A tool for environmental noise control in urban planning: The Population Annoyance Index

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Introduction

Urban planning is a complicated process, many parties are involved, the stakes are high, and the decisions have a long lasting impact. Although several other impacts of road and railroad traffic on the environment must not be neglected, it is clear that noise annoyance is a major dissatisfier in residential areas. In many countries, therefore a system of noise limits is in force. First of all the quantity must be defined for expressing the noise load, e.g. the Day-Evening-Night-level L_{den}, as defined by the European Union (2002). Subsequently a – preferred – noise limit is established, e.g. L_{den} = 50 dB[1](A). Usually it will not be possible to comply with this limit without any exception. Some margin is needed, to allow well-considered divergences. The adequate authorities can then decide if sufficient reasons are present to justify a noise load higher than the preferred noise limit. Nevertheless, it is regarded useful to set also a maximum noise limit.

In projects involving residences in the impact zone of main roads often the problem arises of comparing variants in which at least a part of the residences is exposed to noise loads between the preferred and the maximum noise limit. Of course the maximum limit is to be respected. Comparing is easy if all noise loads in one alternative are lower than in the other, or if in case **B** the number of residences exposed to noise loads of e.g. 55 -60 dB is higher than in case **A**. Sometimes – e.g. in Dutch legislation – the number of annoyed people is used as the criterion for comparison, the line of demarcation being drawn at e.g. 60 dB. All people in dwellings with noise loads over 60 dB are counted then, regardless of the actual sound load, and all other inhabitants are neglected, even if their noise load is 59 dB. The resulting number can be regarded as a measure for the "total extent of noise annoyance". Still, for comparing road alignments or siting and design of residential areas this criterion is too coarse, and this purpose deserves a better method.

Population Annoyance Index (PAI)

Consider an urban extension area, where residential complexes must be added to an existing structure, and roads have to be upgraded to allow for increased traffic flows. Noise limits have been established in general, but it is clear that no practical solution can be found to comply with the preferred noise limits for all residences. Fortunately, the maximum noise limits are not exceeded. Several options are possible, differing in the allocation of traffic to the roads, the location of dwellings and maybe even the quality of public transport and hence of the traffic flows. If alternative **A** results in lower sound loads everywhere than plan **B**, it is easy to conclude that plan **A** is better from the viewpoint of noise control. In most cases however, the comparison is more complicated. Therefore, a comprehensive metric is needed, an indicator for the total extent of noise annoyance in the neighbourhood, caused by these roads. This indicator will be based on noise response functions [1].

The noise response functions express the fraction of the people (p) being (highly) annoyed by the noise under consideration as a function of the noise load (L): $p = f(L)$. For noise loads below L_{den} = 50 dB this fraction is negligible ($p \approx 0$). If in the area bordering a stretch of road, delimited by the 50 dB-contours, the noise loads are known, the notional number of (highly) annoyed people can be calculated and used as in indicator for the total extent of noise annoyance, caused by this road. The Population Annoyance Index *PAI* is based on Miedema's response function for "Highly Annoyed":

[1] All DEN-levels are implicitly A-weighted

$$p = 0{,}0323\,(L_{den} - 42)^2 \qquad (1)$$

This formula is valid for noise loads over L_{den} = 42 dB; for lower noise loads $p = 0$. Noise loads around 50 dB are generally regarded as acceptable; the corresponding number of 2% highly annoyed people is in agreement with this. The absolute value of *PAI* is not relevant, as it depends on the limits of the area considered.

In Norway an analogous approach is being implemented, by means of the SPI ("støyplageindeks" in Norwegian) [2]. It is based on an annoyance score *A*:

$$A = 1{,}58 \cdot (L_{den} + k) - 62{,}25 \qquad (2)$$

For road traffic $k = 0$. The A-score correlates strongly with the percentage of Highly Annoyed people, *p* from formula (1) , but is some 15 (%) higher.

