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Model for total noise assessment under consideration of source specific exposure-response-curves

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ABSTRACT

Although most of the German population is exposed to multiple noise sources, noise legislation in Germany is subdivided in regulations for each noise source. In order to improve the quality of life there is a lack of a total noise assessment. The German Federal Environmental Agency therefor initiated the research project "Model for total noise assessment". As a part of this project the method of the German VDI standard 3722-2 on the assessment of the impact of noise from multiple sources was further developed. With the help of exposure - response relationships for individual source types a total noise assessment for road traffic, railway, aircraft and industrial noise is possible. For this purpose the exposure-response relationships of the new WHO Environmental Noise Guidelines are used. The possibility of considering health effects and combining annoyance ratings and other health effects are discussed. In a second step of this project noise mitigation in case of multiple noise sources are investigated. Different methods for the cost distribution were examined regarding their advantages and disadvantages in the application. The proposed method of cost distribution was finally tested in case studies using the further development of the VDI standard.

Keywords: Total Noise, Exposure-response relationship, financing model, health effects

1. INTRODUCTION

The German population is exposed to a multitude of noise sources; as a general rule, the persons affected are simultaneously impacted by multiple noise sources. For comprehensive protection from noise immission, the implementing regulations subordinated to the German Immissions Protection Law (Bundes-Immissionsschutzgesetz, 1) lack a mandatory total noise assessment. At the same time, persons affected by noise currently do not have a claim to noise mitigation measures, if the noise is caused by already existing traffic routes.

In pursuit of an approach towards a legal regulation of a total noise appraisal, the present publication deals with the issues outlined below. Four work packages are handled by an interdisciplinary project team. Each of the work packages has a special focus, which is handled by the relevant specialists.

The work was split into the following work packages (WP):

- WP 1: Further development of a concept for total noise assessment based on the German standard VDI 3722-2 with the inclusion of health aspects
- WP 2: Proposal for a financing model for noise mitigation measures in connection with a total noise assessment and legal implementation
- WP 3: Enhancement of the Musterstadt "(Sample City)" data set contained in the standard DIN 45687
- WP 4: Testing of the developed model for total noise assessment

In this presentation the results of work packages 1, 2 und 4 are presented.

2. Further development of total noise assessment based on VDI 3722-2

VDI 3722-2 (9) "Effects of traffic noise - Characteristic quantities in case of impact of multiple sources" (VDI 3722 Part 2:2013-05) proposes methods enabling the estimation of total noise annoyance with the help of exposure – response relationships for individual source types (currently:

air, rail and road traffic). The same method is described for estimation of total noise sleep disturbance. These tools can be used for the acoustic assessment of planning alternatives (VDI 3722-2, 1. Scope).

VDI 3722-2 contains a number of regulatory gaps and provides scope for further development, which is covered in WP 1. Five aspects are addressed:

2.1. Application of levels outside the value range

The exposure-response curves used for the determination of effects apply to a defined noise level range for individual source types. This applies to functions describing the percentage of annoyed persons (*%A*), highly annoyed persons (*%HA*), sleep-disturbed persons (*%SD*) and highly sleep-disturbed persons (*%HSD*). The question of how to handle situations, in which individual source types contributing to the total noise exposure are situated outside this value range, remains open. For levels above the value range of the exposure – response curves, a linear extension beyond a calculated 100% annoyance level is proposed, given that information regarding the progression of the curve or the turning point from exponential functions towards sigmoid curves is not available and linear continuation appears to be the simplest assumption with the minimum of uncertainty in this situation. A linear extension of the $L_{r,N}$ level range between 0 dB and 40 dB is recommended for levels below the value range with reported sleep disturbance, in accordance with the approach proposed by Probst & Gillé (4). Concerning exposure-response curves relating to the proportion of (highly) annoyed persons, it is recommended for the source-type related rating levels L_{DEN} < 37 dB (for *%A*) and L_{DEN} < 42 dB (for *%HA*) that the renormalized substitute level be set to 37 dB (for *%A*) and 42 dB (for *%HA*), and the corresponding *%A/HA* portion to 0%. The substitute levels thus defined are considered appropriately in the calculation of the effect-related substitution level L_{AES}.

2.2. Selection of annoyance curves with a view to situation-dependent advantages and disadvantages of % A curves compared to % HA curves

It is suggested that no binding regulation should be established, which exposure- response curves (*%A/HA, %SD/HSD*) has to be used. This decision should be made depending on the concrete planning cases. Rather it is recommended that substitution levels be applied on the basis of all variants of exposure-response curves contained in VDI 3722-2 (currently: *%A, %HA, %SD, %HSD*). Thus different rankings of measures may result, depending on the objective pursued and the effect considered. However, new exposure-response curves are available for noise annoyance and reported sleep disturbance that relate exclusively to *%HA* and *%HSD*. Hence, the effective quantities *%A* and *%SD* can be eliminated completely, if these new curves were to be included in the VDI standard.

2.3. Investigation and assessment of potential interaction between daytime and nighttime effects for different source type combinations.

