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Report

The “Genlyd[*]” Noise Annoyance Model

Dose-Response Relationships Modelled by Logistic Functions

Client: Ministry of Science, Technology and Innovation

AV 1102/07

20 March 2007

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[*] Genlyd” is a contraction of annoyance (“gene” in Danish) and sound (“lyd” in Danish). “Genlyd” also means echo in Danish.

DELTA

Title
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Journal no.	**Project no.**	**Our ref.**
AV 1102/07	FR13402-01	THP/BP/lm/ilk

Client
Ministry of Science, Technology and Innovation
Bredgade 43
DK-1260 Copenhagen K
Denmark

Summary

This report is one of the results of the "Genlyd" project, a project with the purpose of quantifying and modelling annoyance.

Noise annoyance is defined as an emotional and attitudinal reaction from a person exposed to noise in a given context. From this definition it is obvious that other factors, modifiers, than the noise level are highly relevant if one wants to quantify the annoyance.

Different scales for measuring noise annoyance are stated both in English and in Danish.

The dose-response curves for different sound sources are defined in terms of logistic functions. These functions make it easy to implement the effect of different modifying factors.

The effect and magnitude of the modifying factors are stated together with a judgment of the reliability of these effects. Questionnaires for measurement of noise sensitivity and the attitude to the noise sources are given.

A model for noise annoyance which calculates the dose-response curve for specific situations is defined in terms of logistic functions.

DELTA, 20 March 2007

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1. Introduction

This report describes a model for annoyance caused by or associated with noise or sound. The model quantifies the annoyance response from a basic dose-response model with moderators caused by context, personal and acoustic variables. The main emphasis is laid on environmental noise, but the model is thought as a general model which opens for other types of noise, e.g. irrelevant speech in open-plan offices.

Many relations between annoyance and variables are described. Many more relations are not described, either due to lack of knowledge and data or due to the fact that data exist, but are not found or not yet implemented in the model. The focus of the report is the annoyance from one type of noise source at a time, whereas models for more than one type of source (e.g. road and aircraft noise) simultaneously are not included.

The data in the report are widely based on information from other researchers' work. This is stated as references in the text, and it may be consulted for a deeper understanding.

The model has been worked out as part of the "Genlyd" project (explained in Section 2.1).

The text in this report is intended for two purposes:

– As a report, explaining and documenting the background and validity of the model

– As a basis for informative text available in a software model based on the ideas described in the "Genlyd" model

For the sake of the last purpose, some redundancy is allowed in the text of the report.

2. General Information

2.1 "Genlyd"

The word "Genlyd" is a contraction of annoyance ("gene"in Danish) and sound ("lyd" in Danish). "Genlyd" also means echo in Danish.

"Genlyd" was a 3-year research and development project on establishing a model on noise annoyance.

The purpose of the project was to be able to predict the annoyance and thereby give a tool to plan for minimizing the noise annoyance instead of just planning for minimizing the noise level.

The basic idea was to provide a tool for prediction of noise annoyance when the noise characteristics, the context and the persons involved are known.

2.2 Contributors

The work is carried out by DELTA's departments of Acoustics. A number of persons have been more or less involved in the project. A list of the results and the persons behind them are given in 14 (Appendix).

3. Annoyance

3.1 Overview

In some psychophysical measurements there may be a simple relation between the stimulus or the dose and the response. In terms of this project the dose would be the noise level or the noise exposure and the response would be the annoyance.

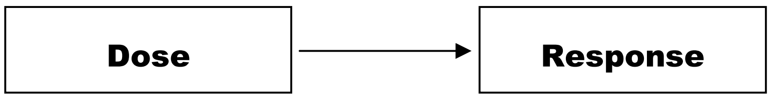

Figure 1
Simple dose-response relationship.