A similar procedure is based [3] on a noise factor ("Lärmfaktor") *LF* defined as a function of the noise load *B*:

$$LF = 2^{(B/10 - 5{,}75)} \qquad (3)$$

If the noise load *B* is taken to be expressed in L_{den}, the response function (1) is in good agreement with the noise factor (3).

The term "the noise load" suggests that there is only one relevant noise load for each dwelling, which cannot be true in general. Usually noise loads on the façades of dwellings will be different from each other, maybe even for ground floor and higher floors. It seems reasonable to assume that there is at least one quiet façade, and the highest value of the noise loads on façades of rooms is taken as representative. If no quiet façade is present, more annoyance is to be expected. [4][5]. Within the framework of the *PAI* however, the presence of at least one quiet façade seems a reasonable assumption.

Procedure PAI

Calculation of the *PAI* requires the noise load on all dwellings in the area of interest to be known, at least the values over 42 dB; neglecting sound loads below 50 dB gives only a small error, which is acceptable if done consistently. In many cases it is sufficient to know the contour lines (see Figure 1) and the number of dwellings between each pair of adjacent contours. For each residence the number of inhabitants is assumed to be equal to the mean size of households[2]. Applying the response function (1), the notional "number of highly annoyed inhabitants" can be calculated for each dwelling. The *PAI* is the expected value (in the statistical sense) of the total of number of highly annoyed people in all dwellings in the area of interest. Other noise sensitive buildings like hospitals or houses for the elderly could be included in the calculation by assigning a fictive number of occupants to them, dependent on the type and size of the building.

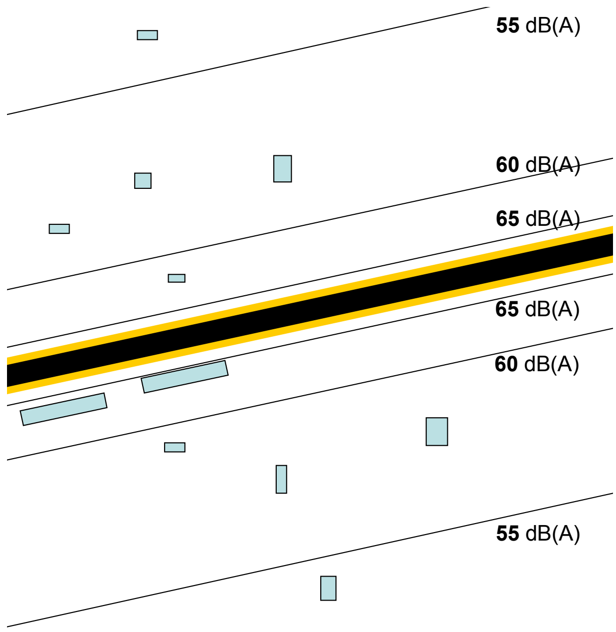

Figure 1. Simple example of a straight road with noise contours and scattered dwellings. The shielding effect of the dwellings has been neglected.

If an appropriate GIS (Geographic Information System) is available, it is easy to implement the necessary calculations. In many cases however the acoustical data are presented as noise contours, for example in 5 dB-steps. Then the number of dwellings in each class (45-50; 50-55; etc.) must be counted and assigned the noise load of the mean value of, in this example 47,5; 52,5 dB etc. It can be practical to set a lower limit at 50 dB, and neglect all dwellings with a noise load below this limit. The deviation introduced in this way is small and acceptable, provided this is done consistently: the comparison between options is more important than the absolute values. Special circumstances,

[2] In The Netherlands approximately 2,5 persons per household.

like dwellings with the most exposed façade noise-insensitive or highly insulated, are neglected, to keep the method simple and practical; loss of accuracy is not relevant, in the light of the (lack of) pretences of the method.

In general it is acceptable to use sound loads at an immission height of 4 m, which is usual in the European Union. The presence of high-rise residences can require an altitude differentiation in the calculation of noise loads.

