# COMPARISON OF NOISE QUALITY INDICATORS

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**Abstract** An approach is described for exploring the effectiveness of noise emission reduction with the aid of noise quality indicators. There are different indicators describing the environmental noise quality. An important effect of environmental noise in annoyance and the following four indicators describe noise annoyance: the percentage highly annoyed persons ($p_{HA}$), the percentage annoyed ($p_A$), the percentage (at least) little annoyed persons ($p_{LA}$) and the mean expected annoyance ($m_{EA}$). Another noise quality indicator is the percentage of area where a certain noise limit is exceeded. In this paper, 50 dB is chosen as limit ($AREA_{50}$). Calculations on the basis of road traffic data of Leiden (the Netherlands) show that the use of different noise quality indicators can lead to different decisions in noise abatement.

**Introduction** Indicators describing the environmental noise quality in a community (e.g. neighbourhood or city) are useful for noise abatement policy and transportation planning. Because annoyance is one of the main health effects of environmental noise, it is important to have indicators for noise annoyance.

Noise annoyance is measured by social surveys in which respondents are asked to what extent they are annoyed due to noise from a specific source (e.g. road traffic). In many studies, the annoyance response has been related to the exposure to environmental noise. Miedema & Oudshoorn (2001) presented a model describing the distribution of noise annoyance as a function of the noise exposure (*DNL* and *DENL*), based on data from different exposure response studies. Because this model describes the entire annoyance distribution, any annoyance measure that summarizes this distribution can be calculated from this model.

The exposure response curves for the percentage highly annoyed (*%HA*) the percentage annoyed (*%A)*, and the percentage at least little annoyed (*%LA*) are derived from the annoyance distribution by choosing different cut-off values on a 0-100 scale: 72 for *%HA*, 50 for *%A* and 28 for *%LA*. Also, the exposure response curve describing expected annoyance score (*EA*) can be derived.

Noise annoyance indicators can be calculated on the basis of the noise exposure of the population, using these exposure response curves. In this paper, the noise exposure is determined on the basis of noise maps (*DENL*). With the above-mentioned dose response curves, the number of people being highly annoyed ($p_{HA}$), annoyed ($p_A$) and (at least) little annoyed ($p_{LA}$) or the mean of the expected annoyance scores in the population are calculated ($m_{EA}$) (EU 2002).

Another type of noise quality indicator is the percentage of surface area where a certain noise limit is exceeded. In this paper, a noise limit of 50 dB (*DENL*) is chosen ($AREA_{50}$) In urban areas below 50 dB the noise quality can be considered to be reasonable.

An important question is, whether the different indicators give a different picture of the noise situation and suggest different noise abatement measures. To explore this question, road traffic noise and noise annoyance in Leiden (the Netherlands) is quantified with the five above-mentioned indicators. Leiden is a city with 116000 inhabitants and an area of 23 km$^2$. The effect of noise abatement on four different road types (motorways, arterial roads, main streets and residential streets) is examined and expressed in terms of the five indicators. The outcome for the five indicators will be discussed.

**Methods**

*Road traffic noise maps* With Urbis, detailed noise maps of Leiden have been made (Borst, 2001). Noise emissions are calculated on the basis of digital road maps in which traffic volume, speed and road surface type are attributes of road segments. Input for the noise transmission calculations are digital maps of land use and maps of buildings and other objects (e.g. noise screens). Meteorological, ground, object and screen attenuation and first order reflections close to the noise source are included for the modelling of noise transmission (Gerretsen et al., 1999).

Noise immissions are calculated for a set of receptor points that consists of a 25 x 25 meter grid, supplemented with receptors close to the noise sources and receptors at the façades of buildings with direct sight on a noise source. A 3×3 meter noise grid is derived by interpolation from the noise levels at these receptors. The noise levels ($L_{Aeq}$) are calculated for the day, evening and night, and combined to a map of the *DENL*.

*Noise exposure of dwellings* The noise annoyance measures are calculated on the basis of the noise load on the most exposed façade of the dwelling. This is determined by taking for each dwelling the maximum of the noise grid cell values on the façades. For each noise exposure class ($i$) of 0.1 dB ($DENL_i$), the number of people in each dwelling in the exposure class is summated, leading to the number of people per exposure class $n_{DENLi}$. The distribution of the population of Leiden over the noise loads (*DENL)* is shown in figure 1.

