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Accuracy and precision of prediction models for road noise[a]

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ABSTRACT

Different calculation methods are used in different countries to calculate the noise caused by road traffic sources. The first step is to calculate the emission of a road from technical parameters like traffic flow, speed and road surface. The models used are quite different with respect to the parameters that are taken into account and in detailing the description of technical and acoustical parameters. The same is true for the calculation of sound propagation – while conservative empirical models describe the main influences like attenuation due to distance, diffraction and reflection with relatively simple algorithms some newer methods include ground reflections, meteorological effects and use even phase relations to predict coherence effects. It is shown that the increase of complexity of a model must not always produce better results, if accuracy, precision and transparency are taken into account.

1. INTRODUCTION

Many methods exist to predict the noise caused by road traffic. In a study financed by BAST (German Federal Highway Research Institute) it was investigated what parameters are taken into account and what methods are applied to describe their influence. The aim of the study was to develop recommendations for the further development or improvement of the existing calculation method RLS-90.

2. ACCURACY AND PRECISION

A lot of decisions must be taken if a calculation method for a complex source type like road traffic shall be optimized. The source itself is in many cases a broad stream of different vehicles and all modeling approaches can nothing be than a rough approximation of the truth. A view from a window to a multilane road nearby shows that the single vehicles are partially screened and that the detailed source distribution changes from minute to minute. Each description in terms of point-, line- or area sources must be an approximation and can only simulate averages with respect to time. If we try to calculate the instantaneous sound pressure level we will fail on account of the complexity to describe the detailed type, position and radiation of all vehicles. It is obvious that there are limits for an improvement of a prediction method by a more and more detailed modeling. The same is true for the detailed modeling of parameter influences on the propagation path – it makes no sense to invest a lot of effort in the detailed description of a certain parameter or effect, if the input data are not available or if other effects dominate the result. At the end the influence of different phenomena on the final result, data availability and cost and effort for the description of these different phenomena should be balanced to get an optimized result.

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Some important aspects should be taken into account if a calculation method is to be developed or evaluated.

Accuracy of a calculation method

describes the deviation of calculated results from the values obtained by an "ideal" measurement. An "ideal" measurement is characterized by negligible uncertainties.

Precision of a calculation method

describes the differences between results, that are obtained if different experts apply the calculation method in exactly the same case.

Transparency

is an expression for the ability to understand and to retrace calculations in each step. It is clearly an advantage if simple plausibility checks can be made and if it's possible to reproduce results in simple cases with a hand held calculator.

With more complex procedures "**Transparency**" must be replaced by a system of

Quality assurance

for software realizations. This means that algorithms and all steps from input to output data must be described so unambiguously, that the application of different software packages on the same test cases produces the same results. Such test cases must be part of the method.

The overall target of measurements and/or calculations is clearly to quantify noise immissions with respect to unwanted noise effects and therefore to compare with limits where such exposures cannot be accepted. Therefore it is always a general target to use **accurate** methods and to get resulting noise levels that indicate the real exposure of people.

But if a calculation method is used to check if a planned situation is in accordance with legal requirements the **precision** of a method may be even more important than the accuracy. An extreme example is the calculation of aircraft noise – if the local position of a noise contour decides if financial compensation will be paid to the owner of a building, a spatial dispersion of more than ± 5 m between the contours calculated by different experts investigating this case is not acceptable. It can easy be shown that this means that the calculation results should show not larger differences than 0,001 dB in many cases. This extremely requirement about precision has nothing to do with human noise reactions – it is a consequence if calculated noise levels decide about permissions, compensations or necessary measures.

It is recommended to think thoroughly about an optimal balance between wanted accuracy and necessary precision. Scientists and acoustic experts show a bias towards increasing the accuracy by including more and more phenomena. But this implements many screws that can – and must - be adjusted and will on the other side produce differences that decrease precision.

