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Uncertainty of calculated noise levels and its influence on exposure-response-relationship in the NORAH-project

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ABSTRACT

In the discussion of noise exposure-response relationships, it is usual to show the scattering of the response variables whereas the uncertainty of the noise levels usually is neglected. In the NORAH project, the uncertainties of the calculated noise levels were estimated for each noise source in order to show its influence on the exposure-response-relationship. The uncertainty of the relevant calculation parameters were estimated for the noise source, the transmissions path and the receiver point for each traffic noise source for different distance classes between source and receiver and then summarized. In a second step, for aircraft noise, the influence of both uncertainties (exposure and response) on the exposure-response-relationship were examined for the response variable annoyance (%HA).

The uncertainty of the level values determined is between 3 and 5 dB, depending on the traffic noise. The influence of the uncertainty of the acoustic level values on the position of the lines of regression of the exposure-response relationship in the cases examined is only slight. However, the enhanced confidence intervals when considering the calculation uncertainty are relevant when comparing exposure-response relationships.

MOTIVATION AND REASON

In noise impact studies, exposure-response relationships are often only depicted with an indication of the uncertainties in the response effect. Basically, uncertainties also exist in the determination of exposure. The exposure value, considered to be independent, is determined either by measurement or by calculation. Each acoustic measurement is subject to uncertainty and can only approximately approach the true value of the variable to be measured. This applies for calculations to the same extent, because the calculations depend on the quality of the model and the quality of the input data. Uncertainty in the determination of exposure is therefore unavoidable.

This uncertainty of exposure can affect the relationship between exposure and response, and, thus, influence the result of the study. In the context of the NORAH [2] noise impact study on noise from air traffic and road and rail transport, the uncertainty of the acoustic level values was quantified in order to contribute to a greater transparency.

ACOUSTIC MODELLING

The acoustic data in NORAH was determined by calculation because measurements would have been too elaborate, due to the number of subjects (up to 1,000,000 addresses in one module). These calculations were based on the calculation methods according to the German AzB [1] standards (with single flight simulation based on FANOMOS radar tracks) for air traffic noise, in accordance with the VBUS [2] for road traffic noise and the VBUSch [3] for rail traffic noise. Errors or deviations from the real situation occur when creating the required sound calculation models (three-dimensional modelling of the propagation of sound)

- due to the choice of input data (level of detail)
- due to conscious simplification in the modelling of local conditions or
- due to errors in the modelling of local conditions

MODEL TO TAKE ACCOUNT OF UNCERTAINTY

In determining the calculation uncertainty, a model was used as a basis that described the calculated immission level as a function of

- the description of the source (emission)
- the effects on the propagation path (transmission) and
- the determination of the place of immission (immission)

As follows:

$$L_{pi} = L_{pe} + K_Q + \sum A_i + K_{IO} \qquad (1)$$

where:

L_{pi}	A-weighted sound pressure level at the place of immission
L_{pe}	A-weighted sound pressure level for the description of the emission
K_Q	Correction value for the description of the source (directional effect, track, etc.)
ΣA_i	Attenuation terms due to the influences on the propagation path
K_{IO}	Correction value to describe the influences of the choice of the immission point

The methods to quantify calculation uncertainty are given in DIN SPEC 45660-1 [4] and Guide to the Expression of Uncertainty in Measurement (GUM) [5]. Accordingly, a parameter Y is computed from N input variables X_1, X_2, ..., X_N by a functional relationship **f**.

$$Y| = f(X_1, X_2, \ldots, X_N) \qquad (2)$$

The standard deviation or standard uncertainty is defined as a measure of the variation of the input variables. If it can be assumed that the input variables are uncorrelated, in other words that they are independent of one another, the combined standard uncertainty of the realization of the parameter **y** is calculated as

$$u_c(y) = \sqrt{\sum_{i=1}^{N} c_i^2 * u^2(x_i)} \qquad (3)$$

UNCERTAINTY VALUES IN THE NORAH STUDY

In the NORAH Study the input variables X_1, X_2, ..., X_N were separated in three different variable groups for each of the considered noise sources (rail, road and air traffic). The grouping of the variables was done by using separating into variables considering the emission, the transmission and the immission according to equation (1). In each of these groups estimations of the uncertainty were made for each variable. In order to do this existing repetition measurements (uncertainty type A / GUM) or empirical values (type B / GUM) were used.

