Community response to noise - A theory-based model for exposure-response relationships

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INTRODUCTION

Dose-response functions that relate transportation noise exposure to the average annoyance experienced by the residents in a community are important tools for city planners. Normally one would want to keep the negative impact from transportation noise as low as possible. However, a "zero target" is seldom feasible. A reliable dose-response function will tell which noise exposure level that is "low enough" to keep the annoyance at an acceptable level.

Since the initial effort by T. J. Schultz to establish a dose-response function for transportation noise (Schultz 1978) numerous attempts have been made to refine and improve such functions. Most of these dose-response functions have been derived by applying more or less sophisticated mathematical and statistical methods to a set of observation data coming from social surveys. Regression analysis is a statistical technique that can identify a function which minimizes the sum of the squares of the distances of a set of points to a line or a curve. A dose-response relationship derived by regression yields a function appropriate for characterizing annoyance prevalence rates of nominal communities located in the middle of a cloud of data points.

If the data points represent noise exposure (x-axis) and prevalence of annoyance (y-axis) the regression can either predict noise exposure from annoyance, or annoyance from noise exposure. Cause and effect are irrelevant in this analysis.

PREVIOUS STUDIES

Figure 1 shows a selection of "approved" dose-response functions for aircraft noise annoyance. The first serious attempt to establish a dose-response curve for transportation noise annoyance was published by in 1978 (Schultz 1978) Schultz's synthesis was based on a number of social surveys, mainly on road traffic noise. However, some studies on railroad noise and aircraft noise were also included. Schultz concluded that there was no difference between these sources. His dose-response function, the dark blue line in Figure 1, is based on 161 data points.

Later more surveys were added to the common data base, and in 1992 FICON (FICON 1992) established a "new and improved" dose-response curve for aircraft noise annoyance. This curve was based on about 400 data points. This function, the yellow line in Figure 1, shows only slight deviations from the original "Schultz curve".

The generally accepted international standard for assessing community noise annoyance, ISO 1996, Pt. 1, (ISO 2002) has yet another dose-response function. This is the same as the original Schultz curve from 1978, but the noise level has been given a source dependent correction. The standard recommends a "correction penalty of 3 to 6 dB". This means that road traffic at for instance 60 dBA is considered equally annoying as aircraft noise at a level between 54 dBA and 57 dBA. The red

line in Figure 1 shows the dose-response function according to ISO with a 6 dB penalty.

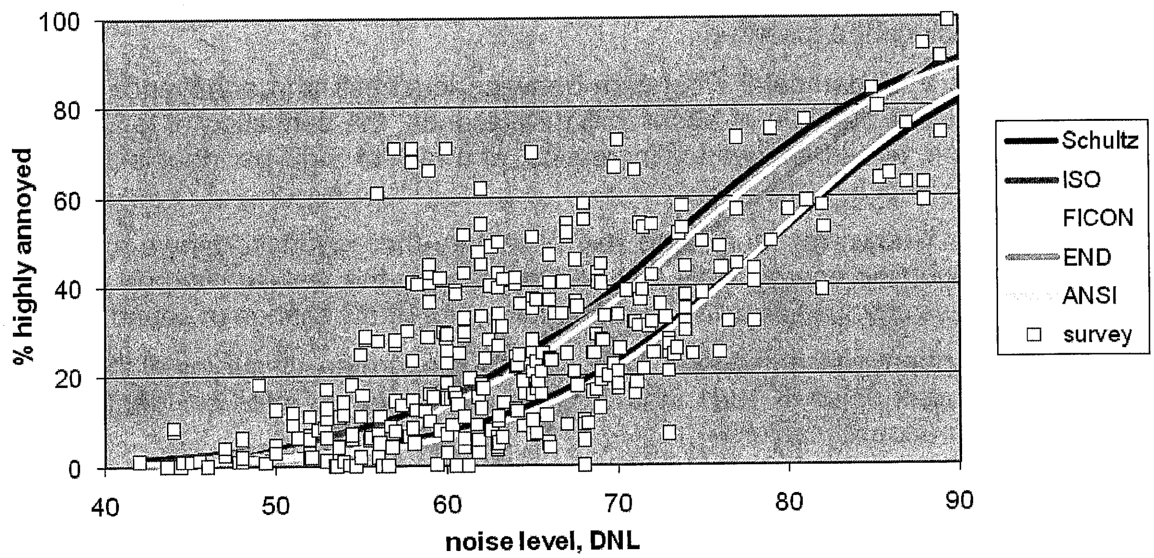

Figure 1: Various "standardized" dose-response curves for aircraft noise annoyance plotted against the results from 24 different surveys