*Calculation of noise quality indicators* The following polynomial approximations of the exposure response curves for road noise are used (Miedema & Oudshoorn, 2001), (Miedema & Vos, in preparation) to calculate the annoyance measures:

$$
\begin{aligned}
\%HA &= 9.868 \times 10^{-4}(DENL - 42)^3 - 1.436 \times 10^{-2}(DENL - 42)^2 + 0.512(DENL - 42) \\
\%A &= 1.795 \times 10^{-4}(DENL - 37)^3 + 2.110 \times 10^{-2}(DENL - 37)^2 + 0.535(DENL - 37) \\
\%LA &= -6.235 \times 10^{-4}(DENL - 32)^3 + 5.509 \times 10^{-2}(DENL - 32)^2 + 0.669(DENL - 32) \\
EA &= -9.154 \times 10^{-5}(DENL - 32)^3 + 2.307 \times 10^{-2}(DENL - 32)^2 + 0.537(DENL - 32)
\end{aligned}
\qquad \textit{(Eq. 1)}
$$

The number of people in each noise exposure class $n(DENL_i)$ is multiplied by the value of the annoyance measures for road noise at that level (*eq. 1*) (divided by 100 except for *EA*) and summated over the noise exposure classes. This gives the number of people being highly annoyed, annoyed, little annoyed and the sum of the annoyance scores. When divided by the number of people in the community ($N$) (multiplied by 100 except for *EA*) this results in the noise quality indicators (*eq. 2*).

$$
\begin{aligned}
p_{HA} &= \frac{100}{N} \times \sum_i \left(n_{DENLi} \times \%HA_{DENLi} / 100\right) \\
p_{A} &= \frac{100}{N} \times \sum_i \left(n_{DENLi} \times \%A_{DENLi} / 100\right) \\
p_{LA} &= \frac{100}{N} \times \sum_i \left(n_{DENLi} \times \%LA_{DENLi} / 100\right) \\
m_{EA} &= \frac{1}{N} \times \sum_i \left(n_{DENLi} \times EA_{DENLi}\right)
\end{aligned}
\qquad \textit{(Eq. 2)}
$$

The area with a noise load exceeding 50 dB ($AREA_{50}$) can be directly calculated from the map of the *DENL*.

*Assessment of emission reduction on different road types* The roads in Leiden are divided in four categories: motorways, arterial roads (> 10000 vehicles / 24h), main streets (1500 – 10000 vehicles / 24h) and residential streets (< 1500 vehicles / 24h). In order to assess the effect of 1 dB emission reduction on the noise quality for the four road types, four maps were calculated, each with 1 dB reduction of the noise emission of one of the road types. This way, a road noise map is obtained with 1 dB emission reduction for only the motorways, a map with 1 dB emission reduction for only the arterial roads and so on. The noise quality indicators, calculated on the basis of these maps are subtracted from the indicators of the initial situation without emission reduction. For comparison, the reduction of the indicator is divided by the total road length of each type in the municipality.

**Results** Figure 1 shows how the population of Leiden and the noise effect indicators are distributed over the noise loads. The thick black line is the percentage of the population in each noise exposure class of 0.1 dB (*DENL*). The thinner lines show per noise exposure class the percentage of the of the total number highly annoyed ($p_{HA}$), annoyed ($p_A$) and little annoyed ($p_{LA}$). The dashed curve shows the contribution of each noise level to the total expected annoyance ($m_{EA}$). This curve is almost overlapping with the $p_{LA}$ curve.

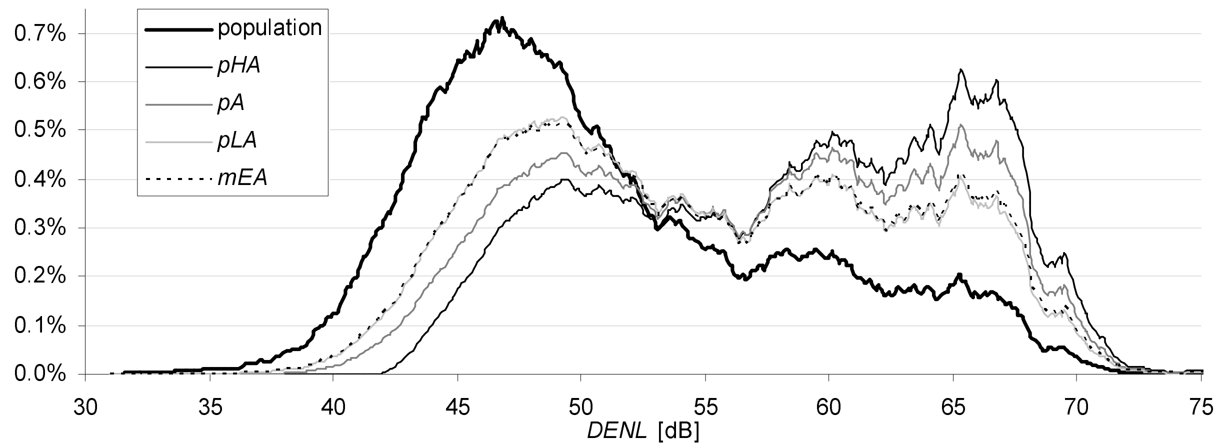


*Figure 1: Distribution of the total population, highly annoyed ($p_{HA}$), annoyed ($p_A$), little annoyed ($p_{LA}$) and expected annoyance ($m_{EA}$) on the basis of road traffic noise load per 0.1 dB (DENL) in Leiden (smoothed).*

