch noise legislation has changed conceptually. There is a new lay that enforces that the infrastructure managers have to prove that they comply with the legal limits, not only when they build or change the infrastructure but also, they have to demonstrate, on a yearly basis, that the actual noise production is within legal limits.

The legal limit is called the noise production ceiling (NPC) and is enforced at a collection of evaluation points (known as reference points) along the infrastructure. The actual noise level is controlled by measurements but determined by noise calculations using the yearly averaged traffic and actual state (with inherent acoustic properties) of the infrastructure. The systematics of NPCs is based on calculations, because noise calculations are considered more robust and cost-efficient than noise measurements. As a consequence, the infrastructure manager needs to have an accurate calculation model for its entire network and it needs to maintain and update this model to be able to check the NPCs yearly.

The necessity to build and maintain a calculation model for several years brings new challenges. One of them is how to deal with model updates if the source data for the existing infrastructure changes. When the model of existing infrastructure or surroundings is updated, the calculated noise levels should not change because nothing has changed in the real world. In practice, there will always be small changes due to inaccuracies in the data collection process. The question is: what accuracy for the input data is required to ensure that the noise level at the reference points does not change due to modeling artifacts? To find an answer to this question we have done a comprehensive study on the sensitivity of the calculated noise levels due to small changes in the input data. We have limited the study to geographical data of infrastructure and surroundings since preliminary studies showed that those data were likely to have largest influence.

2 Noise model for the Dutch railway network

2.1 Automatic model building

For railways, ProRail is the responsible organization to ensure that the noise emission on all national railways remains within the legal limits enforced by the NPCs. This implicates the need of a model of their complete Dutch network (over 3000 km of track) and close surroundings (without buildings). Furthermore, calculation software is required, based on the SRMII calculation method, to be able to check the noise level on the network of about 60.000 reference points.

The calculation model for the NPC calculations consists of three parts: 1) the geographical data for track and infrastructure elements (bridges, tunnels, noise screens etc.) 2) the traffic data (trains, routes, timetable, speed profile etc.) and 3) track properties (track type, rail roughness, and steel bridge emissions). The data on which the model is based are maintained by ProRail.

2.2 Updating

The fact that ProRail has to check the NPCs has led to new requirements for model accuracy that were not relevant before. In the past, an acoustic consultant would make a model to the best of his or her knowledge and would calculate the noise immission and noise control measures using that model. Then, the noise control measures would be implemented and the model would cease to be relevant. The noise control measure is what would remain for the future.

In the ‘NPC world’, not only the noise measures remain, but also the NPC limit values that are enforced by law. And this is where difficulties may arise. The law requires ProRail to update the model every year to reflect the changes that have been made to the track infrastructure in real life. These changes may of course lead to changes in the noise immision at the reference points and may require that new noise reduction measures have to be taken.

However, there is another source of changes to the model: each year, the geographic information department of ProRail updates (part of) their GIS model of the track and its surroundings. Each year, this GIS model might be slightly different due to the fact that the geographic data acquisition has a limited accuracy (in the order of 0.1-0.5 meters for photogrammetric measurements). This means that, although nothing has changed in the outside world, the model used to check the NPCs can have 'small' changes which may lead to changes in the computed noise immission values at the reference points. Of course these modeling uncertainties should not lead to the necessity to take new noise reduction measures because nothing has changed in practice.

Clearly, ProRail wants to know to what extend the yearly model updating process would lead to unwanted changes in the noise immision on the reference points. We therefore devised a parameter study to investigate the impact of model changes to the computed noise immission.

