Event based noise annoyance modeling

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Classical dose response relationships for environmental noise annoyance have been based on L_{dn} or L_{den}. They represent the average response of people to the specific averaged noise level. To model the different response to various types of environmental noise different dose response relationships are used. Shifts in L_{dn} are used to model modifiers like the noise sensitivity. A unified theory that accounts for the different types of sound is clearly desirable. This paper presents a model that unifies the noise annoyance evaluation. The model starts with the premise that only noise that is noticeable causes annoyance. The threshold above which the noise is audible is not only dependent on the level of the noise event itself but also from the background noise, the specific activity of the person which determines the individual attention level, the insulation of the dwelling, etc. Modifiers like the noise sensitivity are included in the overall noise annoyance rating. Other modifiers can be plugged in the extensible modelling architecture. The model has been tested and evaluated against survey data (N=2007) collected in a difficult topography (Alpine valley in Austria). The unified model using the noise sensitivity performs better than the L_{Aeq}-only model even when the unified model uses only simplified traffic data from the two nearest roads and has no access to noise maps.

1 Introduction

During the past decades noise researchers have been focusing very strongly on deriving quantitative relationships between outdoor L_{dn} or L_{den} and annoyance. Although relatively accurate, such relationships do not allow to unravel the phenomena that play a role in the emergence of annoyance. Noise annoyance modifiers have been modelled by adding penalties or bonuses to the averaged noise levels.

A handful of researchers have inclined toward true annoyance modeling by introducing computer assisted models such as neural networks or Bayesian networks. In previous work, we have focused on fuzzy rule based models [1] to account for both the vagueness in concepts involved and uncertainty in relations between them. These models have the advantage that they allow to express knowledge on the construct of noise annoyance in a way that is readable by the human expert. Although it may seem that the models mentioned above model individual noise annoyance they are still far away from that objective. The model introduced in this paper follows a completely different approach. It tries to predict reaction of a small group by simulating a larger number of people belonging to that group. The increasing availability of computer power has made it possible to extract group behaviour from this type of simulations.

The key hypothesis in this model consists in assuming that annoyance has to be noticed before it can become annoying. The strong relationship between noticing a sound and being annoyed by it was already mentioned in earlier work by Fidell [3], Snedden [9], and Schomer [8]. Several new ideas emerge naturally when a model based on this hypotheses is constructed. In Section 2 we will discuss the proposed model in detail. In Section 3 a limited implementation of the model is confronted to observations made in a recent field survey carried out in the Brenner Pass in Austria. The model has also been applied to a noise annoyance field experiment [2, 12].

2 The notice-event model

2.1 General model layout

Figure 1 gives the general layout of the model, the flow of events, and the modifiers that influence the impact a *signal* has. These modifiers are often unknown for an individual. Based on known or assumed probability distributions, samples can be drawn to model that individual by one simulation per modeled individual. Noise sensitivity is a typical example of this modeling approach. Noise sensitivity, a stable personality trait [6] [7] [10] which affects noise annoyance, is included as a modifier of noticing the exposure. It is also included as a modifier in the rating of noise annoyance [11]. If this characteristic of the modeled person is known, as is the case in the experiment given below, it can be included and the model prediction will become more accurate. If it is unknown (e.g. for large scale noise annoyance assessment), sampling a level of noise sensitivity level from a known distribution will result in a distribution of responses. Analyzing this