Figure 1 shows that a large part of the population in Leiden has a noise exposure due to road traffic noise between 40 and 55 dB. The median noise load is 49 dB and 6% of the population has a noise load higher than 65 dB. The distributions of the at least little annoyed, the annoyed and the highly annoyed in Leiden show an increasing shift to the higher noise exposure levels. This means that the indicator $p_{HA}$ is to a greater extent determined by the number of people with higher noise loads than the indicator $p_{LA}$; of the number highly annoyed, 23% has a noise load higher than 65 dB and of the little annoyed this is 13%. The distribution of the expected annoyance ($m_{EA}$) is almost the same as the distribution of the little annoyed. This is because the ratio between the curves for *%LA* and *EA* (*eq. 1*) is almost constant.
The annoyance indicators which are shown in table 1, are calculated on the basis of the distribution of the population over the noise exposure levels (figure 1) with equations 2. Of the population, 29% is (at least a) little annoyed ($p_{LA}$) which means that they have an annoyance score of 28 or higher (on a 0-100 scale). Of the population, 5% is expected to have an annoyance higher than 72 on a 0-100 scale (i.e. highly annoyed). The average expected

annoyance score ($m_{EA}$) is 19. The area with a noise load exceeding 50 dB ($AREA_{50}$) is 58% of the total area of Leiden.

*Table 1: The value of the noise quality indicators in Leiden*

| *Indicator* | *Value* |
|---|---|
| $p_{HA}$ | 5% |
| $p_A$ | 14% |
| $p_{LA}$ | 29% |
| $m_{EA}$ | 19 |
| $AREA_{50}$ | 58% |

The effect of 1 dB reduction per road type is calculated in term of the five indicators. Therefore the total number highly annoyed is calculated on the basis of a noise map with 1 dB emission reduction on all roads of one road type. This number is subtracted from the initial number highly annoyed and divided by the total length of the road type (*dHA*). The same approach is also followed for the other indicators (*dA*, *dLA*, *dEA* and $dAREA_{50}$) shown in figure 2.

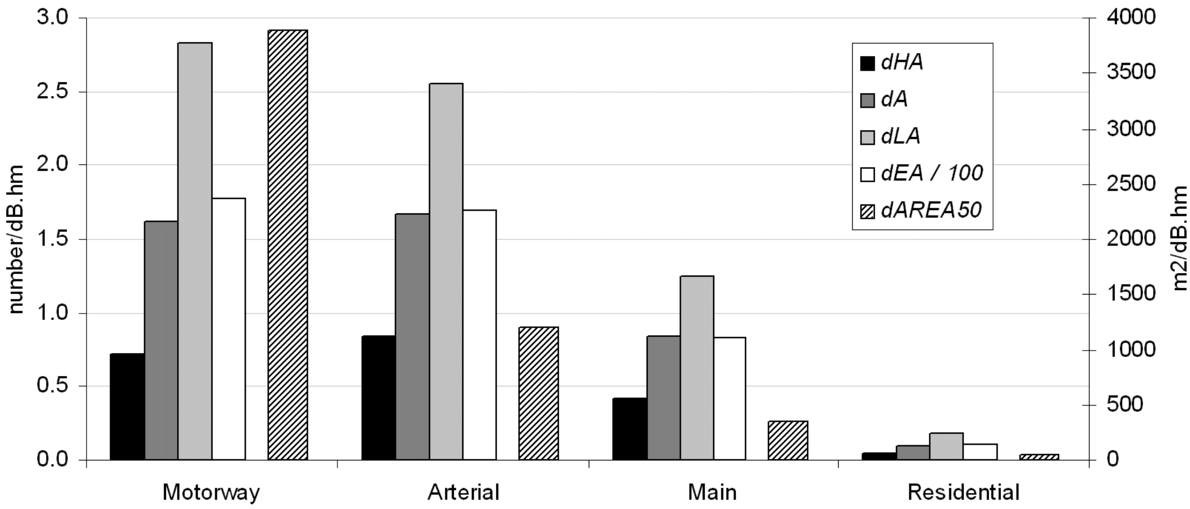


*Figure 2: Reduction in the number people being highly annoyed (dHA), annoyed (dA), little annoyed (dLA), and the reduction in expected annoyance (divided by 100) (dExp.A) and in the area with a noise load > 50 dB ($dAREA_{50}$) (right axis) per dB noise emission reduction per 100 meter (=hm) road for four road types in Leiden.*

