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NOISE PERCEPTION AND SCORING OF NOISE EXPOSURE

Wolfgang J. Probst*

ACCON GmbH and DataKustik GmbH
Gewerbering 5, D-86926 Greifenberg, Germany
Wolfgang.Probst@accon.de

Abstract

Based on the strategic noise maps according to 2002/49/EC, action plans shall be developed to reduce the noise exposure in European agglomerations. To decide among possible alternatives, it is necessary to rank them with respect to noise reduction and number of people exposed. Different strategies have been used to derive a single number noise score. The most often used approach is to estimate the number of Highly Annoyed (HA), because the dependence of the percentage of HA from the exposure can be investigated by scientific evidence. It is shown that this concept fails in many cases. If noise exposures change, we must sum up an annoyance quantity for all persons concerned and not only count the number of persons above a threshold. It is postulated that the relative weighting of different grades of annoyance is a political decision and should be defined taking into account the communities opinion about the best acceptable distribution of unavoidable hazards. Looking to the expressions used to calculate a single number result for assessing noise scenarios, it will be shown that the "Highly Annoyed" expression causes an extremely weak weighting of noise levels – the consequences are often not acceptable. A Noise Score expression taking these findings into account is proposed.

INTRODUCTION

Many attempts have been made to rank noise scenarios using a single number scoring. Some use linear (Lärmkennziffer), some exponential dependency of the Noise Score (NS) from noise level. The most often used concept is to determine the highly annoyed part of the population and to sum up this number in a given scenario.

$$\%HA = 9{,}87 \cdot 10^{-4}\left(L_i - 42\right)^3 - 1{,}44 \cdot 10^{-2}\left(L_i - 42\right)^2 + 0{,}51\left(L_i - 42\right)$$
$$NS = \sum_i n_i \cdot \frac{\%HA}{100} \qquad (1)$$

Miedema and Vos [1] summarized 45 surveys and extracted comparable curves representing the percentage of highly annoyed persons (%HA) as a function of DNL for aircraft, road traffic and railway noise. Equation (1) is the proposed equation to be used with road noise. Miedema take these functions not only as an information about the number of highly annoyed persons caused by a given exposure, but recommends to use this number to compare planning concepts with respect to the noise impact on the community.
The present author focused on the problems when the number of annoyed persons is used to quantify a noise situation using a single number rating [2, 3]. These questions are also dealt with in the new VDI 3722-2 [4].
The practical application of Noise Scoring shows, that the HA-concept is often problematic because the levels are weighted extremely weak. These shortcomings are investigated and an alternative Noise Score expression is proposed.

THE HIGHLY ANNOYED CONCEPT

Typical “HA-curves” for noise from different source types are shown in figure 1.

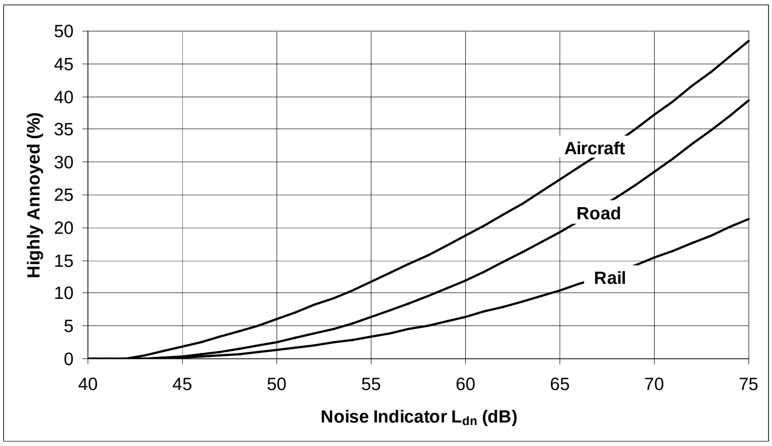

Figure 1 - Percentage of highly annoyed (%HA) for different noise types [4]

Using these functions, the probability to be highly annoyed can be determined for each person with known noise exposure.