3. SOUND EMISSION OF ROADS

The calculation methods that have been included in this comparison are shown in the following table. The corrections $C_{emission}$ have been derived by comparing the calculated receiver levels in short distance to include ground influences at the source – insofar the source is a piece of a road with the vehicles on it and the reflecting road surface. The emission values can be transferred to A-weighted length related sound power levels by

$$L'_{WA} = L_{emission} + C_{emission} \tag{1}$$

Table 1: *Emission quantities and conversion values.*

Method	Country	Emission value $L_{emission}$	$C_{emission}$
ISO 9613-2	International	LWA'	**0.0**
RLS-90	Germany	Lm,e	**19.1**
STL86+	Swizerland	Lr,e	**3.2**
RVS 04.02	Austria	L1A,eq	**4.0**
CRTN	United Kingdom	L10,18h	**15.1**
Nordic Pred. Meth.	Scandinavia	Laeq*,10m	**14.2**
NMPB	France	LWA'	**0.0**
SonRoad	Swizerland	LWA'	**0.0**
Harmonoise	Europe	LWA'	**0.0**
NORD 2000	Scandinavia	LWA'	**0.0**
TNM	USA	Ltraf	**19.8**

The simple scenario shown in figure 1 was used to investigate the dependency of road emission from speed and in some cases from other parameters for passenger cars and trucks.

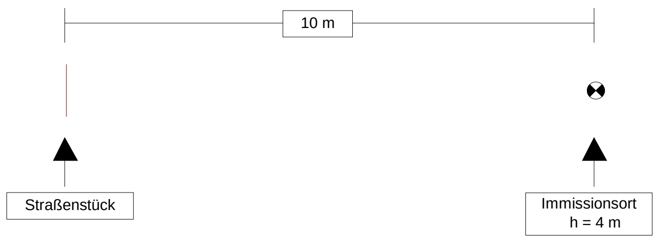

Figure 1: Scenario used to investigate the dependency of emissions from parameters.

The sound level produced by a piece of road was calculated at a receiver in 10 m distance. Even if this is in reality an immission, it reflects exactly the dependency of the emission from parameters. The distance of 10 m was chosen to be independent from different source heights, from ground reflection at the source and other influences that may be different with different methods.

Only for this summary all curves – separate for passenger cars and trucks – are presented in one single diagram. But it shall be taken into account that part of the spread of these curves is produced by different flow conditions by the NMPB methodology.

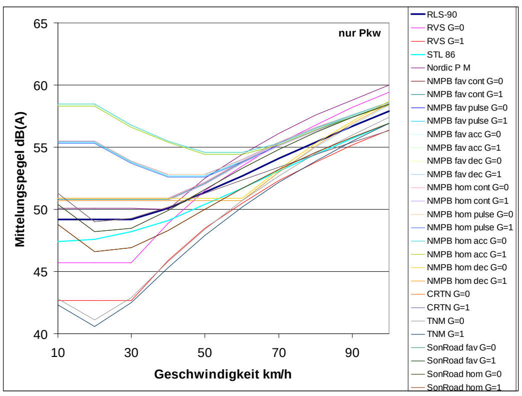

Figure 2: The emission of passenger cars in dependence of speed determined with different methodologies.

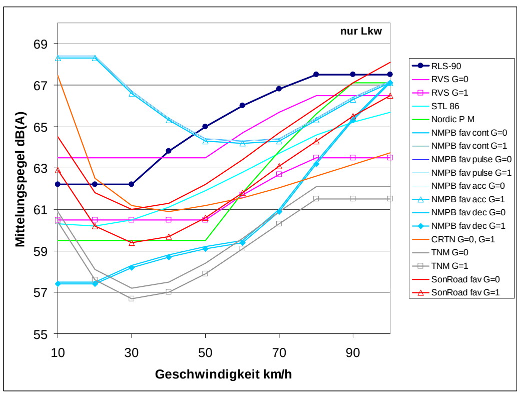

Figure 3: The emission of trucks in dependence of speed determined with different methodologies.

Figure 2 shows that the spread for passenger cars above 50 km/h is less than 5 dB. With lower speeds this spread is determined by different flow conditions.
With trucks the distribution of emission values is by far larger, as it is shown in figure 3.

These are only some of the results presented in the final report. The comparison shows, that alone the corrections according to road gradient or road surface produce considerable different emission values if different methods are applied. The corrections for road gradients in figure 4 are applied to the A-weighted emission value – it is obvious that it makes no sense to calculate emission and propagation very detailed in many narrow frequency bands, if an overall correction of more than 3 dB is applied. The level increase at roads with gradients is caused by the engine and not by the tyres – therefore the spectrum will change. This means that the spectrum used with the same correction in all bands is not correct and it may even be sufficient to calculate only related to A-weighted overall levels.