The American National Standards Institute uses a similar approach in their standard for assessing community response to long term noise exposure, ANSI 12.9, Pt. 4 (ANSI 2005). In this standard the dose-response for aircraft noise annoyance is also based on the original Schultz curve from 1978, but the suggested aircraft noise penalty is level dependent. For noise levels below 55 dBA the correction is 0 dB and for noise levels above 60 dBA a 5 dB penalty is applied. In the transition interval there is a gradually increasing penalty from 0 dB to 5 dB. The dose-response function according to ANSI 12.9 is shown as a green line in Figure 1.

In 2002 the European Union adopted a noise directive, END, dealing with community noise annoyance. A background paper for this directive was a study by Miedema & Vos (1998) who developed a set of dose-response functions for aircraft, road traffic and rail noise. The aircraft noise analysis was based on 19 studies and more than 27,000 observations. The relevant function for "percentage highly annoyed by aircraft noise" is shown as a light blue line in Figure 1.

The five curves in Figure 1 represent different possible dose-response functions for aircraft noise annoyance. They are to a large extent based on the same survey data, but different assumptions during the analysis yield quite different results. The differences are especially prominent in the noise level range 55 dBA to 75 dBA, which is the most relevant for regulatory purposes.

A NEW APPROACH

The result of a regression analysis gives a "best fit" function based on the available input data, but this function does not explain the relationship between the independent and dependent variables. A very different approach to establishing a dose-response function would be to develop a model based on for instance physics and well known psychological inter-relationships, and then check how well the observation data from the surveys fit this model.

Some established findings regarding the relationship between noise exposure and annoyance include the following:

- Duration is a fundamental difference between loudness and annoyance. Once a sound attains a duration of about 250 milliseconds, the sensation of loudness remains stable, but its annoyance increases, at a rate of 3 dB per doubling of duration.
- It has been known for more than half a century that loudness grows as the 0.3 power of acoustic energy. This fact is the basis for the well-known rule of thumb that loudness changes by a factor of two for every 10 dB change in sound level.
- It has also been well understood since the first modern social survey of the annoyance of aircraft noise in 1961 that annoyance prevalence rates are dependent in part on non-acoustic factors.

From laboratory studies that involve assessment of noise samples it is a well known fact that loudness is a very critical and dominating parameter. There are therefore reasons to believe that loudness also plays a big role in the assessment of annoyance in a community noise situation. Since annoyance is closely related to duration-adjusted loudness, it is reasonable to assume that the basic growth rate of annoyance with exposure should be that of duration-adjusted loudness. An estimate of the effective loudness of noise exposure can thus be derived by transforming Day-Night Average Sound Levels into a duration-adjusted dose, *m*, to convert pressure units into a quantity proportional to loudness:

$$m = (10^{(DNL/10)})^{0.3}$$

Fidell, Schultz, and Green (Fidell et al. 1988) noted that social survey respondents' self-reports of their attitudes reflect both their community's transportation noise exposure and a reporting criterion. The more stringent the criterion for reporting annoyance is in a given community, the farther it slides the effective-loudness function to the left (lower levels). The more lenient the criterion is, the farther it slides the effective-loudness function to the right (higher levels).

Predicted annoyance prevalence rates for the calculated dose may be computed as $p(HA) = e^{-(A/m)}$, where A is a non-acoustic decision criterion, *per* Green & Fidell (1991). This exponential function provides a single parameter transition function to describe the change of the proportion of the residents of a community that are "highly annoyed".

This is where the new method departs fundamentally from regression analysis. In regression analysis, a curve is sought which is closest on average to all of the data points. In the new proposed method, the goal is to select the value of A which best describes the fit of the data from a particular community to an *a priori* transition function.

The community-specific constant, A, is found by minimizing the root-mean-square deviation of the annoyance prevalence rates observed at the interviewing sites in each community from those predicted by an exponential function with a slope equal to the rate of growth of loudness with level ("the effective loudness function"). This process slides the effective loudness function along the DNL axis to the point at which a best fit between the predicted and observed points occurs. The value of A that yields the best fitting value for a community's response data to the effective loudness function may then be linearly transformed into a value on the exposure axis that reflects the aggregate influence of all non-DNL related factors on annoyance judgments in a given set of field observations.