In reality it is a fiction that counting up people who declare to be highly annoyed would be a fair assessment of the populations exposure.
Such a metric counts direct or indirect only how many persons cross the line between two categories of annoyance, but it neglects that for all the other people the annoyance raises also with increasing exposure. This is easily understood taking into account the complete curves – figure 1 shows for practical reasons only the lower part of the whole diagram, because in real field surveys we cannot include scenarios where more than 50% of the population is highly annoyed.

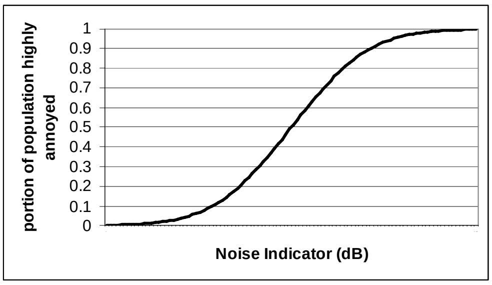

Figure 2 – Portion of exposed population highly annoyed

Figure 2 shows the complete HA-curve – it is obvious that the percentage cannot exceed 100% and therefore the curve must converge against this value. If we take the relation behind this curve to rank a noise situation, an increase of x decibels at medium range levels gives more additional highly annoyed persons than the same increase at high levels. It would be a fatal consequence to conclude that people living in noisy areas suffer less than those in more silent areas if the level is increased by a certain amount. But this is exactly done if we use the HA as a Noise Score that shall be minimized.

RELATION ANNOYANCE (AE) - HIGHLY ANNOYED (HA)

The following summarizes some ideas how people react on noise and the consequences for the assessment and ranking of noise problems. Using this very simple model of a population reacting on noise the relation between "annoyance curves" (AE) and "highly annoyed curves" (%HA) can be demonstrated..
We assume each person can be characterized by an individual relation exposure – annoyance (AE-curve), and these relations shall be represented by an exponential expression

$$A(L) = c \cdot 10^{k \cdot (L - L_0)} \qquad (2)$$

with
A quantity to express annoyance (selected scaling)
L noise indicator (e.g. L_{DEN})
L_0 reference value of noise indicator
k factor to be adjusted (0,03 <= k <= 0,3)

This exponential expression shall be adjusted to represent the relation "exposure" – "acceptability in living areas". The following qualification may help:

- no significant annoyance reactions below 40 dB(A)
- living at and above 80 dB(A) nearly impossible
- increase of annoyance with given increase of level larger at higher levels

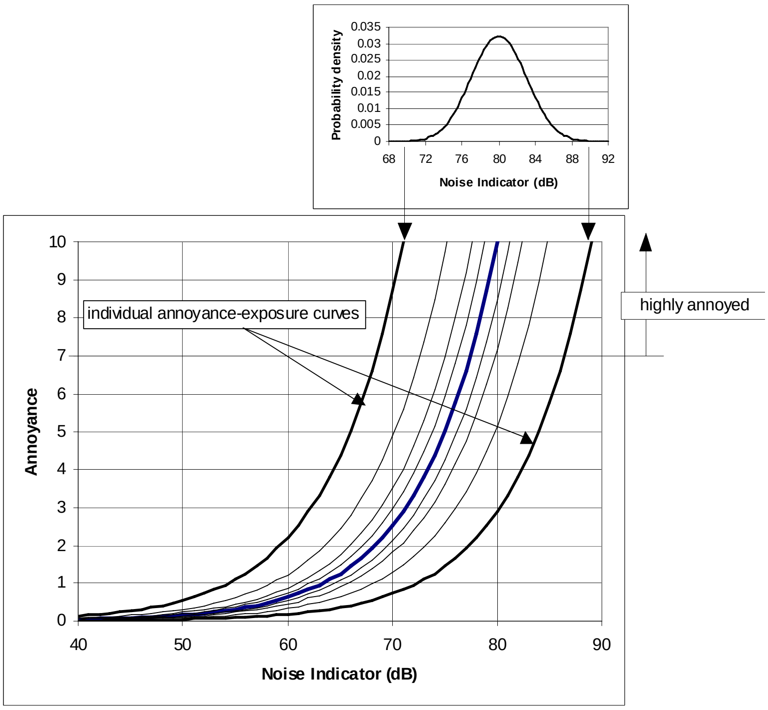

Figure 3 - Dispersion (approximated by a normal distribution) of individual AE-curves