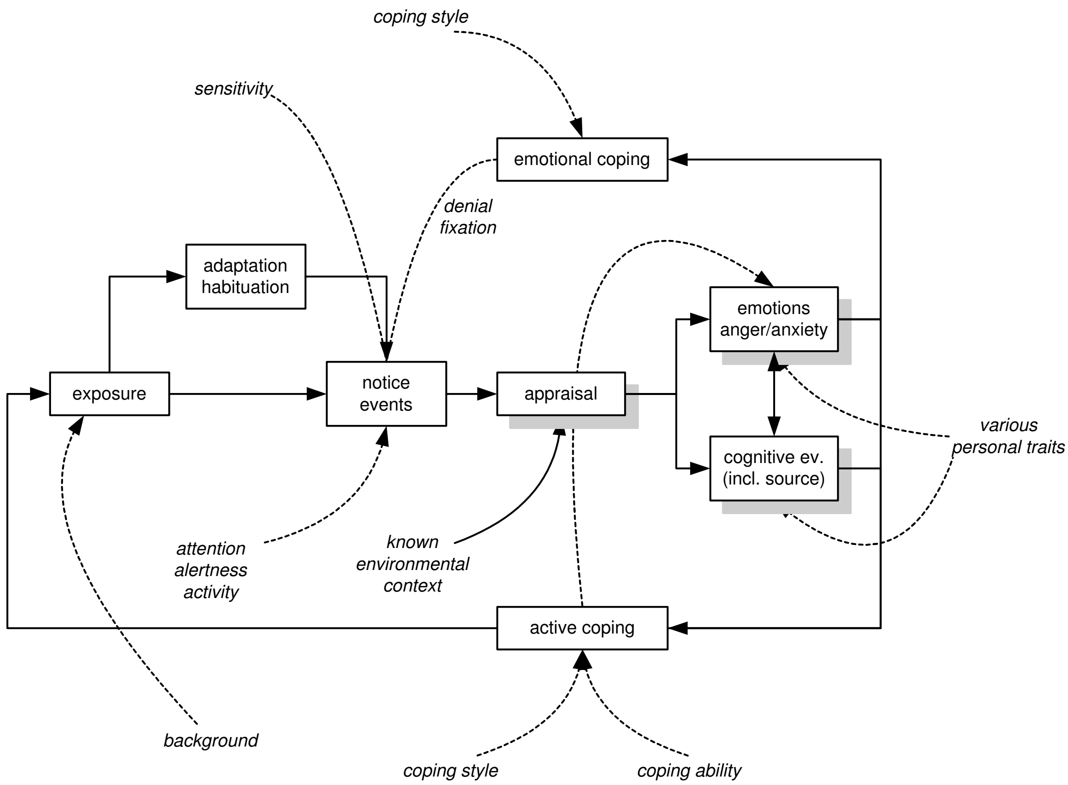


Figure 1: Layout of the general noise impact model

distribution statistically can still yield intersting conclusion, e.g. the fraction of the spread that can be attributed to noise sensitivity). Sound exposure contains a mixture of sound, part of which is regarded as background since it is of no or little interest for the effect under study (e.g. the sound of wind, rain, birds). This sound is not continuously noticed. We define a notice-event as an instant of attention focus on the sound. Activity disturbances (speech interference, sleep disturbance, etc.) for instance are considered a special case of noticing a sound. The occurrence of a notice-event depends on several conditions:

- the level of the sound above the background;
- the degree of alertness or attentiveness of the listener;
- the current activity, whether the activity of the person produces masking noise or how easy it can be disturbed;
- the sensitivity of the person to noise in general;
- the amount of habituation that may have occurred.

Note that a notice-event can occur whenever one of the conditions changes. A sudden increase in alertness may trigger a notice -vent although the sound level did not change significantly. The start of a continuous sound may trigger a notice-event that stops after some time due to habituation. We use the term *habituation* here for short term habituation occurring at a perception level. The model includes long-term effects via a path that leads via emotional coping to some form of denial.

Noticed sounds may or may not be appraised as taxing or exceeding personal resources. For this application only loudness is taken into account although additional sound quality indicators may change the appraisal, like the perceived distance [12].

Following the ideas proposed by Lazarus [4] on stress, appraisal and coping, we assume that negative appraisal can lead to a particular style of coping [1]. Both emotional and cognitive reactions to the stressful event are considered, each leading to a different way of coping. Clearly, there is a strong interaction between both types of reactions, indicated by the bidirectional arrow between both blocks. Note that the whole process sketched in Figure 1 is a dynamic one where reappraisal may occur within the newly developed context.

2.2 Mathematical implementation

The key issue when deriving mathematical expressions for the relationships described above, is that this is a time domain model and thus the time dimension needs special care. The experimental data in the form of the questionnaires does not contain the time dimension. Derivation of some time constants is made based on a noise annoyance field experiment [12], while other time constants are based on psycho-acoustic literature.

Notice event A notice event ,E_n, is defined as an instance of consciously observing a sound. The notice event has a well-defined starting moment. Simulations are performed with one second time resolution. The detection of a notice event requires a decision on the start and the end of the event. The condition used to identify the start is primarily based on the difference between the sound level produced by the modeled individual (MI) itself L_s and the natural background hum L_n at the one hand, and the intruding sound L_i entering its living environment at the other. The noise L_s covers all sources of sound which the MI has direct control over or is the direct cause of (e.g. its own radio or TV, the noise produced by cooking). For simplicity, we will further discuss L_s, L_n, and L_i as noise levels, but specific features of the noise such as tonality, that increase noticeability could be included. The condition for the start of a notice event becomes:

$$L_i - L_s - L_n > T(a) \tag{1}$$

where we explicitly introduced the dependence of the notice-threshold on alertness a toward the intruding sound.

Alertness In this work, alertness is used as a basic variable to model the process of focussing attention to the intruding sound. It gathers various aspects. The non-acoustic factors are mainly natural circadian variation, attention controlled gating of the sound due to attention focusing on a task and the current activity (e.g. sleeping) that lowers alertness for external stimuli. We will call this part a_{activity}. High alertness for intruding sounds can be expected during relaxing. Note that this alertness is toward noise and not a general state of awareness. Results from a recent field experiment [2] also suggest a dependence of the noise sensitivity. An effect which is found in less pronounced form in [11].