The following tables show the results of the estimated uncertainties for rail, road and air traffic calculations. Because of the influence of the distance between source and receiver on the uncertainty in the transmission path these estimations were done in three different distance classes.

Table 1: Estimation of uncertainties for each calculation variable and combined uncertainty for air traffic noise

	Air traffic noise								
Distance	1000 m			2000 m			5000 m		
	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$
Emission									
Source emission	1	3.0	9.0	1	3.0	9.0	1	3.0	9.0
Directivity	1	1.0	1.0	1	1.0	1.0	1	1.0	1.0
Velocity	1	0.8	0.6	1	0.8	0.6	1	0.8	0.6
Number of detected aircrafts	1	0.4	0.2	1	0.4	0.2	1	0.4	0.2
Aircraft types	1	0.7	0.5	1	0.7	0.5	1	0.7	0.5
Transmission									
Geometrical divergence according to received aircraft position	1	0.9	0.8	1	0.4	0.2	1	0.2	0.0
Geometrical divergence according to altitude correction	1	0.0	0.0	1	0.8	0.6	1	0.3	0.1
Atmospheric absortion	1	0.5	0.3	1	0.5	0.3	1	0.5	0.3
Ground effect	1	0.0	0.0	1	0.0	0.0	1	0.1	0.0
Screening	1	0.0	0.0	1	0.0	0.0	1	0.0	0.0
reflections	1	0.0	0.0	1	0.0	0.0	1	0.0	0.0
Immission									
Position of immission point	1	0.0	0.0	1	0.0	0.0	1	0.0	0.0
Combined uncertainty u_c		**3.5**			**3.5**			**3.4**	

Table 2: Estimation of uncertainties for each calculation variable and combined uncertainty for road traffic noise

	Road Traffic Noise								
Distance	20 m			200 m			500 m		
	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$
Emission									
Input data	1	0.3	0.1	1	0.3	0.1	1	0.3	0.1
Source emission	1	1.9	3.6	1	1.9	3.6	1	1.9	3.6
Directivity	1	0	0.0	1	0	0.0	1	0	0.0
Velocity	1	0.7	0.5	1	0.7	0.5	1	0.7	0.5
Number of vehicles	1	1	1.0	1	1	1.0	1	1	1.0
Road surface	1	0.6	0.3	1	0.6	0.3	1	0.6	0.3
Transmission									
Position of source	1	1.8	3.2	1	0.1	0.0	1	0	0.0
Ground effect and absorption	1	1.7	2.9	1	1.7	2.9	1	1.7	2.9
Screening by buildings	1	0	0.0	1	1.5	4.4	1	0.2	0.0
Screening by barriers	1	1.1	2.3	1	0.1	0.0	1	0.2	0.0
Reflection	1	0.9	0.8	1	0.9	0.8	1	0.9	0.8
Immission									
Position of immission point	1	1.8	3.2	1	0.1	0.0	1	0	0.0
Combined uncertainty u_c		**4.1**			**3.4**			**3.0**	

Table 3: Estimation of uncertainties for each calculation variable and combined uncertainty for railway noise

	Railway noise								
distance	40 m			200 m			500 m		
	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$	c_i	u_i [dB]	$(c_i * u_i)^2$
Emission									
Source emission	1	2.9	8.4	1	2.9	8.4	1	2.9	8.4
Directivity	1	0.0	0.0	1	0.0	0.0	1	0.0	0.0
Velocity	1	1.3	1.7	1	1.3	1.7	1	1.3	1.7
Number of trains	1	0.3	0.1	1	0.3	0.1	1	0.3	0.1
Track quality	1	0.9	0.8	1	0.9	0.8	1	0.9	0.8
Transmission									
Source position	1	1.7	3.2	1	0.1	0.0	1	0.0	0.0
Ground effect and absorption	1	1.7	2.9	1	1.7	2.9	1	1.7	2.9
Screening by buildings	1	0.0	0.0	1	0.7	0.5	1	0.6	0.4
Screening by barriers	1	1.3	1.7	1	0.9	0.8	1	0.2	0.0
Immission									
Position of immission point	1	1.7	3.2	1	0.1	0.0	1	0.0	0.0
Combined uncertainty u_c		**4.6**			**3.9**			**3.8**	

