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Comprehensive noise assessment in complex situations with more than one mode of transport

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Abstract

The exposure to noise from more than one source is no rarity nowadays. In most cases the assessment of immission load is performed for each traffic carrier individually and superposition of different sound levels is not treated in any special way when mitigation measures are realized. Thus, health-impairing situations are not properly resolved or even remain undetected. In order to establish a comprehensive approach for the joint evaluation of road, railway, aircraft and shipping noise immission, we look at different test cases, which serve as exemplary scenarios for critical noise situations. By comparing different calculation and assessment methods (e.g. energetic sum, spectral analysis, weighted noise index, VDI 3722-2 ...) we want to give first answers to the questions: How to calculate the overall sound level when several noise sources are present? How to consider the diverse physiological and psychological effects of noise on people? What are possible unambiguous indicators for triggering acoustically effective mitigation measures?

Keywords: noise immission; noise effect; sound level calculation.

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1. Introduction

In former times (the beginning of industrialization) sound from industrial facilities and the different means of transport were not annoying. This was because of three reasons. The first and simplest reason was just the population density. The second reason was, like the first, also simple. It was just the low amount of sound emitting machines and vehicles at the beginning of industrialization. From these two reasons it can be derived, that the occurrence of "machine"-noise was not very high. This is a physical or rather mathematical factor, calculated from noise level and duration. The third reason that "machine"-noise wasn't that annoying in former times is a psychological one. It was the sound of industrialization. The sound of the economic boom. Hence the sound had a positive connotation.

From the 1950s until now world population has more or less tripled. Industry has grown, cars on the roads, trains on the rails and planes in the air are no longer single events. And now we have recognized, that humans not only become annoyed from noise, they also can get affected in their wellbeing. Due to globalication and the wish of humankind for unlimited mobility, noise emissions from the different modes of transport get more and more relevance.

In the planning stage of new traffic infrastructure or the extension of existing traffic infrastructure, there are standard procedures of noise precaution to protect residents from high noise levels. When, e.g. because of increasing traffic the noise level is rising above a certain value, noise measures in the context of noise remediation can take place to protect residents.

These procedures exist for every single mode of transport. But in complex situations with more than just one mode of transport there is no approved method to handle this. What makes these complex situations with more than one mode of transport hard to handle are a lot of measurable quantities like the different frequency spectra, the different temporal development of the noise level, the amount and position of the sound sources, the frequency of incidence and many more. But there are also non-measurable or rather "soft" values, because they depend on psychological factors that not only vary between different human beings, but also depend on the emotional state of one person. All these factors are playing a role in the so-called noise effect research. The problem is to unify these with the goal to obtain an indicator for rating the different situations. Afterwards measures should be triggered depending on the indicator.

The "German Federal Ministry of Transport and digital Infrastructure" sets up a program, called "Expertennetzwerk" (expert network), that deals with many environmental topics. This paper refers to the key topic "Minderungsmöglichkeiten von verkehrsbedingten Geräuschemissionen und Lärmimmissionen in Luft" (Possibilities for the mitigation of sound emissions and noise immissions in air). The long-term goal of the project is to have a catalogue of indicators and mitigation measures for complex situations with more than one mode of transport. First we start by comparing different calculation and assessment methods, like the energetic sum, spectral analysis, weighted noise index, VDI 3722-2 and so on, in order to answer the questions how to calculate the overall sound level of the different sound sources, how to consider the diverse physiological and psychological effects of noise on people und work out what are possible unambiguous indicators for triggering acoustically effective mitigation measures.

2. Calculation and assessment methods

There are different ways coexisting, to physically/mathematically calculate a sound level resulting from more than one sound source. There are also different methods coexisting, to assess a situation where a physical/mathematical calculation cannot lead to a result. Which of the different methods in generally has to be choosen for a specific situation depends for example on the task and boundary conditions like the coherence of the sound sources, the sound level difference between the sound sources or the required accuracy of the result and so on. If one of these methods is suitable for the calculation of the overall sound level solely, has to be evaluated. In some cases it might also be constructive to combine different methods.