Very little is known on the dependence of the threshold for noticing a sound on the alertness. It is safe to assume that the function $T(a)$ is a monotonous decreasing function, hence for simplicity we approximate it by a linear function on dB scale $T(a) = T - f_a \cdot a$. The effect of sensitivity is translated in an offset on the alertness $a = a_{\text{activity}} + f_{a,s} \cdot sens$.

Gating After a sound is noticed, subsequent peaks in the intruding sound will not trigger the beginning of a new notice event unless they are sufficiently more noticeable. The psychophysical mechanism closest to explaining this is *gating* (perceptual and attentional). The gating condition holds as long as the event that was first noticed continues but also slightly after that, since it is known that non-negligible time constants are involved in the process. Condition 1 is thus extended to condition 2 to lump multiple peaks in one of the levels that occur shortly after each other into one notice event:

$$L_i - L_s - L_n > T(a) + T_{\text{new}} \cdot e^{\frac{t_{ld} - t}{\tau_{ld}}} \tag{2}$$

where t is the time and t_{ld} is the time when condition 2 was last fulfilled. Within a notice event no new notice events can occur unless the difference $L_i - L_s - L_n$ increases by almost T_{new}. The exponential tail (time constant τ_{ld}) also reduces noticeability immediately after the previous event.

Habituation Because of habituation, response to sound exposure can vary over time. In the modeled individual (MI) habituation takes two forms. Long term habituation is modeled through the coping mechanism. Short term habituation or adaptation is included via a direct path from the sound exposure to the to event noticing. Although it seems obvious that habituation is limited, we assume that the sound levels under consideration do not cause saturation in the MI. Habituation ha is assumed to be proportional to the exponentially averaged sound level where the time constant is a few minutes. Hence, habituation ha is assumed to be proportional to the exponentially averaged sound level

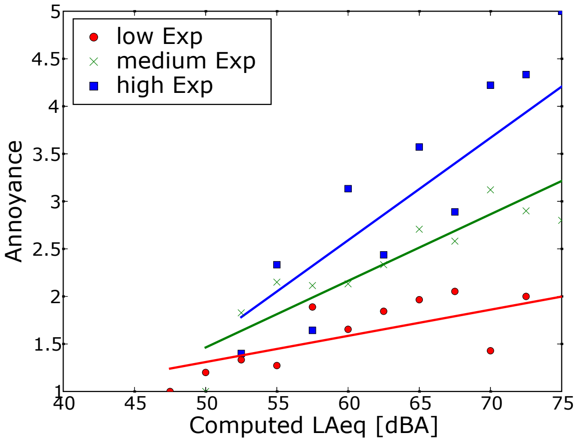
$$ha(t) = \frac{C_{ha}}{\tau_{ha}} \int_t^{-\infty} L_i(t') e^{-\frac{t-t'}{\tau_{ha}}} \tag{3}$$

where τ_{ha} is a few minutes. In the MI, short term habituation is included via a reduced alertness toward the intruding sound. A linear relationship is assumed:

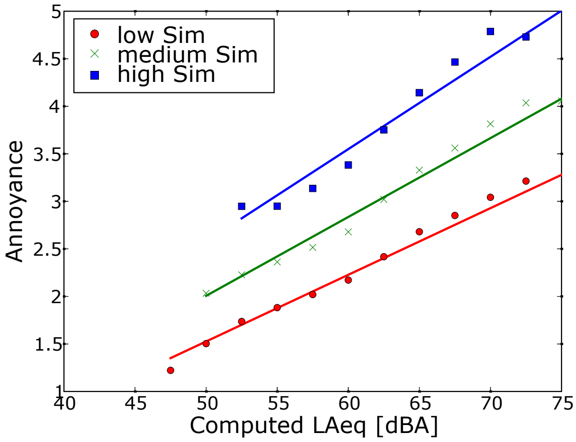
$$a(t) = a_{\text{activity}}(t) - ha(t). \tag{4}$$

The constant C_{ha} is determined from the observation that $f_a C_{ha}$ is the magnitude of the noticing-threshold shift that can be caused by habituation in the MI.