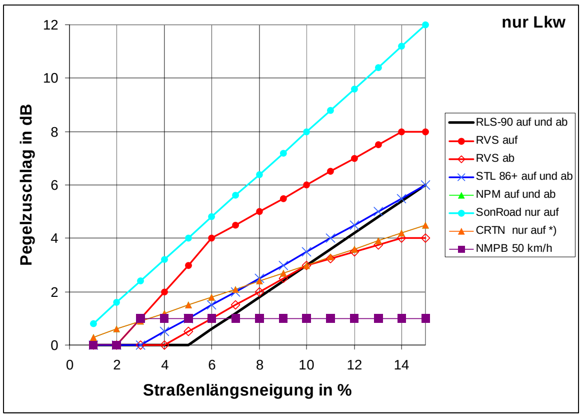

Figure 4: Level correction for road gradients according to different methodologies.

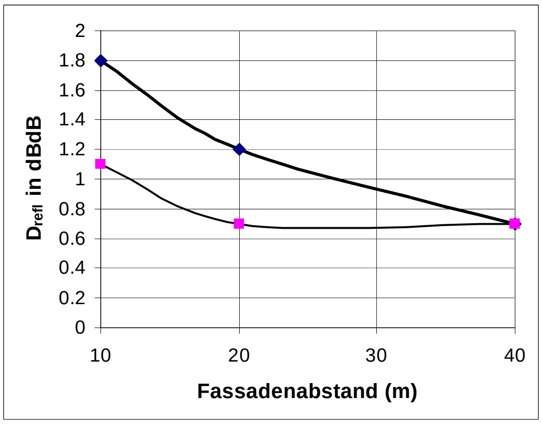

Figure 5: Level increase caused by reflections in dependence of the distance of the facades at opposite sides of a road (absorption coefficient 0.05 and 0.2).

With RLS-90 reflections of 1st order at facades and barriers are calculated in detail applying the mirror image method – a further level increase caused by multi-reflections in canyon-type roads is added as correction. This strategy is sufficiently accurate and very precise, because the correction for multiple reflections is exactly defined as a function of the geometric parameters of a street canyon. Using mirror image method to calculate higher reflection orders will always reduce the precision of the method, because software strategies apply different break conditions and will produce different results in such nearly closed spaces.
Based on experience it was assumed that the multi-reflection correction D_{ref} in RLS-90 is to large. Therefore this correction has been determined by calculating the level in street canyons summing up the contributions of reflections up to the 10th order. Figure 5 shows the result as level increase in dependence of façade distance. This result shows that the detailed calculation of first order reflections is sufficient and the additional canyon effect can be taken into account by a small correction of 1 – 2 dB. But this procedure should be defined unambiguously.

The abovementioned standards and guidelines (Table 1) apply extremely different methods to describe the emission of roads. The simplest method is to use an A-weighted emission level as single number value. Although in the national methods even for this single number value different definitions are used, these can be transformed to a length related sound power level L'_{WA}. An exception is the $L_{10,18h}$ according to CRTN (UK). This value can only be transformed if the timely variation of the emission is known.

This A-weighted emission value is generally derived from analytical functions or tables that define the influence of parameters like traffic flow and road properties.
Even this first step is relatively complex, because one parameter may modify the relation between emission and another parameter. All the used relations are more or less crude approximations, because the real multi-parametric dependencies are by far too complex to derive them for all possible combinations of these parameters from measurements.

In some standards like RVS (Austria) or NMPB (France) the emission levels are defined in octave bands and a common reference spectrum is used to transform a single number emission value into levels of frequency bands. With the new draft of NMPB as well as with Nord 2000, Harmonoise-Imagine and TNM one third octave bands are used. With SonRoad (Switzerland) each 1/3 octave band is further subdivided in 9 separate bands, so that at the end 216 values define the emission of one single source.
The argument for detailed modeling of frequency distribution is generally that superposition of different rays like direct sound and ground reflection should take into account coherence effects and these need extremely narrow frequency bands. But on the other side the abovementioned corrections are not frequency dependent, because it's absolutely impossible to determine the relation between the influencing parameters in all possible combinations and the emission level separately for each of these frequency bands. On the other side a single number correction applied to a detailed frequency spectrum produces a spectrum with a wrong shape, if the real influence is frequency dependent. Therefore it makes no sense to describe the emissions very detailed and apply coherent superposition if on the other side single number corrections are used that determine the result.

