Annoyance accumulation modeling in a community noise annoyance expert system

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Abstract: When the state of the sound environment in a region is monitored by tracing the percentage of people that is annoyed by noise, simulation models for community noise annoyance are needed. Building such simulation tools is not an easy task because information is scarce and relations between quantities involved is uncertain. Therefor an expert system that makes optimal use of the scare information is constructed. Modifier fuzzyness is fully taken into account. Combination of annoyance caused by different sources is an important part of the system. The probability approximation is used in this paper to incorporate perceptual annoyance models for combined community noises. The uncertainty that still exists in this field does not pose any problems to the system.

FUZZY AND ANNOYANCE

Annoyance is a vague concept. Often vague or fuzzy concepts are context dependent. In annoyance models this is sometimes referred to as the principle of compromise (1). Modifiers (e.g. highly, moderately) show a similar fuzzyness. In annoyance surveys one often gets around the fuzzyness in modifiers by using a discrete numerical scale. In the expert system proposed here, both numerical and verbal scales can be used, as long as consistency is maintained in all calculations. It is advantageous to cover the whole range of modifiers in the calculations including for example zero on a numerical scale or "not annoyed" on a verbal scale.

THE EXPERT SYSTEM

The expert system designed for community noise annoyance simulation, consists of an environment that allows to take into account uncertainty and vagueness in all calculations. Uncertainty on quntities is represented by a probability distribution. Interfaces to Gaussian and level set descriptions are provided. The latter approach is preferred for input in many cases. It consists in fixing a number of uncertainty intervals for each input (e.g. 68%, 95% and 100% certainty intervals). Standard operations such as adding, multiplying, matrix multiplication or interpolation are defined for uncertain variables. The key feature of the system is "consensus". It allows to combine in a formal way, different calculations or different expert opinions to obtain a possibly better approximation from the scarce pieces of uncertain information. Details on the expert system were reported in (2).

ANNOYANE ACCUMULATION

In community noise annoyance simulation, accumulation of annoyance caused by different sound sources is an important step in the process. Several perceptual models backed up by laboratory experiments exist, but no detailed data based on annoyance reports is available (1). In particular the principle of compromise poses major problems.

In this work a general approach based on probability theory is introduced. Assume two sources of annoyance A and B. Let the subscript denote the quantifier of annoyance. The probability that a single individual in a population is annoyed at level i is assumed to be equal to the percentage of individuals in that population that is annoyed at level i. If the total annoyance is called H, than the probability that an individual is annoyed to level i is given by

$$P(H_k) = \sum_{i,j} P(H_k|A_i, B_j)P(A_i, B_j), \tag{1}$$

where | indicates conditional probability. The only requirement for this equation to be valid is that all levels of annoyance are covered by the subscripts. The advantage of using equation 1 lies in the fact that the conditional probability will probably be less dependent on exposure levels. This is a basic assumption of most perceptual models. $P(A_i, B_j)$ gives the probability of simultaneous theoretical annoyance in the absence of the other source. It therefor does not take into account masking or inhibition. In some cases $P(A_i, B_j)$ can be obtained directly from an exposure model in other cases it is useful to further expand it as $P(A_i|B_j)P(B_j)$. In the absence of geographical clustering of noise sources independence can be assumed, which leads to $P(A_i, B_j) = P(A_i)P(B_j)$. The probability tensor $P(H_k|A_i, B_j)$

TABLE 1. Comparison of annoyance accumulation and sound level summation for total annoyance calculation

model	moderately annoyed			highly annoyed		
	68% low	most probable	68% high	68% low	most probable	68% high
level summation	27	34	48	13	18	25
annoyance accumulation	41	53	66	19	26	34

includes the influence of the presence of the other source, the summation principle and the compromise principle. At this moment there is not enough knowledge available about the probabilities $P(H_k|A_i, B_j)$. Therefor each element of the tensor is implemented as an uncertain value. This allows to incorporate knowledge as vague as:

`"if a person is highly annoyed by sound of source A and highly annoyed by sound of source B, then he will QUITE LIKELY be highly annoyed by the combination of both sources"` or

`"if a person is not annoyed by sound of source A and highly annoyed by sound of source B, then he will PROBABLY be less highly annoyed by the combination of both sources"`

where the fuzzy quantifiers are underlined and the uncertain element of $P(H_k|A_i, B_j)$ is written in capital letters.

In community noise annoyance calculations, introducing a secondary condition can often be very helpful to accurately quantify $P(H_k|A_i, B_j)$ and to verify the independence of exposure. A good example are well localized sources (e.g. airports) where a region can be identified to which the impact of one source is limited. As an example assume that $P(T)$ is the probability that a person lives within an area where both sources A and B can be important. In $\overline{T}$ source A is not present. Total annoyance can than be split as $P(H_k) = P(H_k|T)P(T) + P(H_k|\overline{T})P(\overline{T})$, or after similar processing as Eqs 1

$$P(H_k) = \sum_{i,j} P(H_k|A_i, B_j|T)P(A_i, B_j|T)P(T) + \sum_{j} P(H_k|A_0, B_j|\overline{T})P(B_j|\overline{T})P(\overline{T}) \tag{2}$$

The first part of the equation describes real accumulation, while the second part only includes the compromise principle.

EXAMPLE

Within the limited space of this written paper, only one extreme example is given to illustrate the technique. Traffic noise annoyance is assessed in two different ways. First total noise exposure is determined (in a sample taken at random) and multiplied by average dose-response relations to yield a distribution of the population over different annoyance levels. Secondly the exposure to local traffic noise is obtained as well as exposure to highway traffic noise. Both exposure lead to a distribution of the population over annoyance levels. Finally annoyance of both sources is accumulated using the extreme assumptions of exposure independence, a strongest component perceptual model and no context dependence. In this case the tensor $P(H_k|A_i, B_j)$ is reduced to

$$\begin{array}{cccc} \multicolumn{4}{c}{H_{not}} \\ & A_n & A_m & A_h \\ B_n & 1 & 0 & 0 \\ B_m & 0 & 0 & 0 \\ B_h & 0 & 0 & 0 \end{array} \qquad \begin{array}{cccc} \multicolumn{4}{c}{H_{moderately}} \\ & A_n & A_m & A_h \\ B_n & 0 & 1 & 0 \\ B_m & 1 & 1 & 0 \\ B_h & 0 & 0 & 0 \end{array} \qquad \begin{array}{cccc} \multicolumn{4}{c}{H_{highly}} \\ & A_n & A_m & A_h \\ B_n & 0 & 0 & 1 \\ B_m & 0 & 0 & 1 \\ B_h & 1 & 1 & 1 \end{array} \tag{3}$$

without any uncertainty. Certainty intervals (68%) and most probable value for percentage of people highly and moderately annoyed are given in table 1 for both approaches.

REFERENCES

1. B. Berglund and M.E. Nilsson, "Empirical issues concerning annoyance models for combined community noises," *Proceedings of Internoise 97*, Budapest, Hungary, 1053-1058, 1997
2. J. De Poorter and D. Botteldooren, "Vagueness and Uncertainty in Community Noise Annoyance Modeling," *Proceedings of Internoise 97*, Budapest, Hungary, 1207-1210, 1997