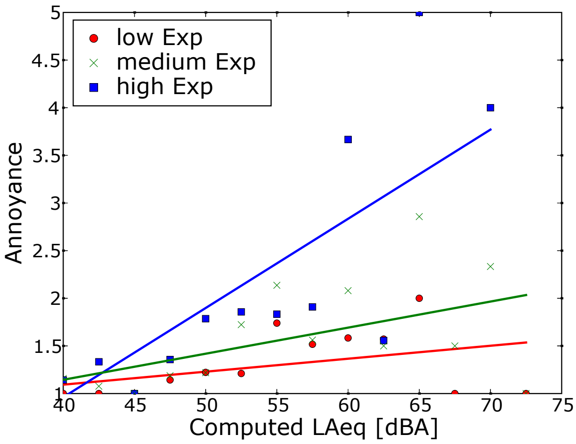
Sound Level All sound levels handled by the model are expressed in $L_{Aeq,1s}$. The time resolution is based on the expected resolution of notice events. Using the A-weighted sound level has the benefit of ease-of-use in a first approach while still providing a reasonable approximation for the loudness of the sound. The time pattern of the sound level at the facade caused by the road and rail traffic is artificially generated. The sound generated by the road traffic is based on the distance between the



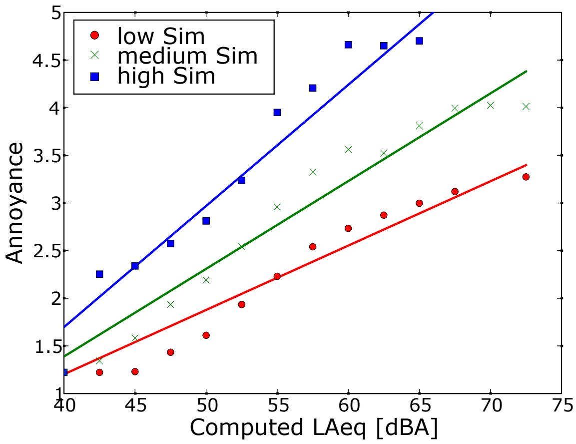
(a) Road Experiment



(b) Road Simulation



(c) Train Experiment



(d) Train Experiment

Figure 2: Annoyance as a function of L_{Aeq} for different groups of sensitivity.

road and the facade. The speed and sound level of each car in the flow is randomized around the mean expected speed and level. The interarrival time of cars is exponential, thus following a Poisson proces, known to be a good first order approximation for road traffic. A similar model is used for the rail traffic. Statistics about the traffic are extracted from measurements.

For the sound produced by the MI, L_s, and the natural background, L_n, only statistical estimates can be made. The distribution of instantaneous L_s that is used to reconstruct the time series randomly, is a function of the MI activity. It is estimated on the basis of time-activity patterns and typical levels associated with the activity obtained from dosimeter measurements on a limited number of volunteers.

Appraisal A notice event is appraised by the modeled individual (MI) based on a number of characteristics of the intruding sound. The first and most important characteristic is related to its loudness. It is approximated by the integrated A-weighted acoustic energy between the start, t_s and the end t_e of the notice event.

$$L_E = \int_{t_s}^{t_e} 10^{\frac{L_i(t)}{10}} dt \tag{5}$$

Other characteristics of the intruding sound can be added, but are not used in the example discussed below and hence are not discussed. For the purpose of this paper, we reduce the complexity of the emotional and cognitive evaluation to a single variable A, representing annoyance. Annoyance after a new notice event is obtained from

$$A_{\text{notice event}} = f(L_E, s) \tag{6}$$

where s is the sensitivity towards noise of the IM.

3 Results

The performance of the model has been tested on data obtained from a field survey conducted in the Brenner Pass in Austria. For a large number of respondents the location of their dwelling was available and was linked to the available GIS data. The model takes the distance to the closest highway and main road and the approximated traffic intensity of it as input. The distance to the train track is taken from GIS and the number of trains has been measured. Individual reported noise sensitivity is known from the survey and used as an input for the model. Figures 2(a) and 2(b) show the annoyance rating in function of the computed L_{Aeq} respectively for road and train traffic. The computed L_{Aeq} is the L_{Aeq} that the model predicts based on the traffic and the geometrical divergence, no propagation model is used. Note that the rating by the model is on a different scale than the experiment. Both scales are however linearly related.

For road traffic the correspondence between the experiment (on the left) and the simulation is clear. Individuals were grouped into one of three categories based on their reported noise sensitivity. For train traffic a linear trend does not fit the results well due to outliers in the experimental data. What is however clearly visible is the general trend. The reported annoyance for train annoyance seems more an effect of different rating than a shift in level. For road traffic the difference in sensitivity also introduces a complementary shift in rating. The greater variance visible in the experimental data can be partially attributed to the fact that the L_{Aeq} used in the X-axis is only an approximation.

4 Conclusion

In this paper a model for noise annoyance is proposed based on the stress, appraisal and coping ideas of Lazarus. The different aspects specific for noise annoyance are identified and put in perspective. Based on this physiological and psychological model a mathematical time model is derived. The key hypothesis is that annoyance is triggered by a notice event, defined as an instant of attention focus to sound. In this paper the effect of noise sensitivity is investigated and found to correspond well with the experimental data.

Acknowledgements

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