The same is true for even more sophisticated methods like Nord 2000 and Harmonoise. They use relations of type

$$L_W(f) = a(f) + b(f) \cdot \lg\left(\frac{v}{v_{ref}}\right) \qquad (2)$$

to describe the dependency of the sound power level L_W in 1/3 octave bands f in dependence of speed v. For all 27 frequency bands the coefficients a and b are presented in tables separately for the emission caused by tyres and engine. Single number corrections for road surface depending on age and type are applied generally to tyre noise and corrections for acceleration and deceleration are applied to engine noise.

Summing up it can be stated that there is a tendency to describe the emission of road traffic more and more detailed. This reduces precision and transparency to an extent that possibly cannot be compensated by an improved accuracy of the results because the influence of parameters of traffic flow and road cannot be determined with the same resolution in frequency domain. It's worth to find a balanced description of all influences not to waste effort and to loose control without any real benefit.
Taking all results of this investigation together from our point of view it may be the best approach to distinguish between tyre noise and engine noise (as it is proposed by SonRoad and other methods) and to model the traffic of a one lane road by two line sources, one for engine noise and one for tyre noise, each of these characterized by an octave band spectrum and a separate height. Small or rarely used parameter influences are defined as single number corrections, large influences should be defined approximately frequency dependent (e. g. separate for 2 or three frequency intervals).

4. GEOMETRICAL MODELLING OF ROADS

The traffic of one lane is modelled by one or more vertically staggered line sources. If there are more parallel lanes, the calculated levels at receivers nearby may be wrong if this multi lane road is modelled only by one source line in ground projection.

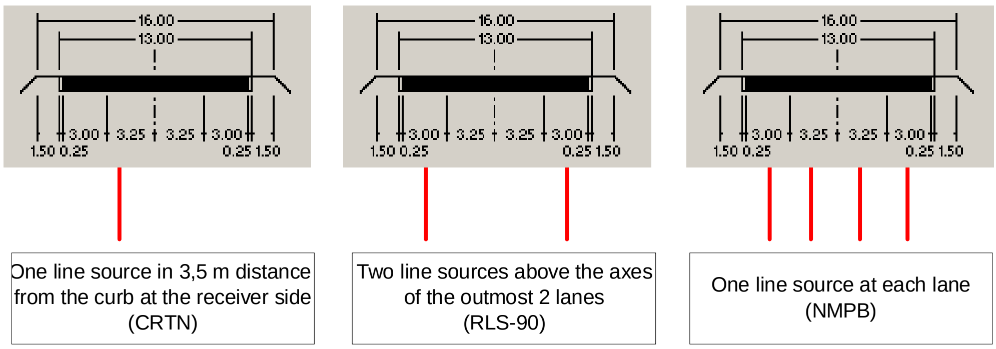

Figure 6: Level correction for road gradients according to different methodologies.

According to CRTN the source line is located in 3.5 m distance from the curb at the receiver side. Such "jumping" conditions are old fashioned and cannot be recommended in times where the levels are even calculated in vertical grids.
With RLS-90 the sources are the axes of the outer lanes, while in NMPB all lanes are used as source separately. With calculation of the sound level distribution on vertical grids with the scenario shown in figure 7 for both cases the error induced by the RLS approximation was determined by calculating the level differences.

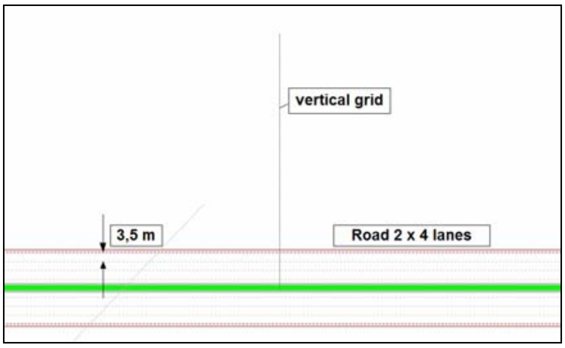

Figure 7: Road with 2 x 4 lanes and vertical grid.