On the assumption that adequate, physiological quality of sleep is the major target for the night period, it is suggested that maximum level criteria and physiological awakening criteria related to these maximum level criteria should be included in VDI 3722-2, rather than restricting oneself to the night-time continuous noise level alone. However, this presupposes the availability of exposure-response curves for additional, noise-induced awakenings from field studies for all noise type sources included, and for a variety of further population groups (such as children, persons with sleep-relevant diseases). The total noise assessment in this case will not be made on the basis of (high) sleep-disturbed persons or annoyed persons, but rather on the basis of the number of additional (total) noise-induced awakenings. In addition, the night-time continuous noise level should be maintained, so as to be able to show night-time effects going beyond physiological awakenings.

Furthermore, it is suggested that characteristic quantities both on the effect and on the exposure side should be selected according to the envisaged effective times of the proposed noise abatement measures. Measures aimed at 24 hour protection throughout the day, or effective over 24 hours, may be assessed in terms of the total noise effects with a substitution method with the inclusion of $L_{r,TAN}$ and, e.g., noise annoyance as effective quantity (*%A, %HA*), even if the different noise type sources used in the calculations are effective at different times of the day. On the other hand, measures aimed at night-time protection (such as operational restrictions limited to certain times of the day) will be evaluated with exposure-response curves for sleep disturbance (*%SD, %HSD*).

2.4. Further development of VDI 3722-2 with a view to the inclusion of industrial and commercial noise.

Our recommendation for the further development of VDI 3722-2 is, that in the absence of novel findings, the exposure-response curves proposed by Miedema & Vos (3) for the *%HA* related to the noise emitted by year-round industrial facilities (other industries) should be used.

As for the consideration of noise generated by wind turbines in the VDI 3722-2 the exposure-response curve for %HA (interior) from Janssen & Vos (2) may be used, if only noise annoyance is considered. In the case of the calculation of a total-noise effect index, the use of *%HA* and *%HSD* functions for road traffic noise is recommended as alternative, as in the case of industrial and commercial noise.

2.5. Evaluation of VDI 3722-2 under considerations of health protection and suggestions for improvement.

Up to now, the VDI 3722-2 considers methods for the estimation of noise annoyance and sleep disturbance. No further health effects are taken into account. Meanwhile a number of studies are available that investigated the evidence of health risks caused by noise immissions. These noise induced health risks mostly under investigation are cardiovascular diseases. In order to include these effects into the method of VDI 3722-2 the use of exposure-response relationships based on the WHO-Review regarding noise induced health risks for cardiovascular diseases (van Kempen et al., 7,8) are proposed.

To take into consideration further health aspects and to be able to show all effects (annoyance, sleep disturbance, different diseases) considered in an index, a procedure based on the concept of the DALY-index (Tobollik, M., Plaß, D., Steckling, N. et al., 6) is suggested. The DALY-index (disability adjusted life years) represents the total amount of lost life years caused by environmental impact and is calculated by summing up different (noise related) health effects weighted with an effect related disability weight. The disability weight DW ranges from 0 (full healthy) to 1 (death).

For planning purposes the following approach is suggested:

- Calculation of effect-related substitution levels $L_{r,TAN}$ for *%HA* and $L_{r,N}$ for *%HSD* with the help of the latest, most recent exposure-response curves.
- Calculation of the number of highly annoyed persons in the area under review using the function for road traffic noise, and of the number of highly sleep-disturbed persons in the area under review using the function for road traffic noise, in each case multiplied with the number of inhabitants.
- Calculation of the number of persons additionally suffering from total-noise induced disease (population-attributable risk, *PAR*) for selected major diseases. The calculation should be based on up-to-date, robust relative risk estimates for total noise related to L_{DEN} and information on the prevalence of the respective disease in the area being surveyed. Alternatively, the calculation can be based on information on prevalence from official statistics (regional, state-wide or national health reports).
- Multiplication of the number of (highly) annoyed, sleep-disturbed and additional disease-affected persons with their respective disability weight (DW). Rounding of the weighted values to the neared whole number of cases.
- If several diseases are considered, select the one with the highest DW weighted *PAR*.
- Summation to obtain an overall index: Addition of weighted (rounded) numbers of cases of annoyance, sleep disturbance and (selected) diseases to obtain an overall index of the number of cases of impairment due to total noise.
- Inclusion of input data pertaining to age, life expectancy, duration of disability from official statistics: Calculation of disability-free life years lost (*disability-adjusted life years,* DALYs).

3. Financing model for noise abatement measures

To ensure sustainable and effective protection of the population against noise, a reduction of the total noise level should be aimed for. Despite technical advances regarding the implementation of noise mitigation measures at source, noise mitigation at the propagation path (such as noise protection walls and acoustic barriers) must still play a key role in planning when it comes to reducing the noise load. The latter will be effective for more than a single source, meaning that the costs need to be distributed to the polluters according to a consistent distribution model. Until now, such procedures and regulations for sharing the costs for noise abatement measures between different polluters have not been provided for.