2.3 Sources of modeling inaccuracies

The impact of small changes in the model data is different for the various input data types:

- Discrete data (such as train type, track type, speed profile, routes) may have a large influence but there is no inherent inaccuracy in the acquisition of these data: when they are stored correctly and do not change during the year, then they have no impact on the calculations from year to year;
- Proportional data (such as number of vehicles, rail roughness) have a proportional influence: a small change of these data leads to a proportionally small change in the calculated level at the reference points (e.g. a 10% error in the number of vehicles will typically lead to a 0.4 dB change in noise immission). But, as for discrete data, there is no inherent inaccuracy in the acquisition of these data;
- Geographic (such as position of track and all infrastructure elements) have a non-proportional influence on the noise calculations: a small change of e.g. 10 cm noise barrier height can have an impact on the calculated noise level between 0 and say 5 dB, depending on the relative position of track, noise screen and receiver. So small geographic changes due to the acquisition process may lead to a fictitious exceeding of the NPC.

This means that for ProRail, the first priority is to control the accuracy of the geographic input data.

2.4 Parameter study strategy

To investigate the impact of geographic changes we have made a parameter study. For this study, a typical approach would be to define a limited number of typical model configurations and vary the geographic position of the model components (e.g. tracks position in X, Y, Z, noise barrier height and distance from track, small variations in the terrain model, horizontal and vertical position of bridges etc.). This provides a well-controlled environment for the parameter study, but has some disadvantages:

1. It requires a lot of model building and separate calculations for each parameter variation;
2. A lot of care has to be taken to ensure model consistency when individual model components are varied. For example by changing the position of the bridge surface with respect to the track, the track may be off or under the bridge surface, which is physically impossible. Or by changing a noise screen position, it may get unrealistically close to the track. So these studies may lead to false conclusions. These consistency rules imply that the parameter variation models need to be checked by hand. A time-consuming task;
3. Even with consistent models, the question arises: to what extend these 'typical' model configurations are representative for the actual model covering the whole of the Netherlands. Do we have the worst cases or are we underestimating the problem?

To overcome these disadvantages, we chose a different approach: we chose not to vary the model components but to vary the position of the reference points on which the immision level is computed. Here we use a kind of 'geographic reciprocity' principle. You can bring the track closer to the receiver or you can bring the receiver closer to the track. Both will lead to approximately the same change in noise immision level. The big advantage of changing the receiver and not the source is that the model consistency remains unaffected. And since no manual check is necessary, the variations can be done automated so it takes less time to do the parameter studies. The automation makes it possible to do the parameter study on the complete model of the Netherlands, so representativity is guaranteed.

2.5 Parameter variation study

The first step in the study was to vary this position in three orthogonal directions: perpendicular (R) to the track, parallel to the track (P) and in height (Z) (see Fig. 1). The reference points for the NPC calculations are placed at 50 m from the nearest track, at a height of 4 m above the ground level. For each of the reference points we calculated the change in computed sound level compared with the original computed value.

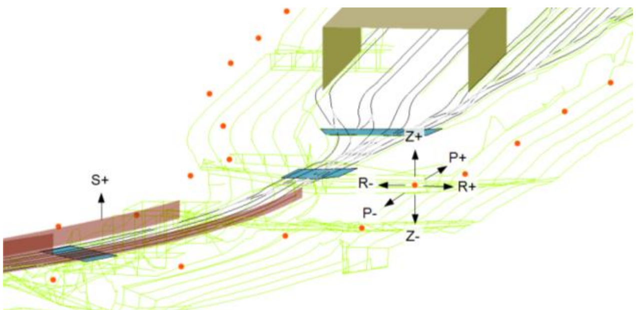

Fig. 1. Variations for the reference point position

3 Results

3.1 Distance variation

The influence of distance variation can be assessed by comparing the results of the R+1 m and R-1 m sets with the REF set. In Fig. 2 the computed difference due to the distance variation is shown as a histogram.

If we just look at the distance effect, we can estimate the expected change in noise level by looking at the noise emission formulae in the Dutch computation method. The noise source is a dipole line source so the geometric attenuation term follows the $lg(1/r)$ rule. This means that we would expect a change of about 0.09 dB at a distance of 50 meter from the track. The actual average change is -0.12 and +0.13 dB for the R+1 m and R-1 m respectively. This corresponds well with the lg(1/r) dependency of noise level to the source-to-receiver distance r in the noise emission formulae in the Dutch computation model. We also observe that both distributions are symmetrical with respect to 0 dB. We expect that if we would randomly vary the distance to the track, a distribution with an average of 0 dB would be the result.