The numerical values u_c are determined for all three types of source (air, road, rail) for three typical distances in each case. The sensitivity factors are set in the first approximation at $c_i = 1$ (equal weighting of the influence factors). Indeed, correlations between the influencing factors can lead to a reduction in the total uncertainty, when individual opposing uncertainties run counter. The result of the selected procedure is thus an estimation of the maximum calculation uncertainty. From the standard uncertainties for each influencing factor, the combined uncertainty is formed according to equation (3). The results of u_c for the three different noise sources are shown in the following figure:

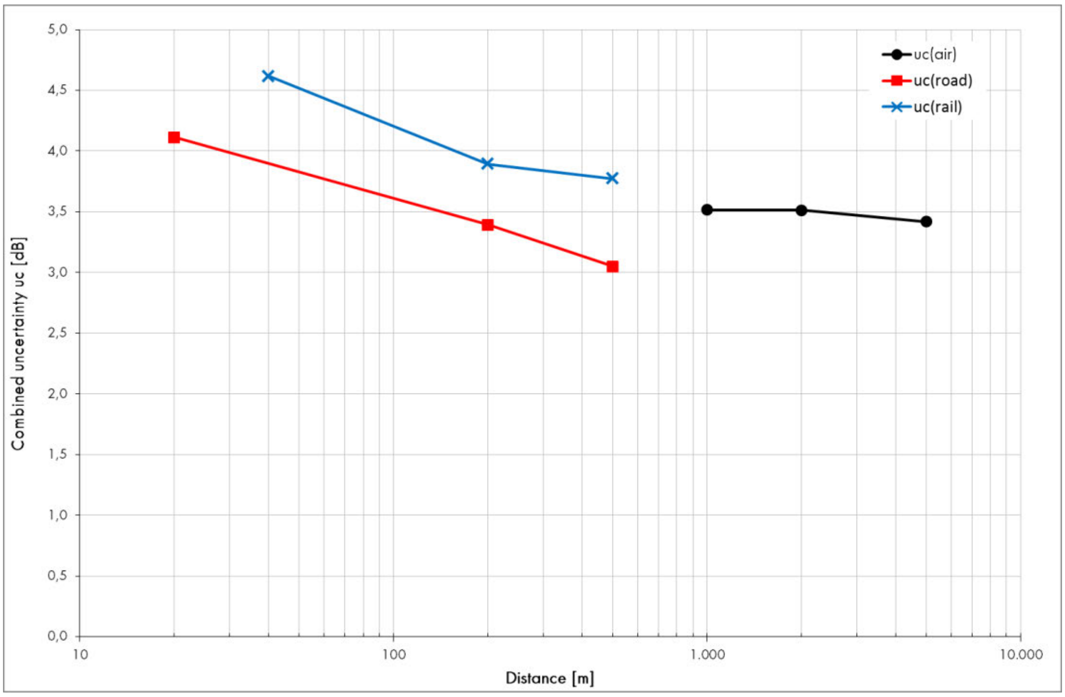

Figure 1: Combined standard uncertainty $\mathbf{u_c}$ for air, road and rail traffic noise depending on distance

Typically, the effect of the noise level in the function of the level is represented in so-called “exposure-response relationships”. This type of representation contains no information whatsoever on the distance. However, the uncertainties displayed above are a function of the distance to the source. They need to be “transformed” into a level-dependent uncertainty so that they can be applied to the exposure-response relationships. This is performed for road and rail noise with the aid of a conversion function, which displays the noise level as a function of the distance, based on the calculations in the NORAH study. The total uncertainty of air traffic noise is, however, in the case of single flight simulations, dominated by the source uncertainty and is therefore distance-independent, while in road and rail traffic noise the uncertainty of the input data for screening by barriers and buildings leads to higher uncertainty at short distances.