Figure 3 presents the simple model of normal distributed AE-curves – some people react later than others if exposures are increased. According to Miedema and Vos [1], the lower edge of the category HA is at an AE-value of 7,2 if we use a ordinal 0-10 scale. The curves in figure 3 represent a model-community of 9 persons.
Based on this simple model the portion of a population being highly annoyed can be written

$$w(L') = 1 - \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot \int_{-\infty}^{L'} e^{-\frac{(L-L_m)^2}{2\sigma^2}} dL \qquad (3)$$

where

$$L_m = \frac{1}{k} \cdot \lg\left(\frac{A_T}{c}\right) + L_0 .$$

The HA-curve figure 2 results from integrating equation (3).

The derivation of the %HA-curve from the individual AE-curves proofs that this %HA-curve is not suitable to rank the increase of noise exposures for a population, because its slope is nothing but a measure of the distribution of the individual AE-curves. Figure 3 demonstrates in accordance with experience, that annoyance grows continuously with the level for each person (where we use the word “level” as default for a well adapted noise indicator that correlates with annoyance). If the value of the indicator grows, the annoyance of all people exposed will increase.
To understand the relation AE – HA, we use the AE – curves of our 9-person-

community and investigate the increase of AE and HA if the level is increased from L1 to L2 (figure 4). Two curves intersect the L1-line above the HA-threshold and 8 at L2 – this means the HA-value is increased from 2 to 8 (factor 4). We can also count the points ⧓ left from a vertical line at level L to get the number HA.

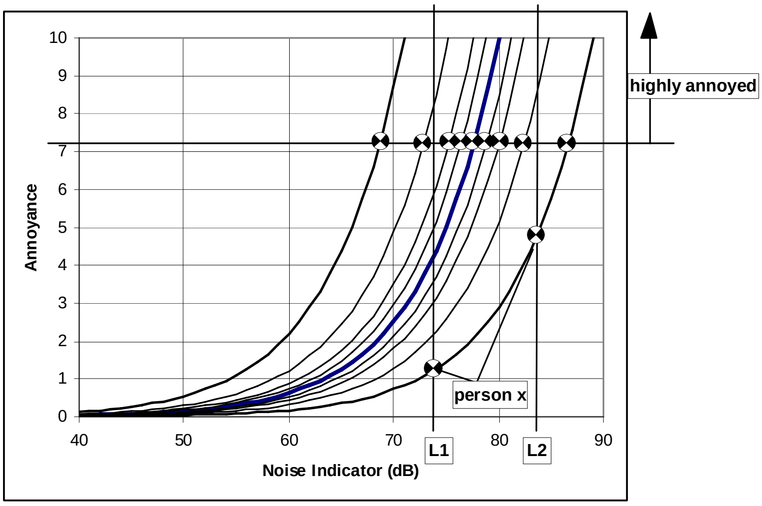

Figure 4 - Increase of AE and HA when the level is increased

This proofs, that the number of HA has nothing to do with the increase of annoyance if the level is increased from L1 to L2. This can easily be proven: If we use AE-curves with a steeper slope keeping the intersecting points of these curves with the lower limit of the HA-section (horizontal line at AE = 7,2) constant, we will get the same increase of HA. But, for any of these 9 persons the increase of annoyance is larger caused by the steeper curve. With HA we neglect the increase in annoyance for all persons not crossing the lower HA-edge, as it is shown for person x in figure 4.