2.1. Energetic sum

With the “energetic sum” the total sound pressure level of n incoherent sound sources can be calculated. For the single n sound pressure levels the antilogarithm have to be taken. The resulting square sound pressures can now be summed up. The energetic sum is ten times the logarithm of the sum.

$$L_{p\,sum} = 10 \cdot log\,(\sum_1^n 10^{(0.1 \cdot L_{p,i})}) \tag{1}$$

$L_{p,\,sum}$: Total sound pressure level
$L_{p,\,i}$: sound pressure level of a single source
n: number of sound sources

The energetic sum is a single number describing the overall value of signals. Very different sound compositions can have the same value of the energetic sum. So the energetic sum does not distinguish how the sound signal looks like in its chronological sequence or in its frequency composition.

The calculation of the energetic sum of coherent sources with equation (1) is not possible because of interference. Here the superposition principle is needed. Depending on the position of immission, an increase of up to 6 dB as well as total cancelation (for two similar signals) is possible. The determining factor for the degree of cancelation/enhancement is the phase difference between the signals.

Generally speaking, the energetic sum is best suitable to calculate the overall sound level of n sound sources of broadband sound without tonal components. A good example is road traffic noise, which normally has no tonal components.

2.2. Spectral analysis

To consider the frequency composition of the sound spectra of different sound sources and to show this in the result as well, a spectral analysis is necessary. Mathematically the spectra analysis works like the energetic sum. However, in the spectral analysis not the overall sound levels of the different sources are added up, but the single frequency components. The outcome is also a frequency spectrum. This spectral analysis can be in 1/n-CPB classification (constant percentage bandwidth) or as FFT (Fast Fourier Transformation).

2.2.1. CPB analysis

Common CPB partitions are octave or third-octave ranges. For 1/3 octave partitions an octave is divided into 3 parts (see example Table 1). The sectioning is in a logarithmic scale.

Table 1. Example for 1/1-octave and 1/3-octave centre frequencies.

Octav	Hz	63			125			250			500			1000		
Third-octave	Hz	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250

For a more detailed analysis, the octaves can be divided into 6, 12, 24, … partitions (1/6-, 1/12-, 1/24-octave bands). The value of a 1/n-octave band sound level represents the sound energy of a certain bandwidth, where the upper (f_o) and the lower frequency limit (f_u) follow the ratio

$$\frac{f_o}{f_u} = \sqrt[n]{2} \tag{2}$$

f_u: lower frequency limit
f_o: upper frequency limit
n: division of one octave

In a CPB analysis all sound energy in the frequency range is included. Nothing will get lost. You just cannot say, where exactly in the chosen 1/n octave band it is.

2.2.2. FFT analysis

If an accurate determination of frequencies is required, an FFT analysis is needed. In an FFT analysis discrete frequencies are calculated, which depend on the frequency range and the number of supporting points. The sectioning is in a linear scale.

$$df = \frac{\Delta f}{n-1} \tag{3}$$

df: frequency steps between two supporting points
Δf: frequency range
n: number of supporting points

The advantage of an FFT analysis is the knowledge of the specific frequencies. But you do not really know what is in between two supporting points.

2.3. Weighted noise index

The weighted noise index is a combined method of the energetic noise level and the number of inhabitants. It uses the noise exceedance and the number of affected people. The noise exceedance is the difference between the noise exposure and a certain threshold value. It is calculated like in equation (4): Number of affected people times the noise exceedance.

$$LKZ = \sum n \cdot (L_e - L_t) \tag{4}$$

LKZ: weighted noise index (German: Lärmkennziffer)
n: number of people affected
L_e: noise exposure
L_t: threshold value

Sometimes it is very difficult for planers of noise abatement measures to decide where they have to spend their limited budget to get the greatest benefit. The weighted noise index helps to classify different districts with different numbers of inhabitants, different noise exposure and maybe also different threshold values. So the planer has a mathematical basis to decide, if it is for example more “worth” to slightly reduce the noise for a huge amount of people, or to largely reduce the noise for a few people.

2.4. VDI 3722-2

The German VDI 3722 (VDI: „Verein Deutscher Ingenieure“, association of german engineers) consists of two parts. The first Part (VDI 3722-1) describes terms and definitions and explains the different influence of noise on human being. Part two of the VDI 3722 is a guideline where procedures to determine characteristics for evaluating in cases of impact of different types of noise sources are proposed. This with regard to annoyance and self-reported sleep disturbance.

Like the weighted noise index (LKZ) the VDI 3722-2 does not only calculate just values of noise levels. It also combines the noise level and the number of affected people. It shows a methodology to rate complex noise situations with different sources (road traffic, rail traffic and air traffic) and distinguish between different kinds of annoyance/disturbance of affected people.