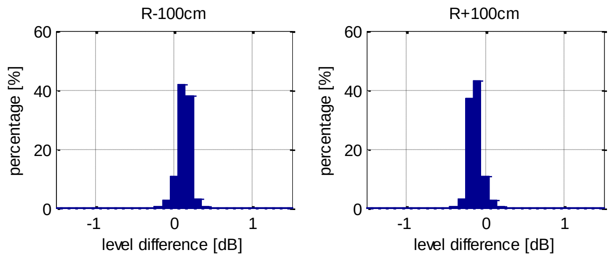

Fig. 2. Computed noise level difference for a distance change minus/plus 100 cm.

3.2 Position change in along the track

Changing the position of noise screens, platforms and bridges along the track is equivalent to changing the position of the reference points parallel to the track. The reference points are positioned at 50 m from the track and have a mutual distance of 100 m. We changed this position with plus and minus 1 m. This showed a symmetric noise level change around the average value of 0 dB and a sensitivity of 0.0018 dB/m (see Fig. 3).

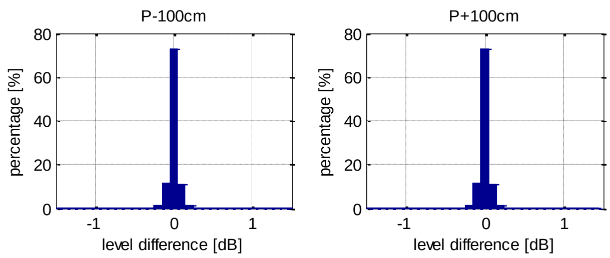

Fig. 3. Computed noise level difference for a parallel position change minus/plus 100 cm.

3.3 Vertical position

Changing the position of the track and the height of the noise screening objects (noise barriers, platform walls, bridges etc.) can be simulated by changing the vertical position of the reference points. But a change of 1 m in the position of a reference point can or cannot be equivalent to a 1 m change of track position. It all depends on the relative position of source and receiver and whether or not there are objects in the line of sight from source to receiver. In general a displacement of the receiver of <x> m in vertical direction is equivalent to a change of track vertical position of <x> m when there are no objects in the line of sight, or the objects close to the track move in vertical direction with the same amount as the track (e.g. a screen will be defined with a height relative to the track, so if the track is raised, the top of the screen will be raised with the same amount in acoustic models).

To assess the sensitivity of the computed noise levels to vertical position, we have done four parameter variations: Z-100 cm, Z+100 cm, Z+50 cm, and Z+10 cm. The histograms of the level differences are displayed in Fig. 4. The parameter study shows that the noise level on average will change with 0.7 dB/m.

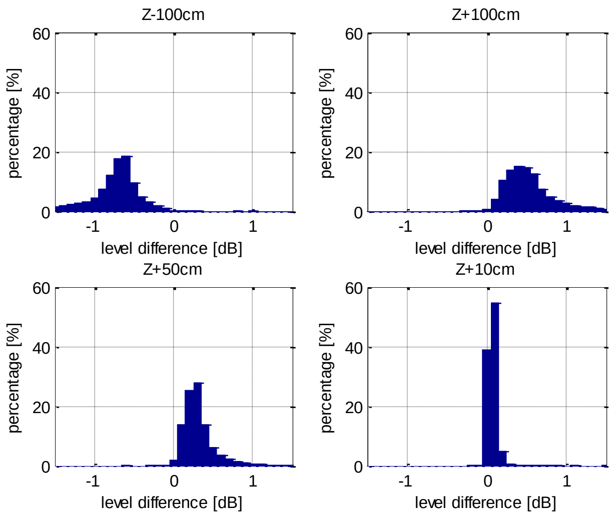

Fig. 4. Computed noise level difference for a vertical position change

In the analyses above we make no distinction between reference points that are behind noise screens (about 9% of the total) and reference points that have no screen between track and reference point. If we separate these two groups and determine the sensitivity we see that the reference points behind screens are more affected by the vertical position change: 1.2 dB/m for reference points behind screens and 0.64 dB/m for reference points without a screen immediately between source and receiver.