The perception and reaction to sound is much more complex than illustrated in Figure 1. The sound level is only one dimension of the sound character, and many other characteristics of the sound will influence the reaction. Furthermore, there may be a difference between the physical characteristics – as they are described by instrumental measurements resulting in numbers and metrics – and the way the sound is perceived by humans. The reaction on the perceived sound will furthermore depend on both non-acoustical factors of the context and on the persons exposed to the sound. What may be a wanted sound in some situations (e.g. loud music at a party), may be an annoying noise in other situations (e.g. music from the neighbour's party – even at a lower level – when you are going to sleep).

It is desirable to have a model that relates physical measurements (metrics) to auditory perception combined with a model that relates auditory perception to annoyance. The requirements for such a general combined model are extensive. Not only are relevant physical characteristics of the noise required, but also variables pertaining to the listener, the listener's expectations, attitudes and present activities. Physical identical sounds may become noise to one person and music to another and the same sound may be pleasant at midday, but annoying at midnight.

This is described by the filter model, shown in Figure 2, which illustrates the relations between physical or instrumental measurements, sensory or perceptive measurements and subjective measurements. Except for the physical measurements humans, are involved in the process as "measuring instruments".

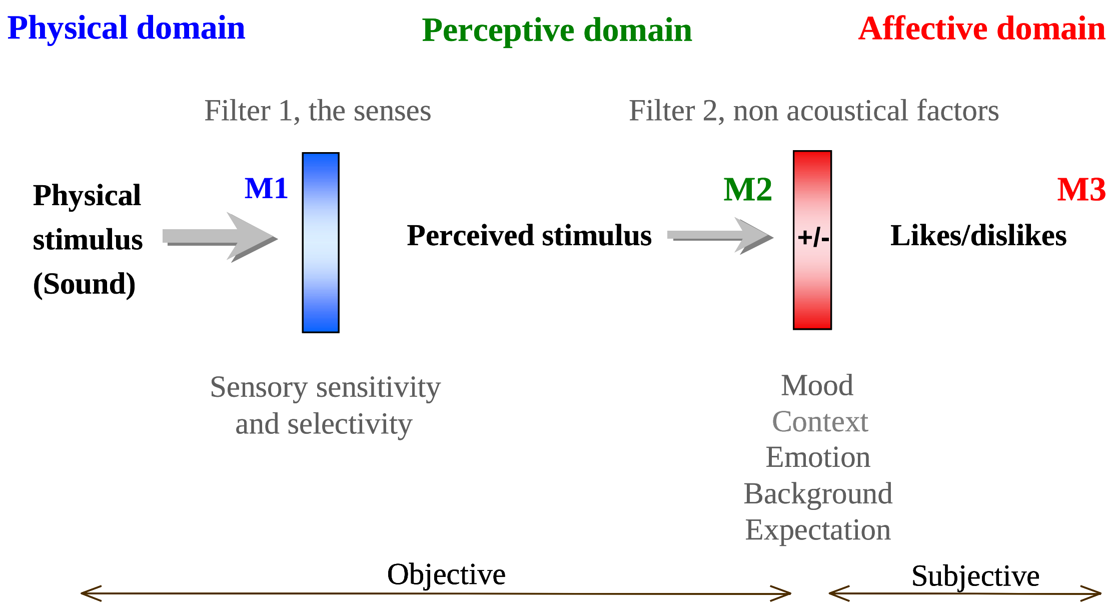

Figure 2
The filter model illustrates the relations between the physical/instrumental, the perceptive/sensory and the affective/subjective measurements. Filter 1 symbolises our senses (hearing). Filter 2 symbolises our mental processing of sensory perceptions. M1, M2 and M3 illustrate measuring points. Measurements at each of these points may be made independently of each other and for certain purposes measurements in any point(s) without the others being made. M1: physical measurements (sound pressure levels, loudness …), M2: perceptive measurements (psychoacoustics) and M3: affective tests and surveys.

Measuring point M1 represents the physical/instrumental measurements, i.e. sound pressure levels, spectra, psychoacoustic metrics (such as loudness, sharpness roughness, and fluctuation strength), prominence of tones, prominence of impulses or any other characteristic of the sound.