Measured or calculated noise level values will be converted into a renormalized substitute level. This renormalization is based on exposure-response functions for the different sources. The road traffic noise level and one or both of the other renormalized substitute levels can simply obtained with the energetic approach. The result is called the “effect related substitute level”. It is a single number value that represents the cumulated noise level of at least two different noise sources respectively modes of transport and does already involve the impact of different noise sources on humans.

With the VDI 3722-2 it is possible to calculate the percentage of the annoyed (% A), the highly annoyed (% HA), the self-reported sleep disturbed (% SD) and self-reported highly sleep disturbed (% HSD) separately for every single mode of transport from the rating level (L_r).

3. Comparison

With a noise propagation calculation software, the "normal" energetic sum, the summation with VDI 3722-2 and the frequency spectra are being compared. The investigation is limited to the two modes of transport often appearing together, namely road and railway traffic in parallel. Besides the initial situation of free sound propagation, four different setups of noise barrier installations are calculated (see Fig. 1). The sound levels at two points on both sides of the sound sources are considered for the comparison.

1. Initial situation:
   - road and railway in parallel,
   - free sound propagation.
2. Road with noise barriers of 4 m hight at both sides:
   - surfaces of noise barriers facing road were defined as sound absorbent,
   - railway without noise barriers.
3. Railway with noise barriers of 4 m hight at both sides:
   - surfaces of noise barriers facing railway were defined as sound absorbent
   - roadway without noise barriers
4. Road and railway in between noise barriers of 4 m hight:
   - surfaces facing railway and roadway were defined as sound absorbent.
5. Road and railway in between noise barriers of 4 m hight:
   - additional noise barrier between road and railway,
   - both sides of this barrier were defined as sound absorbent.

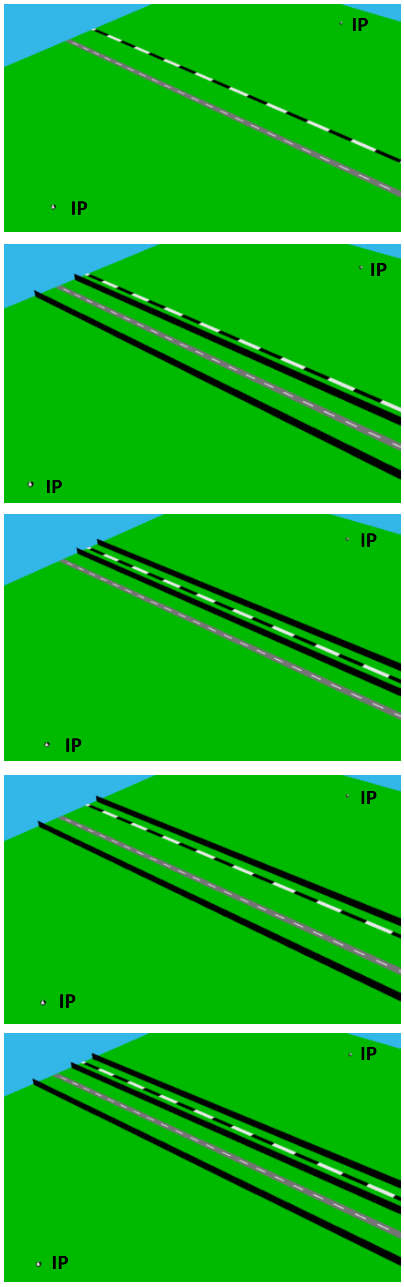

Fig. 1 Five different setups for the placement of noise barriers.

4. Results

For the results, the initial setup of free sound propagation has been taken as the reference for the other four different setups with noise barrier installations. All calculated sound levels at the two points of immission of these four setups have been set in reference to the initial setup.

$$\Delta L_{rel,\,setup} = L_{setup} - L_{initial\ setup}$$

Negative values of ΔL represent an improvement of the setup in comparison with the initial setup. Of course it is needless to say, that every setup with noise barriers has an improvement in the reduction of the sound level in comparison to the initial setup. The interesting questions are on the one hand, how the different setups with noise barriers differ among each other and which setup lead to the best benefit, and on the other hand how the different calculation methods assess the respective noise situation. Figure 2 and 3 show the results for the different mitigation measures for the points of immission on the side of the road and on the side of the railway respectively.