Figure 2 shows how different noise quality indicators respond to the same amount of noise reduction (1dB) of the same road length (100 meter) for different road types. For example: noise emission reduction of 1 dB on 100 meter arterial road would (on average) lead to 0.84 less highly annoyed, while for 100 meter of main street this would be 0.42. Noise emission reduction of 1 dB on 100 meter motorway would reduce the area with a noise load exceeding 50 dB by 3900 $m^2$, while for 100 meter arterial road this would be 1200 $m^2$.

*Table 2: Ranking of effectiveness of 1 dB noise emission reduction on 100 meter of different road types in Leiden on the basis of different noise quality indicators.*

| | $p_{HA}$ | $p_A$ | $p_{LA}$ | $m_{EA}$ | $AREA_{50}$ |
|---|---|---|---|---|---|
| Motorways | 2 | 2 | 1 | 1 | 1 |
| Arterial | 1 | 1 | 2 | 2 | 2 |
| Main | 3 | 3 | 3 | 3 | 3 |
| Residential | 4 | 4 | 4 | 4 | 4 |

Table 2 shows the ranking of the effectiveness of emission reduction on the different road types in Leiden, based on figure 2. The ranking of the 'effectiveness' depends on the indicator that is chosen. On the noise annoyance indicators $p_{HA}$ and $p_A$, emission reduction on arterial roads has the greatest impact per meter. On the indicators $p_{LA}$ and $m_{EA}$, emission reduction on motorways is (slightly) more effective per meter. For the indicator $AREA_{50}$, the difference in effectiveness is greater.

**Discussion** In the example of Leiden, the ranking of effectiveness of 1 dB noise emission reduction on different road types depends on the indicator that is chosen. Therefore, the use of different noise quality indicators can lead to different noise abatement measures.

The main difference can be seen between the indicator $AREA_{50}$ and the indicators describing noise annoyance. The reason for this is that the distributions of noise exposure and noise load to surface differ between road types. Motorways have a high noise emission and not many dwelling nearby (in Leiden). This leads to a large area with high noise levels and a contribution to the noise load of many people, but few people being exposed to high noise loads due to (only) motorways. Arterial roads and main streets have lower emission levels, and more dwellings (and other buildings) nearby. This leads to relatively more people being exposed to higher noise level, but the impact is limited to a smaller area. Therefore, the indicator $AREA_{50}$ in our example points towards noise abatement on motorways leading to more quiet space, where the noise annoyance indicators $p_{HA}$ and $p_A$ point towards noise abatement on arterial roads.

The distribution of $m_{EA}$ does hardy differ from the distribution of $p_{LA}$ as shown by figure 1. Although these different indicators describe something else (the average expected annoyance versus the percentage of people being at least a little annoyed), these two indicators will in nearly always (so not only in our example) lead to the same choice in road noise abatement. This is because the ratio between the exposure response curves for *%LA* and *EA* (*eq. 1*) is nearly constant. Whether this also holds for air traffic noise and rail traffic noise is not investigated.

Although the results were obtained for Leiden and cannot be transposed to other cities, the conclusion that the use of different noise quality indicators can lead to different decisions in noise abatement is general.

The number of highly annoyed is a good indicator for the description of noise annoyance. However, this indicator does not describe the noise quality outside the dwellings. Another aspect of a good environment is the possibility to walk, cycle or just be outdoors without being exposed to high noise levels. Therefore the indicator $AREA_{50}$ can be used in combination with a noise effect indicator to prevent that a 'blanket of noise' is created outside the residential areas

There are other effects of environmental noise besides annoyance (HCN 1994). An effect of noise that is not described in this paper is sleep disturbance. Sleep disturbance is caused by nighttime noise. There are indicators describing sleep disturbance, which are calculated on the basis of the $L_{night}$ noise exposure in analogy with noise annoyance. Using sleep disturbance as indicator would probably put more focus on noise abatement on motorways, because motorways have relative high nighttime noise emissions.

In this paper, an approach is described in which the effectiveness of noise emission reduction is calculated per road type. This approach can be elaborated into an instrument that calculates the effectiveness of noise abatement per road or road segment. This information can be combined with an assessment of noise abatement options including cost calculations (e.g. the possibility and costs for new pavement). This way, a road map can be created with cost effectiveness for noise abatement for a given noise quality indicator.

**Keywords:** noise mapping, annoyance measures, transportation noise, noise abatement

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