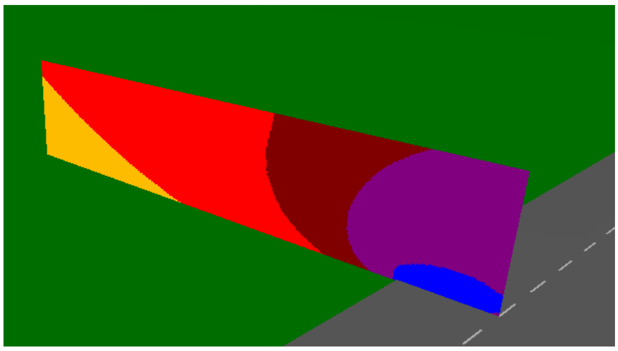

Figure 8: Level distribution on vertical grid.

One calculation is made with equal traffic flow on all lanes (8 line sources) and another one with half of the flow on each of the two outer lanes. The vertical difference map is shown in figure 9. This presentation shows that the error induced by the 2-source-line approximation is smaller 0.5 dB and vanishes completely more far away.
Other calculations have been made with and without barriers. From all these results it can be stated that the 2 line approximation is a good compromise taking into account that the real distribution of traffic flow on all separate lanes is not known and that in reality the more noisy heavy trucks drive mainly on the outer lanes.

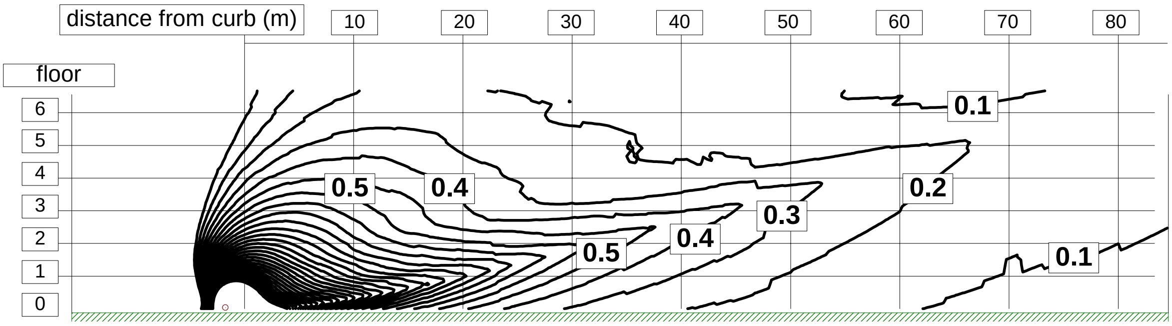

Figure 9: Error in dB induced by the simulation of the road by two line sources.

5. SOUND PROPAGATION

Consequences of different sound propagation calculations have been studied using the simple scenario shown in figure 10.

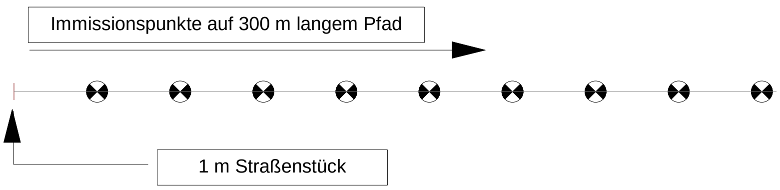

Figure 10: Piece of road and receivers with height 3 m above ground up to 300 m distance.

All the abovementioned methods have been used to calculate sound propagation with absorbing and reflecting ground. Two examples of these propagation diagrams are shown in figures 10 and 11. The attenuation by geometrical divergence has been eliminated – therefore these diagrams show the influence of the ground in dependence of distance.