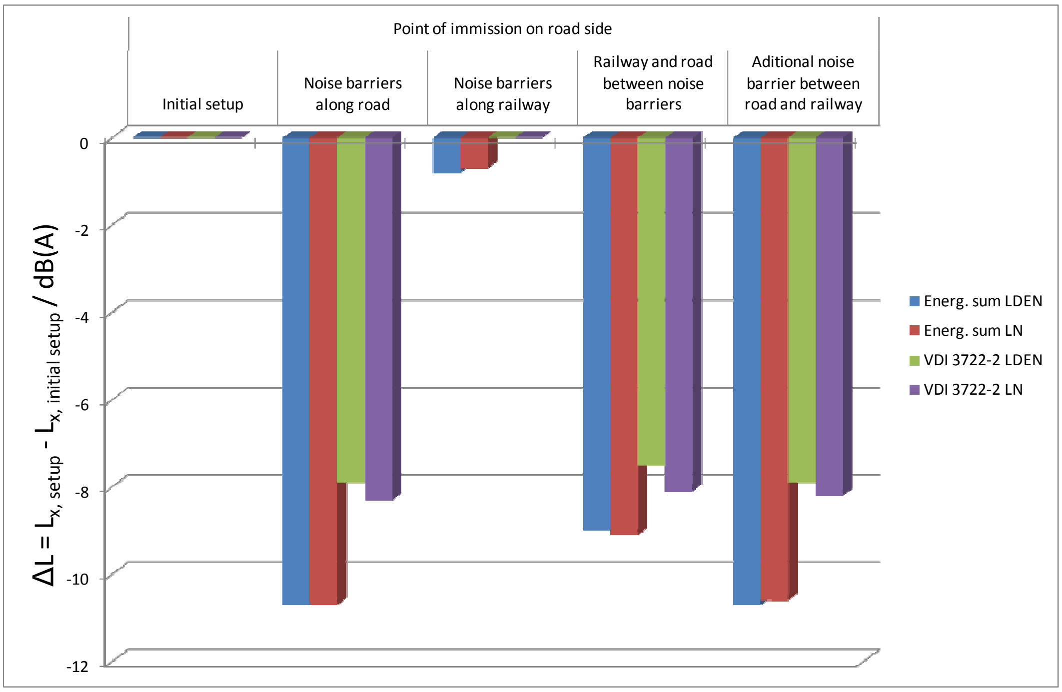

Fig. 2 Mitigation of sound level in the different setups at the roadside point of immission.

For the roadside point of immission one can determine, that the noise barriers along the roadway are sufficient for the mitigation of noise level. The noise barrier between the point of immission and the road is best situated to reduce the road-noise. The other barrier between the road and the railway in turn is, for the roadside point of immission, the best place to reduce the noise from the railway. Without this noise barrier the reduction is less (case 4, road and railway in between noise barriers). Because the point of immission on the roadside is closer to the road than to the railway and the level of emission of the railway is lower than the level of emission of the road, noise barriers just along the railway do not have any significant effect to the mitigation here.

In the comparison between the two methods (VDI 3722-2 and energetic sum), the VDI assesses the setups of “noise barriers along road”, “road and railway between noise barriers” and “additional noise barrier between road and railway” nearly at the same level. The energetic sum values the 4th case (“road and railway between noise barriers”) about 2 dB(A) less efficient than the other two setups (2 and 5).