The distribution of cost to one or more originators of the total noise load must be achieved transparently and without discrimination. Otherwise acceptance by the parties involved in the planning process and affected persons cannot be expected. In particular, the following aspects must be considered, which are essential for the distribution of costs:

- Observation of polluter-pays principle (fairness of cost): Costs should be attributed to that traffic authority benefiting from the measure in terms of their obligation to reduce the noise level.
- Commutativity (interchangeability): Cost distribution should not be affected by the order in which the measures are implemented.
- Independence from a given effective date: Costs should not be dependent upon an arbitrary effective date.
- Area independence: The exact selection of the boundaries of a designated area selected for implementation of noise abatement measures should not influence the distribution of cost.

The present investigation presents existing approaches towards cost distribution and submits further proposals. From the above, four financing models based on different approaches were identified and presented. These different models are:

- *Financing model "Contribution to existing noise":* Cost is distributed on the basis of the energetic contribution of a noise source towards the total noise load *prior to the implementation* of the noise abatement measure (energetic percentage contribution of a noise source towards overall noise).

$$\frac{10^{0,1\times A}}{(10^{0,1\times A}+10^{0,1\times B})}\times 100 = contribution\ A\ in\ \% \tag{1}$$

- Financing model *"Contribution to noise level reduction":* Cost is distributed on the basis of the ratio between the reduction of the noise from a given source and the reduction of total noise from all sources.

$$Cost_A = \frac{\sum_i 10^{0,1\times(L_{A,i,prior}-L_{A,i,subsequent})}}{\sum_i 10^{0,1\times(L_{A,i,prior}-L_{A,i,subsequent})}+\sum_i 10^{0,1\times(L_{B,i,prior}-L_{B,i,subsequent})}}\times Cost_{Tot} \tag{2}$$

- Financing model "*Weighted contribution to noise level reduction":* As in the case of the preceding model, cost is distributed on the basis of the ratio between reduction of noise from a given source and the reduction of noise from all sources; however, the contribution of a given source is weighted with its contribution towards total noise load, whereby while sources that do not contribute to total noise will not take a share of the cost.

$$Cost_A = \frac{\sum_i g_{Ai}\times 10^{0.1\times(L_{A,i,prior}-L_{A,i,subsequent})}}{\sum_i g_{Ai}\times 10^{0.1\times(L_{A,i,prior}-L_{A,i,subsequent})}+\sum_i g_{Bi}\times 10^{0.1\times(L_{B,i,prior}-L_{B,i,subsequent})}}\times Cost_{Tot}$$

$$g = -\frac{1}{10} * \Delta L_{prior} + 1 \quad \text{for } \Delta L \le 10 \tag{3}$$
$$g = 0 \quad \text{for } \Delta L > 10$$

where *g*: Weighting
ΔL_{prior}: Difference between the assessment level of the total noise

load and the assessment level of the traffic noise source under consideration prior to the implementation of the measures

- Financing model "*Contribution to energetic load reduction":* Cost is distributed on the basis of the ratio between the reduction of an effect-related load index for a given source and the reduction of this index related to overall noise.

$$Cost_j = Cost_{tot} \times \frac{WEBI_{j,prior} - WEBI_{j,subsequent}}{WEBI_{prior} - WEBI_{subsequent}} \quad (4)$$

$$WEBI = \sum_{I=1}^{I} N_i \times 10^{0,1\, L_{AES,i}}$$

where: $L_{AES,i}$: Effect-related substitution level to VDI 3722-2 for %HA at calculation point i
N_i: Number of affected persons at calculation point i

On the basis of methodological considerations and calculation examples, the four models are compared using the criteria for a financing model listed above. The results of the comparison are shown in the following table.

Table 1: Comparison of the different financing models

Financing model / Criteria	*"Contribution to existing noise"*	"Contribution to noise level reduction"	"Weighted contribution to noise level reduction"	"Contribution to energetic load reduction"
Fairness of cost	No, within the meaning of noise reduction	No	Yes	Yes
Commutativity	No, except when initial situation is chosen equal for all noise mitigation measures	Yes	No, except when initial situation is chosen equal for all noise mitigation measures	Limited decrease of commutativity when initial situation is chosen equal for all noise mitigation measures
Independence from an effective date	No, as timing of initial situation influences cost distribution	Yes	Limited, as timing of initial situation influences cost distribution	Limited
Area independence	No	Yes	Yes	Yes

As good practice, the financing model "Contribution to energetic load reduction" was chosen, based on the renormalized substitute levels and effect-related substitution levels to VDI 3722-2 for *%HA* as characteristic quantity for load.

A possible further development of this approach may consist in the inclusion of the summary effect indicator (Population-attributable risk PAR) shown before instead of the characteristic quantity $\%HA$. The respective calculation formula for the financing model would be as follows:

$$Cost_j = Cost_{Tot} \times \frac{PAR_{j,prior} - PAR_{j,subsequent}}{PAR_{vorher} - PAR_{subsequent}} \quad (5)$$

with

PAR_j: Population-attributable risk from source j; with prior = prior to the implementation of a measure, and subsequent = subsequent to the implementation of a measure

PAR: Population-attributable risk from total noise; where prior: prior to the implementation of a measure and subsequent = subsequent to the implementation of a measure

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