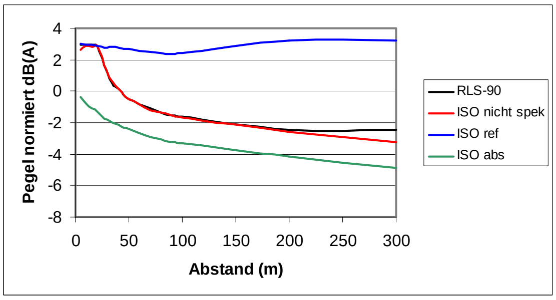

Figure 10: Ground attenuation according to RLS-90 and ISO 9613-2

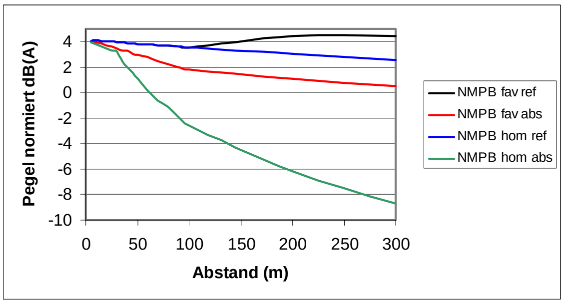

Figure 11: Ground attenuation according to NMPB

ISO 9613-2 has been used with A-level-calculation (not spectral) as well as spectral with reflecting and absorbing ground. RLS-90 is not spectral and ground absorption cannot be varied.

With the French NMPB method favourable and homogenous propagation conditions as well as reflecting and absorbing ground is included.

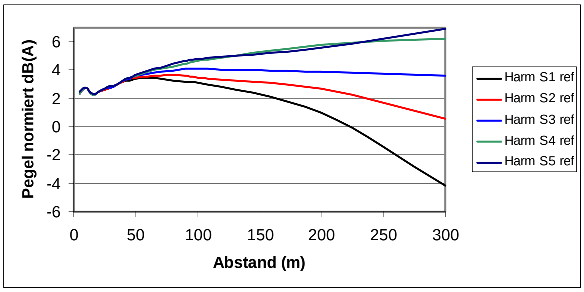

Figure 12: Ground attenuation according to Harmonoise P2P with 5 stability classes:

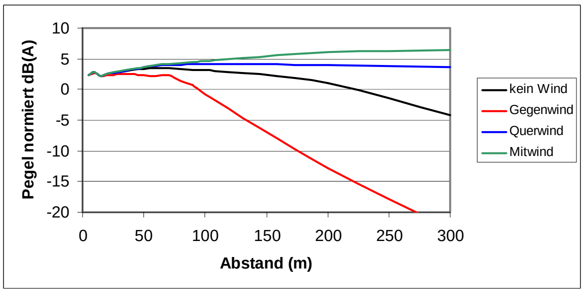

Figure 13: Ground attenuation according to Harmonoise P2P with reflecting ground, stability class S1 and wind 10 m/s from different directions:

The influence of partially coherent superposition of direct sound and ground reflection was studied using the procedures applied in the SonRoad methodology.

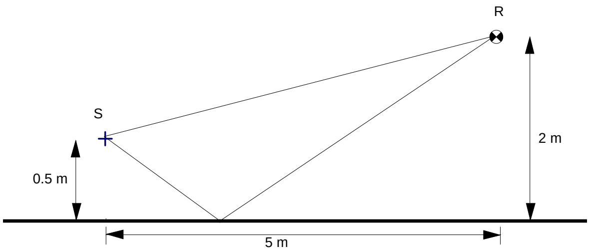

Figure 14: Dimensions of calculated source receiver layout:

Figure 15 shows the frequency dependent ground effect A_{gr} calculated in a narrow 1/27 octave band and – by summing energetically – in a 1/3 octave band. The interference effects vanish more and more if broader frequency bands are taken into account.

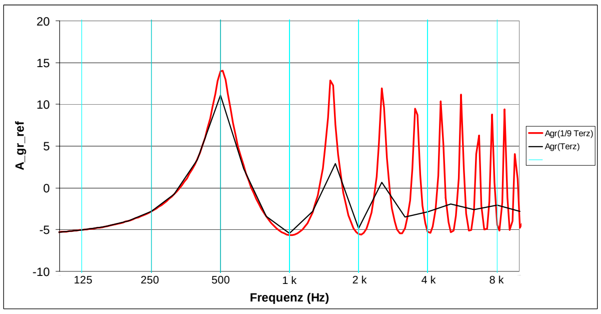

Figure 15: Frequency dependent ground effect Agr with 1/27 and 1/3 octave band 500 Hz at distance 5 m.