One minor complication arises when the family of curves described by the function $e^{-(A/m)}$ is applied to individual communities. The complication is finding a standard way to anchor the curve to a point on the DNL axis so that its position can be easily described. A simple solution is to pick some point on the function, and refer to the abscissa value, the DNL value, at that point. For reasons of convenience, the "middle" of the function – the point at which half of the people in the community describe themselves as highly annoyed by noise exposure, and half do not – is an obvious choice. The value of DNL that corresponds to the middle of the effective-loudness function for a given community may be thought of as a measure of how tolerant the community is toward noise exposure, or as a Community Tolerance Level (abbreviated "CTL", and represented symbolically in mathematical expressions as L_{ct}).

Results from social surveys indicate that in some communities half of the residents may not be highly annoyed until DNL reaches a level in the 80 dB range. These communities may be described as "very tolerant to noise". In other communities the 50 % point for highly annoyed may be in the DNL 60 dB range. These communities have "a low tolerance for noise". In Figure 2 the CTL-method has been applied to the results from several aircraft noise studies. The CTL values vary from 63 dB (Frankfurt) to 84 dB (Heathrow).

In Figure 3 the CTL-method has been applied to the combined data sets from 43 different aircraft noise surveys. The grand mean of the CTL values is 73.3 dB.

Figure 4 compares this dose-response relationship with that derived by Miedema & Vos (1998). Miedema and Vos have based their calculations on practically the same data sets. The two curves are nearly identical in the noise exposure range of primary interest.

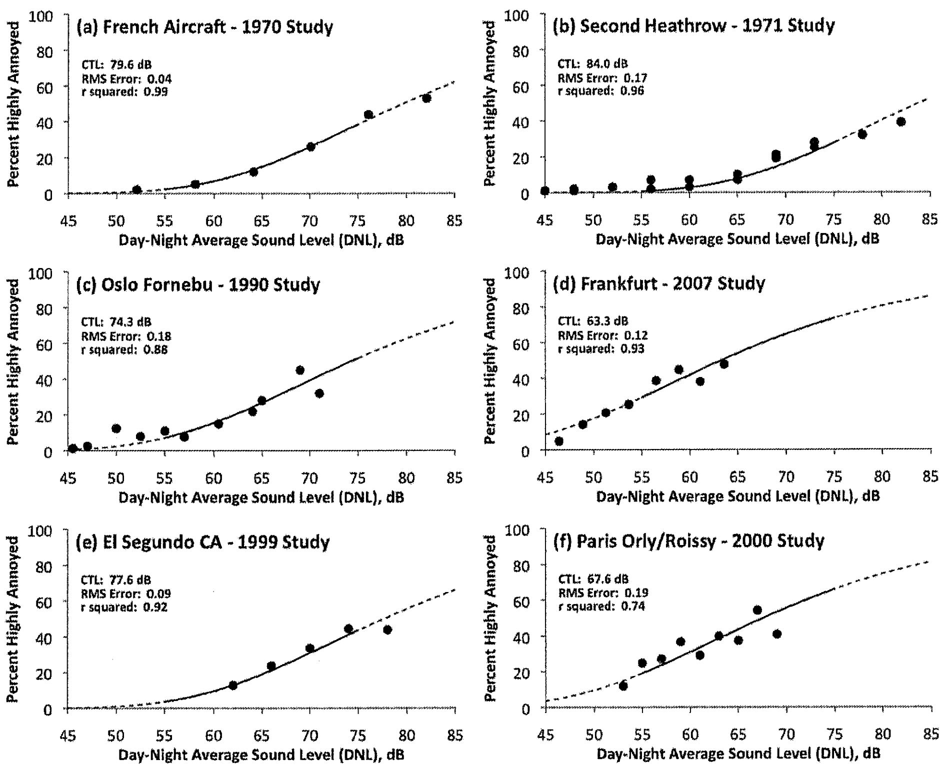

Figure 2: Fits of community response data for several surveys on aircraft noise annoyance