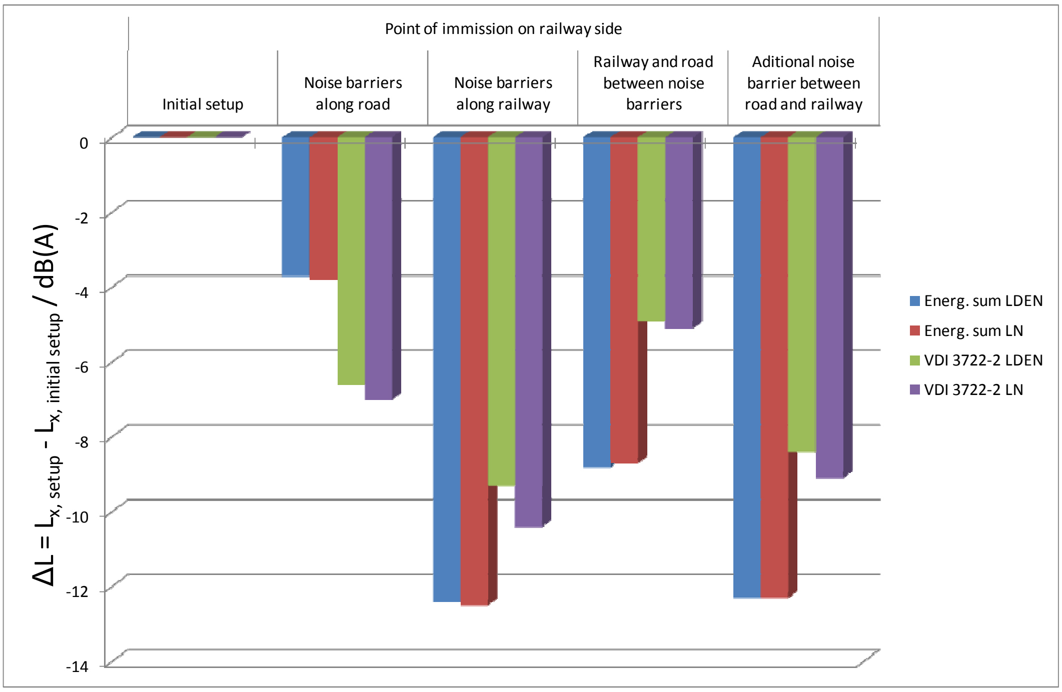

Fig. 3 Mitigation of sound level of different setup at the railwayside point of immission.

For the immission point on the railway side the results vary much more. The setups 3 (“noise barrier along railway”) and 5 (“additional noise barrier between road and railway”), are the same for the energetic sum and nearly the same calculated on VDI-bases. As for the point of immission on the road side, for the point of immission on the railway side it is sufficient to install the two nearer noise barriers. And also for this side, the energetic sum values the 4th case (“road and railway between noise barriers”) less efficient than the other two setups (2 and 5). Because the road has a higher sound power level as the railway, the value of lower efficiency here is about 4 dB(A).

In the comparison of the two valuation methods (VDI 3722-2 and energetic sum) for the setups 3 to 5 the energetic sum values the mitigation of the measures about 4 dB(A) more efficient than the VDI. But for the second case (“noise barriers along the road”), it is reversed. Here the VDI valuates the situation about 3 dB(A) more effective.

In the following figure (Fig. 4) the difference in frequency composition of the received sound between the two sides where the points of immission are situated for the different mitigation measures are shown. For the symmetric setups (“initial setup”, “road and railway between noise barriers” and “additional noise barrier between road and railway”) the frequency composition is more or less the same. The differences appear in the asymmetric setups (“noise barriers along road” and “noise barriers along railway”) where one mode of transport becomes repressed.

These difference in the frequency composition are better represented in figure 5, where for each point of immission the differences of the two asymmetric setups have been calculated. For the point of immission on the road side, the sound level especially of the frequency of 125 Hz and the range from 1000 Hz to 4000 Hz is conspicuous. In the other case, for the point of immission on the railway side, a wider frequency range from 500 Hz to 8000 Hz of the sound level is conspicuous, but not as high in its maximum.