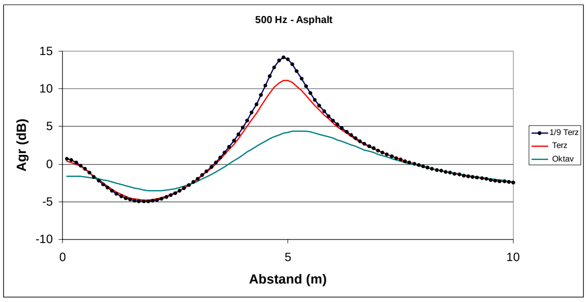

Figure 16: Ground effect Agr for different bandwidths at 500 Hz in dependence of distance with reflecting ground.

Figure 16 shows this effect in dependence of distance – interference effects are smoothened with broader frequency bands.
This coherent superposition of direct sound and ground reflection was also applied to calculate the sound pressure levels in dependence of distance from a long road with a typical road traffic frequency spectrum. Figure 17 shows the normalized A-weighted level calculated with the SonRoad methodology (coherent superposition of direct sound and ground reflection) based on 1/27 octave bands (these are 216 calculations for each source element) for reflecting (G=0), partially reflecting (G=0.5) and absorbing (G=1) ground. Normalized means that the levels calculated with ISO 9613-2 neglecting ground influences are subtracted.

The same propagation diagram calculated with ISO 9613-2 is shown in figure 18. In both cases the same typical road emission spectrum has been used.

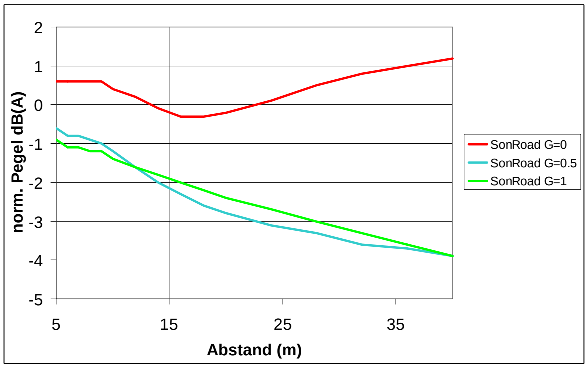

Figure 17: Normalized levels calculated with SonRoad in dependence of distance from al long road.

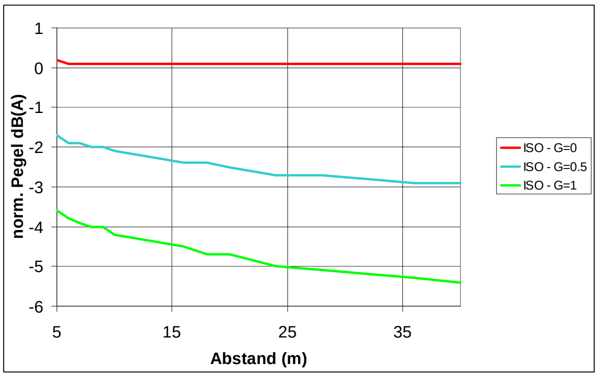

Figure 18: Normalized levels calculated with ISO 9613-2 in dependence of distance from al long road.

These and many other comparisons show, that coherence effects are not important if real spectra and source extensions are taken into account. On the other side many effects like combined diffraction over the upper edge and lateral diffraction are neglected with these more complicated models. Regarding all uncertainties that come into play in realistic built up areas in determining emissions and calculation of propagation, this phase oriented superposition of direct sound and ground reflection worsens the balance of accuracy, precision and transparency. It may be helpful for clarifications in special cases, but it cannot be recommended to be applied generally. This is especially true if the method shall be used in cases where legal requirements have to be checked.

Another effect that has been investigated is the influence caused by meteorological conditions. The technique in the existing RLS-90 is to calculate sound propagation generally in all directions with respect to slight midwind conditions and to neglect effects caused by vertical temperature and sound speed gradients like inversions.
The NMPB method distinguishes favourable and homogenous propagation conditions and for each combination source – receiver two calculations have to be made. For the French cities the percentage of occurrence of both conditions is published in dependence of direction and the calculated contributions are summed up to the long term average by using this proportion.