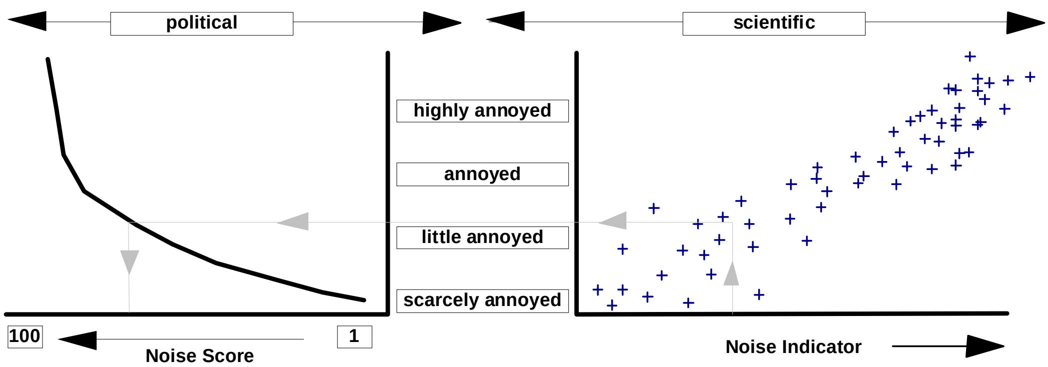

Figure 5 - Scientific and political parts of the relation between noise indicator and noise score

It can be shown that HA-curves as derived from social questionnaires produce an extremely weak weighting of levels – the HA value doubles with a level increase of about 8 dB. Using it as Noise Score NS to rank mitigation measures will always result in concentrating traffic flows as much as technically possible independent of the resulting exposure for the residents living there.

Figure 5 is an attempt to show the different steps if noise exposures are ranked. The diagram right shows the dependency of annoyance qualification from level – this can be found from social questionnaires. How we rank different grades of annoyance is a more or less political decision, because there is no evidence based method to find a scale. We must decide for how many little annoyed persons the level must be reduced by x dB to justify a level increase of x dB for one highly annoyed person. This trade-off is symbolized in the left diagram. If both diagrams are combined, we can omit the annoyance scale and use the score NS versus noise indicator directly.

INFLUENCE OF SCORING ON TRAFFIC DISTRIBUTION

The exponential function (2) was used to investigate the influence of the parameter k on the distribution of traffic flows if the NS value is minimized. Only some aspects of the investigation are presented here. Figure 6 shows the simplest possible situation used – how to distribute the traffic flow on both roads 1 and 2 to minimize the Score?

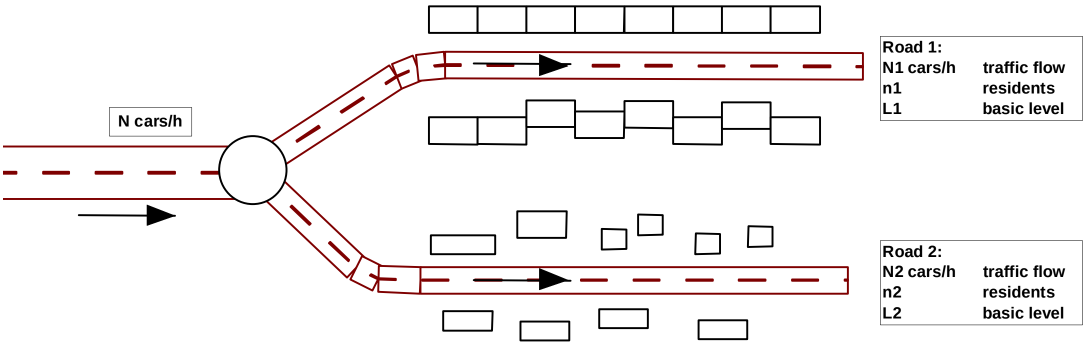

Figure 6 - A road with traffic flow N cars/h is splitted up into two roads

If we solve the NS-equation we get

$$NS = 10^{-k \cdot L_R} \cdot \left(n_1 \cdot 10^{k \cdot \overline{L}_1} \cdot N_1^{10k} + n_2 \cdot 10^{k \cdot \overline{L}_2} \cdot N_2^{10k} + \ldots \right) \qquad (4)$$

This function is plotted in figures 7 and 8 in dependence of the traffic flow distribution.

The left diagram uses k = 0,03 – this means the Noise Score doubles all 10 dB. It is comparable to the HA-concept (doubling all 8 dB). The diagram shows that a minimum is always achieved with maximum or zero traffic through a road. This concept recommends in all cases to concentrate the traffic as much as possible – a direct consequence of the weak weighting of levels. The level for a person living in

an area with 70 dB can be increased further by x dB, if we reduce the level by x dB for two others living with 60 dB. Taking into account that 60 dB is a normal and acceptable environment in cities and 70 dB is unacceptable noisy, it's a question if we can accept this optimization. The problem is that using this concept we minimize the total Noise Score if we expose some people as much as possible.
With k > 0,1 this disadvantage is avoided as it is shown in figure 8. The recommended distribution concentrates the traffic more at roads with fewer residents, but the steep evaluation curve does not allow to expose only one group with high levels to get low levels for others.