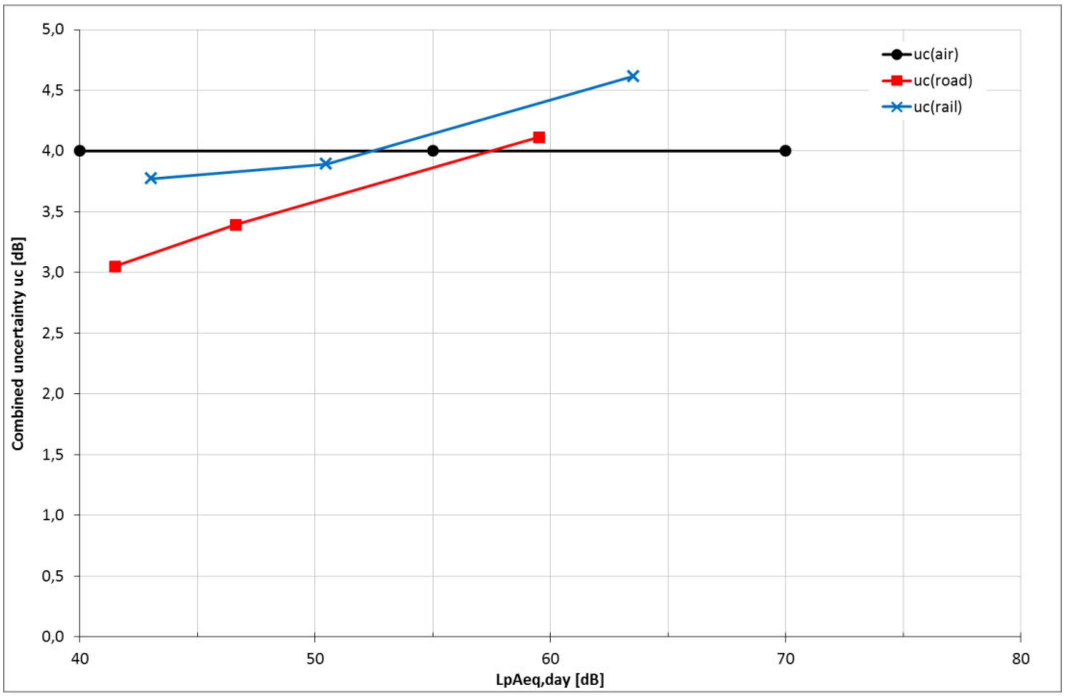

Figure 2: Combined standard uncertainty $\mathbf{u_c}$ for air, road and rail traffic noise depending on average noise level for the daytime ($L_{pAeq,day}$)

CONSIDERATION OF UNCERTAINTY IN EXPOSURE-RESPONSE-RELATIONSHIPS

Consideration of the calculation uncertainty is shown on an example for the response variable "percentage highly annoyed by aircraft noise" (%HA) of the NORAH study. The following figure 3 shows the relationship between the average level ($L_{Aeq,day}$) caused by aircraft noise and %HA for the sample of 3508 subjects of module 1:

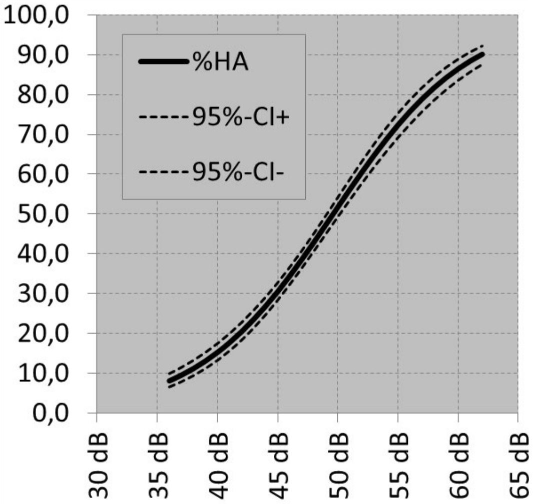

Figure 3: Relationship between the variables %HA and average level of the air traffic noise: logistic regression with confidence interval

In figure 3 the relationship is shown using a logistic regression with its confidence interval. The relationship in figure 3 does not yet include any uncertainty caused by the calculation of the noise levels. In order to add an expression for uncertainty of noise levels this regression is represented by discrete values at given noise levels in steps of 1 dB (on the left of figure 4).

For each of these discrete values of the exposure-response relationship the uncertainty values from figure 2 for aircraft noise were added. The result is shown in figure 4 on the right side, where vertical error bars represent the uncertainty of the model and horizontal error bars represent uncertainty of noise calculation.