The question is how important is this inclusion of two different meteorological conditions for the calculation of road noise at building facades. To check this the façade levels at 80000 buildings of a German city have been calculated where for each building the number of inhabitants are known. Then the distribution of inhabitants on level intervals was derived. This calculation was performed using the NMPB method – once with pure favourable conditions and once with homogenous conditions.

The difference map is shown in figure 19. These differences are nearly negligible inside the built up areas and only far away from roads relevant level differences occur. The distribution of residents over level intervals show, that only at lower levels some percent are shifted from one class to the neighbouring class with lower levels. The more interesting higher levels are not affected by the meteorological conditions according to NMPB.

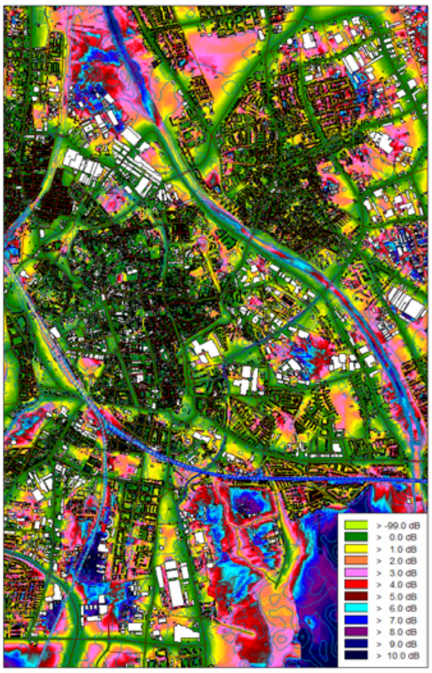

Figure 19: Level differences in a city with 80000 building when calculated with favourable and with homogenous propagation conditions according to NMPB.

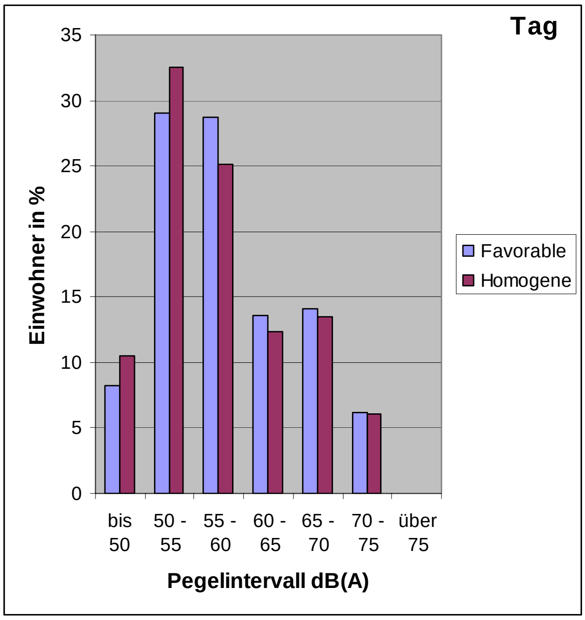

Figure 20: Distribution of the calculated exposure of residents alternatively determined with purely (100 % of the time) favourable and with homogenous propagation conditions according to NMPB.

This rather unrealistic assumption – purely favourable or purely homogenous conditions – was supplemented by the same calculation using the realistic meteorological conditions of two different French cities (Brest and Nantes) – the results are nearly exact identical distributions.

Summing up it can be stated that meteorological conditions may be important if long range propagation determines the results. This is clearly not the case if hot spots of noise immission shall be detected or if legal requirements shall be controlled.

RECOMMENDATIONS

The comparison and evaluation of different calculation methods has shown, that increasing the complexity by including more and more physical phenomena and effects will not automatically produce "better" results, if accuracy, precision and transparency or aspects of software quality assurance are used to qualify a method. Instead a robust and stable propagation model like ISO 9613-2 should be linked to an emission part describing the source "road traffic". This source model should also be kept simple e. g. with two source lines – one for tyres and one for engine. Description in octave bands with speed dependent corrections for road surfaces that can easily be supplemented based on pass by measurements will be the best balance of the partial targets mentioned above.

REFERENCES

1. W. Probst: "Comparison of the noise calculation methods for roads with other European methodologies", *Federal Highway Research Institute, Germany, publication in preparation*.