Measuring point M2 represents the perceptive measurements which are objective tests (sensory evaluations, perceptive analysis) where humans are used as measuring instruments. The characteristics of the perceived stimuli are rated in objective terms without asking the test persons for preferences or annoyance. The main purpose is to give information about the character of the sound as perceived by humans. The tests are usually made with a panel of trained persons. The persons are trained to express their sensory perception in terms that have been well defined to or defined in cooperation with the test persons in advance.

Measuring point M3 represents affective measurements which are subjective listening tests or surveys normally performed with a group of naive (untrained and without experience in listening tests) test persons who are representative of the relevant group of persons.

It may be “a consumer jury” or just a group of citizens exposed to noise in their homes. As they may use other words than acousticians for the attributes of the product or noise source they hear or the noise they are exposed to, the relevant words for expression of the heard sound often have to be “found” before the answering forms for listening tests or surveys can be made. The main purpose is to give information about humans in relation to the sound in a given context. The context will usually have a major influence on the final result.

The filter model can be found in [33].

As described above the dose-response model in Figure 1 is far too simple to describe the relations between a noise exposure and the annoyance. A model – still simple – as the one shown in Figure 3 is more relevant.

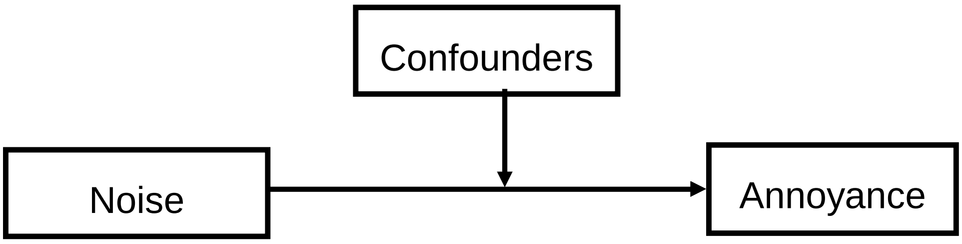

Figure 3
Simple model of noise annoyance. The noise may be characterised by a number of metrics, not only the sound level. The confounders include both context and personal variables.

The confounders in Figure 3 include context variables as the time of day, the location (indoor, outdoor, at work or at home ...), the current occupation (working or leisure activities, relaxation, sleep ...) and personal variables (noise sensitivity, fear from the source, age, attitude to the source ...). For modelling noise annoyance this may be illustrated on a more suitable form as shown in Figure 4.

As illustrated below, the annoyance may be “found” from three main “components”. We anticipate (as a hypothesis) that they contribute approximately equally to the annoyance.

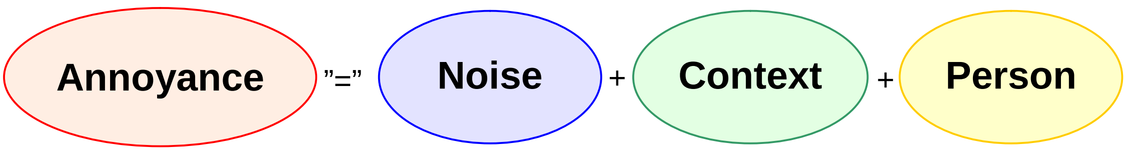

Figure 4
Annoyance ”components” in a real-life situation. On an individual basis in a specific context it is the hypothesis that each of the components contribute approximately equally to the annoyance.

The context is all circumstances and conditions of significance for a reaction or judgment, i.e. the noise source, the location, the surroundings, the time of day, the working or leisure situation, etc.

The model illustrated in Figure 4 will explain why loud music at a party may be less annoying than less loud music from the neighbour's party when you are going to sleep.