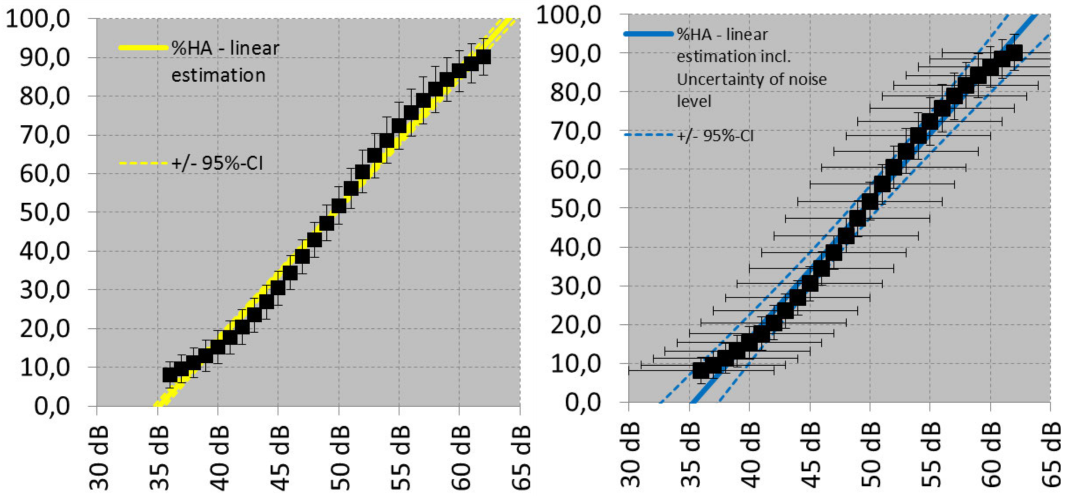

Figure 4: Relationship between the variables %HA and average level of the air traffic noise; left: discrete values of this relationship (black boxes) with linear estimation and confidence interval (yellow line and yellow dotted lines); right: discrete values of the relationship (black boxes) with uncertainty of model (vertical error bars) and uncertainty of noise exposure (horizontal error bars) with linear estimation with confidence interval (blue line and blue dotted lines) including uncertainty of noise exposure

In order to compare the results between figure 4 without and with uncertainty of noise calculation linear estimations of the relationship were made for both cases.

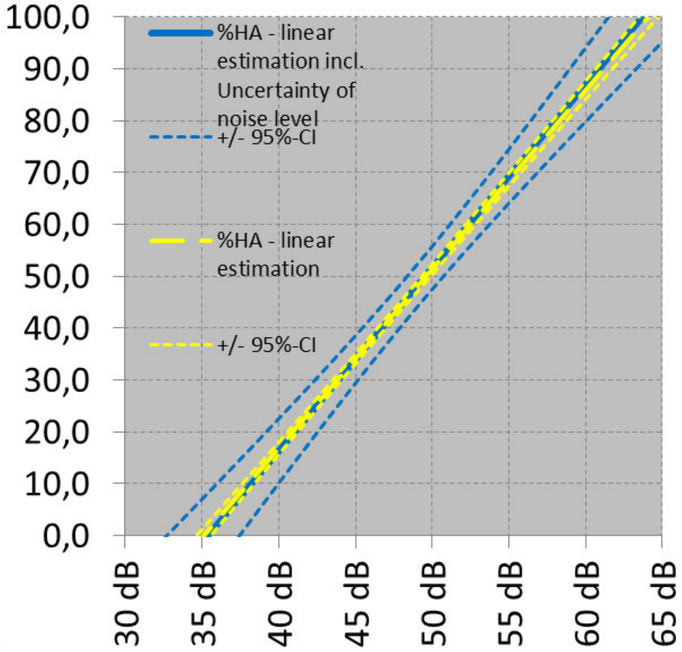

Figure 5: Relationship between the variables %HA and average level of the air traffic noise; linear estimation and confidence interval without (yellow line and yellow dotted lines) and with uncertainty of noise exposure (blue line and blue dotted lines)

The comparison in figure 5 shows

- The linear estimation of the exposure-response-relationship for the variable %HA referring to the average noise level $L_{Aeq,day}$ by air traffic noise does not show great differences whether the uncertainty in noise calculation is considered or not
- The regression line that is achieved when considering uncertainty in noise calculation (blue line in figure 5) is inside the confidence interval of the regression when no uncertainty in noise calculation is considered (yellow dotted lines)
- When considering uncertainty in noise calculation the confidence interval increases (blue dotted lines in figure 5)

RESULT

The uncertainty of the level values determined is between 3 and 5 dB, depending on the traffic noise. The influence of the uncertainty of the acoustic level values on the position of the lines of regression of the exposure-response relationship in the cases examined is only slight. However, the enhanced confidence intervals when considering the calculation uncertainty are relevant when comparing exposure-response relationships.

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