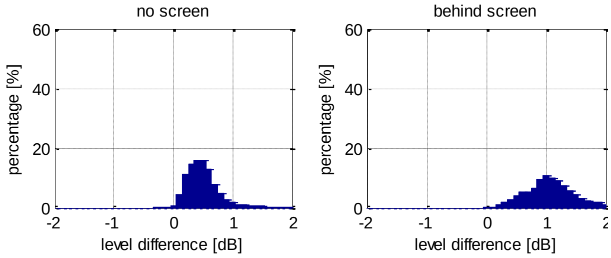

Fig. 5. Computed noise level difference for receivers for vertical position change of 1 m without and with noise screen in between track and receiver.

3.4 Screen height

To further investigate the influence of screens on the sensitivity, we have made another parameter study where we varied the screen height with 10, 20 and 50 cm and analyzed the computed noise level change. Off course, in most cases, there will be no sound level difference because in 91% of the cases, there is no screen between track and reference point. If we leave out the category with a 0 dB change, we get the histograms of Fig. 6.

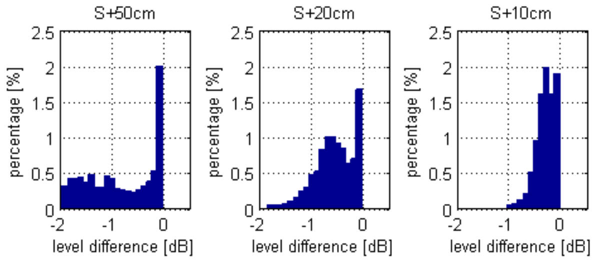

Fig. 6. Computed noise level difference with an increase of screen height of 50, 20 and 10 cm.

We found that the sensitivity is rather large and does not resemble a normal distribution. When we separately assess the sensitivity for reference points behind screens we find a value of: +3.1 dB/m. This implies that an 'artificial' exceeding of the NPC is most likely at reference points where the screen height is acquired independently of the source (track) height. The recommended solution is to always relate the screen height relative to the track height. The track and screen couple will move as a rigid system with respect to the reference point. In that case, the sensitivity is reduced to +1.2 dB/m (see section 3.3).

3.5 Combined sensitivity

We have used the GUM-method [3] to obtain a value for the combined sensitivity due to geographic uncertainty, where we have assumed that the positional uncertainty is independent in r, p, and z direction and that the screen height uncertainty is eliminated by relating the screen to the track height. In that case the total sensitivity is a defined as:

$$u_{\text{total}}^2 = \left(\frac{\partial f}{\partial r}\right)^2 u^2(r) + \left(\frac{\partial f}{\partial p}\right)^2 u^2(p) + \left(\frac{\partial f}{\partial z}\right)^2 u^2(z)$$

If we assume a standard uncertainty for the positional data of 0.1 m, then we get a combined uncertainty as shown in the table below.

parameter	sensitivity [dB/m]	standard deviation [dB]
distance	0.126	0.0126
parallel position	0.0018	0.00018
height (behind screen)	0.64 (1.2)	0.064 (0.12)
total		0.065 (0.12)

4 Conclusion

Computed noise levels at the reference points for NPCs are not very sensitive to small variations of the geographic position in the horizontal plane. However, the computed noise levels are rather sensitive to accuracy of the vertical position of the model components, especially for noise screen height and/or the position of the track close to noise screens. The high sensitivity of the results for changes in the screen height can be eliminated by always relating the top of the screen to the actual track height, when building the computation model.
Using this approach we have estimated the standard uncertainty in the computations to be 0.065 or 0.12 dB for reference points without and with screen respectively.

References

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