Example of calculation

The noise contours of L_{den}= 50, 55, 60, 65 and 70 dB along a length of road have been determined. There is some scattered building, giving no substantial shielding for the dwellings at larger distances from the road. The residences between the contours were counted. The results and further calculations are shown in Table 1 below.

Contour area (dB)	Midvalue class (dB)	Resid-ences	Inhabit ants (*n*)	*p* (%)	*n.p*
45..50 dB	47,5	400	1000	0,98	9,8
50..55	52,5	250	625	3,56	22,3
55..60	57,5	150	375	7,76	29,1
60..65	62,5	100	250	13,57	33,9
65..70	67,5	6	15	21,00	3,2
				Sum:	**98**

Table 1. Calculation *PAI* case 1.

The sum of the values in the last column is 98, so *PAI* = 98.

For case 2 a different alignment is chosen, yielding different noise contours. The numbers of dwellings are counted again. Table 2 contains the results.

Contour area (dB)	Midvalue class (dB)	Resid-ences	Inhabit ants (*n*)	*p* (%)	*n.p*
45..50 dB	47,5 dB	400	1000	0,98	9,8
50..55	52,5	294	735	3,56	26,2
55..60	57,5	125	312	7,76	24,2
60..65	62,5	75	188	13,57	25,5
65..70	67,5	12	30	21,00	6,3
				Sum:	**92**

Table 2. Calculation *PAI* case 2.

The sum of the values in the last column is 92, so *PAI* = 92.

Although the number of residences with high noise load (over 65 dB) is higher in case 2, the total score is better (lower *PAI*). Case 2 should be preferred. Table 2 also shows that the dwellings in the lowest class (45-50 dB) give a minor contribution to the *PAI*, and might have been neglected.

The PAI-tool was applied in several EIA-studies (*Environmental Impact Assessment*) in The Netherlands [6].

Noise maps.

If an appropriate grid is defined in an area containing one or more roads, it is possible in many cases, to calculate the sound load for all immission points on this grid. Through interpolation lines of equal noise load (equi-dB-contours) can be constructed and plotted in what is called a noise map; see Figure 2.

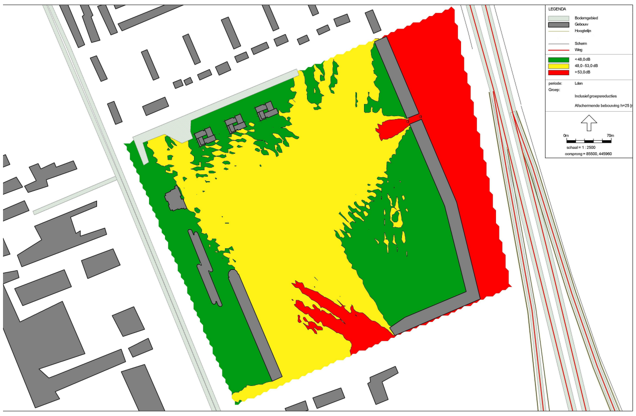

Figure 2. Example of a noise map, with buildings and calculated noise contour areas.

Most of the relevant factors regarding sound emission and transmission can be taken into account, including shielding and reflections by buildings, barriers etc. From the values in the grid-points, contour lines can be determined by interpolation. These contour lines can be drawn on a topographical map, or, more sophisticatedly, by assigning specific ranges different colours of noise load. In Figure 2 an example is given. It must be kept in mind, that these contours or colour coding are valid at one specified height only (usually 4 m); for different immission heights different sound loads will be found.

Maps allow a quick impression of the problematic locations, and the trouble-free areas. In addition, the magnitude of the noise problems can easily be appraised, at least in a rough way. For comparing options however noise maps are less suited, especially if the differences are moderate or varying: higher noise loads at some locations and lower values elsewhere. An aggregated indicator for the magnitude of the noise annoyance like PAI, as mentioned before, would serve much better.

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