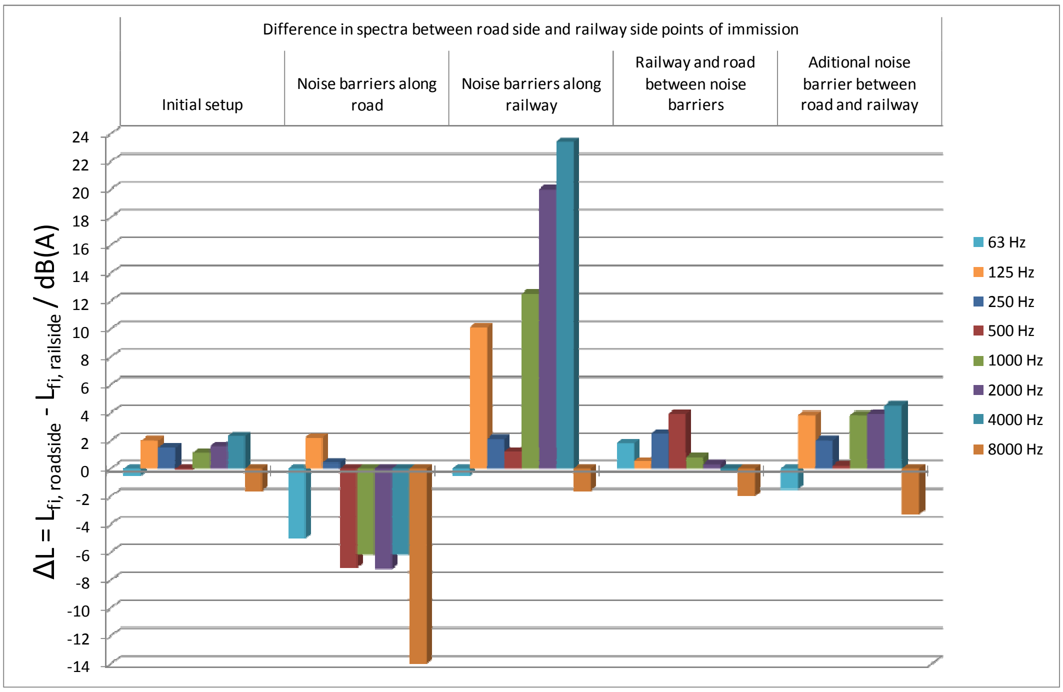

Fig. 4 Differences in spectra between road side and railway side points of immission.

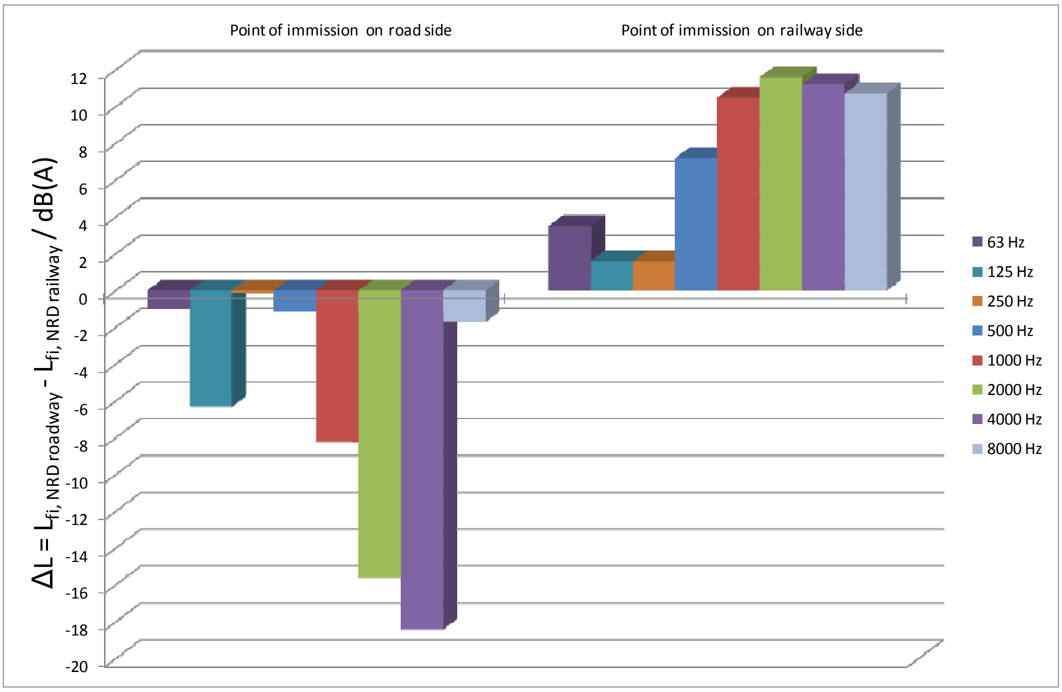

Fig. 5 Difference in spectra of the two setups “noise barriers along roadway” and “noise barriers along railway” for the points of immission on the road side and railway side.

5. Conclusion

In this survey, the difficulty of calculating an overall noise level of different sound sources has been illustrated. Different methods to calculate this overall noise level have been introduced. Advantages and disadvantages of the methods have been shown.

A simple example of a road and a railway in parallel has been set up in a noise propagation calculation software. With this example, differences in the rating of the two methods of the energetic sum and the VDI 3722-2 could have been shown as well as the effect of different measures to mitigate the noise in areas beside transport infrastructure. In further investigations, that has to be done in more detail and under inclusion of other methods the expertise on this subject has to be increased with the goal to get a fair method to assess complex noise situations and to work out measures for different complex situations, that ensure efficient noise mitigation under economic aspects.

6. References

Acoustics Effects of traffic noise - Part 2: Characteristic quantities in case of impact of multiple sources. VDI 3722-2 (2013).
Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation. ISO 9613-2 (1999).
Konzept für eine ruhigere Umwelt. Ministerium für Verkehr und Infrastruktur Baden-Württemberg (2015).