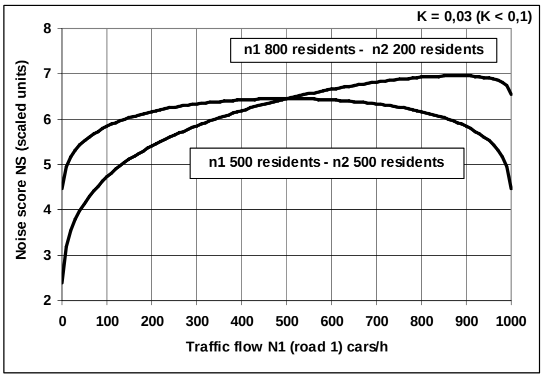

Figure 7 – Noise Score with k = 0,03 (HA-concept)

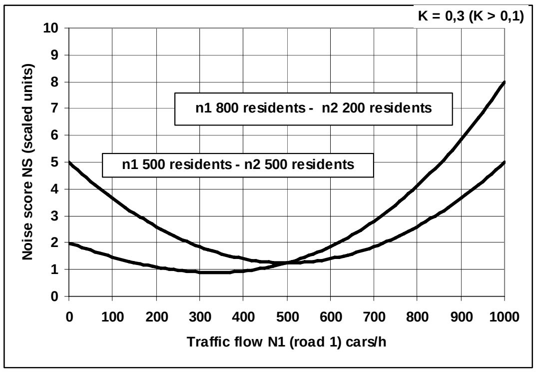

Figure 8 – Noise Score with k = 0,3

Based on these results and further investigations the following Noise Score function was developed :

$$NS = \sum_i \begin{pmatrix} n_i \cdot 10^{0.15 \cdot (L_{den,i} - 50 - dI + dL_{source})} & \text{with } L_{den,i} \leq 65\ dB(A) \\ n_i \cdot 10^{0.30 \cdot (L_{den,i} - 57.5 - dI + dL_{source})} & \text{with } L_{den,i} > 65\ dB(A) \end{pmatrix} \quad (5)$$

with

NS	Noise Score
n_i	number of persons exposed with level $L_{den,I}$
$L_{den,j}$	Noise indicator at most exposed façade at dwelling i
dI	deviation of mean sound insulation of dwelling i from the mean insulation of all dwellings
dL_{source}	correction that accounts for different reaction versus noise from roads, railways, aircraft and industry

This Noise Score takes into account that above 65 dB(A) the risk of noise induced deceases cannot be neglected. If the sound insulation of the buildings is comparable, there is always an optimal traffic distribution where more traffic flow is accepted on roads with fewer exposed residents. It does not allow to expose these fewer residents as much as possible, because the NS-value increases exponentially with increasing level. But it recommends to bundle the traffic on roads with large capacity if additional measures like the acoustical improvement of the buildings for these highly exposed residents are included.

SUMMARY

A Noise Scoring System cannot be derived completely evidence based. It includes the public opinion about a fair distribution of unavoidable hazards. The Highly Annoyed concept provides a very weak weighting of levels and the results will in many cases not reflect peoples opinion about a fair distribution of unavoidable hazards. A better adapted Scoring function is proposed.

REFERENCES

[1] Miedema, H. M. E., Vos H. (**1998**). « Exposure-response relationships for transportation noise . J. Acoust. Soc. Am. **104** (6)

[2] Probst, W. (**1978**) „Zur wirkungsbezogenen Gesamtbeurteilung von Lärmsituationen“, Kampf dem Lärm 25, 167 - 171

[3] Probst., W. (**1979**) “ Zur Beurteilung von Planungssituationen im Hinblick auf Verkehrslärm-Immissionen”. Kampf dem Lärm (**26**) 25 – 33

[4] VDI-Richtlinie 3722-2 „Ermittlung von Kenngrößen zur Beurteilung von Verkehrsgeräuschen beim Einwirken mehrerer Quellenarten“, internal draft Dez. 2005