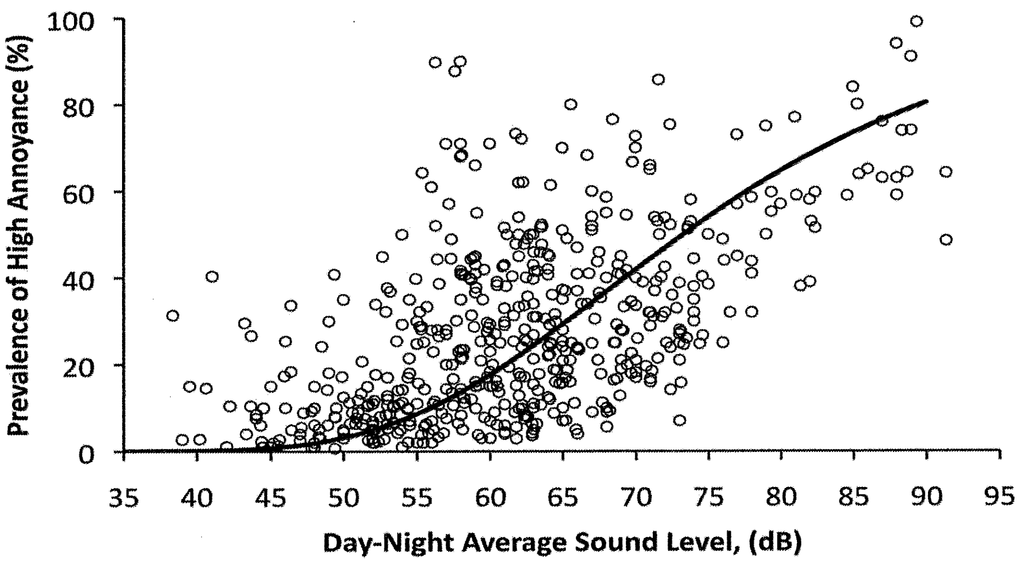

Figure 3: Fit of 43 aircraft annoyance data sets to effective loudness function for a CTL value 73 dB

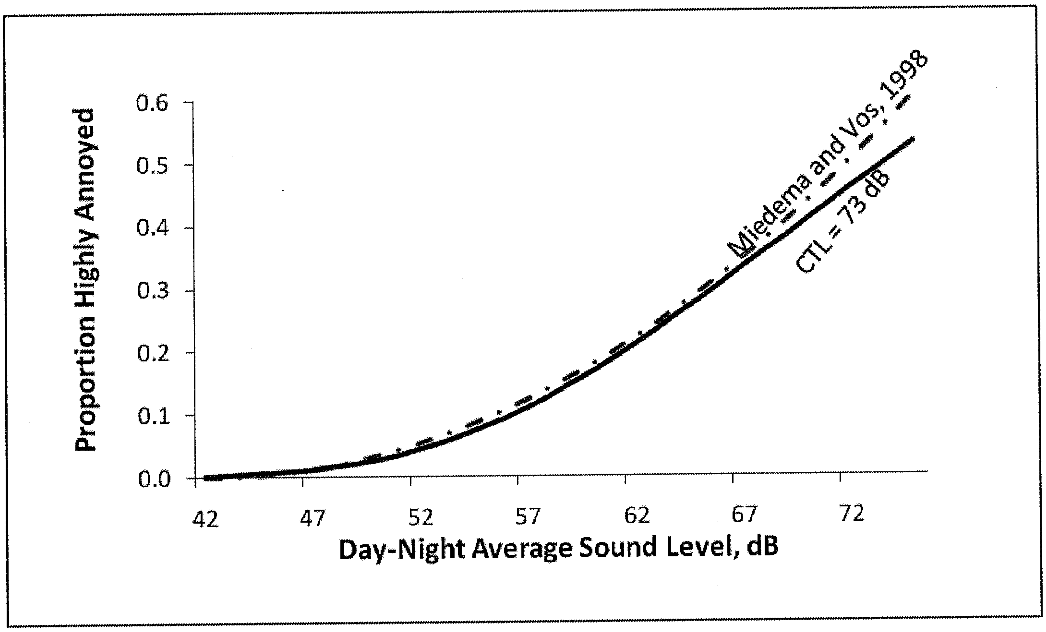

Figure 4: Comparison of two dose-response curves for aircraft noise annoyance

CONCLUSIONS

The present findings indicate that the prevalence of annoyance with transportation noise in communities may be usefully predicted from 1) estimates of the duration-corrected loudness of noise exposure, and 2) estimates of community-specific tolerances for noise exposure. The relationship between average annoyance prevalence rates and noise exposure derived as described above closely resembles dose-response relationships for transportation noise derived by Miedema & Vos (1998) by regression analysis. This close resemblance provides further pragmatic reason to believe 1) that the dose-related determinants of annoyance are driven by duration-corrected loudness, and 2) that when applied to any given community, predictions of response to transportation noise exposure which are derived from generic statistical analyses must be adjusted by the tolerance of that community for noise exposure.

A more detailed presentation of the proposed method backed by calculation examples based on previous annoyance studies of transportation noise can be found in Fidell et al. (2011) and Schomer et al. (2011).

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