In investigations of community annoyance, the effects of a number of noise characteristics and many context and personal variables are averaged. The main exceptions are the noise level at the receiver, the type of source (road traffic, aircraft, railway, industry ...) and the time of day. The latter is often included either as separate noise limits for day, evening and night or in the exposure metric, L_{den}, which is a combined noise exposure level where noise in the evening and the night is given a greater weight, see Section 3.3.1 for a definition. Also the characteristics of the noise are often averaged to a large extent; the main exception for that is the prominence of tones and impulses in noise from wind turbines and industry.

3.2 Annoyance Measured by Experiments

Normally annoyance is measured by asking people exposed to the noise in a real context, e.g. in their homes, to express the experienced annoyance on some sort of scale.

In practice, it is difficult to find out how e.g. different characteristics of the noise influence the annoyance in a field survey. Instead it will be attractive to try to obtain such information by setting up an experiment, where the characteristics can be varied in a systematic and controlled way.

But if an experiment is set up, regardless whether it is in the field or in a laboratory, you have changed the context and in many cases also the persons as illustrated in Figure 5.

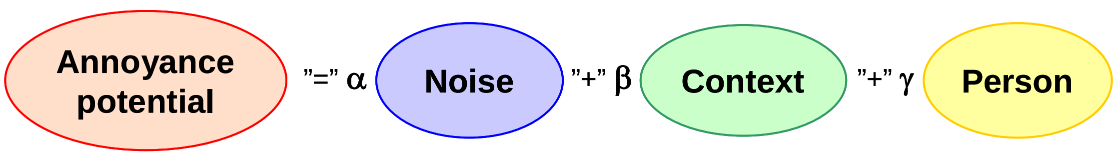

Figure 5
Annoyance "components" in an experimental (arranged field or laboratory) situation. Both the weight and the content of the contextual and personal factors may be changed relatively to a real-life situation.

In thorough experiments on annoyance it is customary to simulate the context as far as possible and furthermore to ask the test persons to imagine a relevant scenario (a scenario is an imagined or future context) by asking questions as e.g. “if you were sitting at home reading, how annoying would you judge this sound to be?”

Even in field experiment differences from survey measurements must be expected. If e.g. listeners in a street are asked to judge the annoyance of the traffic noise it is questionable whether the results of such experiments can be transferred to the residents in noisy living areas. First of all such experiments usually gives the immediate annoyance (see Section 3.3.4 for a definition) secondly the context differs from the many situations relevant in the home environment.

Annoyance results found by experiments should be distinguished from annoyance measured in real situations by denoting it the “annoyance potential” of the noise.

If possible, the validity of such results for real situations should be demonstrated.

3.3 Definitions

3.3.1 Noise

For the purpose of this project, noise is defined as unwanted sound.

In special situations noise may also characterise unwanted sound characteristics of a sound.

The noise may e characterised by its sound pressure level and other metrics describing specific attributes of the noise, e.g. for the prominence of tones and impulses, the sharpness of the sound, etc.

The noise level may be described by its maximum value, the variations in level, some statistical level descriptors (L_5, L_{10}, L_{50}, L_{95}), etc., or L_{Aeq} the energy equivalent continuous A-weighted sound pressure level in decibels (dB). Only the widely used descriptor for the noise level L_{den} will be defined here.

$\mathbf{L_{den}}$ (Level day-evening-night) is defined in terms of averaged A-weighted sound pressure levels, L_{Aeq}, for the day L_{day}, for the evening $L_{evening}$ and for the night L_{night} and applies a 5-dB penalty to the L_{Aeq} in the evening and a 10-dB penalty for the noise level L_{Aeq} in the night. L_{den} is calculated or measured as the free-field value at the position of the most exposed facade.

Day, evening and night is defined as:

- Day: 07.00-19.00 hours
- Evening: 19.00-23.00 hours
- Night: 23.00-07.00 hours

L_{den} is found from:

$$L_{den} = 10 \log [(12/24) \times 10^{LD/10} + (4/24) \times 10^{(LE+5)/10} + (8/24) \times 10^{(LN+10)/10}]$$

L_{den} is sometimes referred to as DENL and LDEN. L_{den} should not be confused with L_{dn}, which is a similar measure where the 24 hours are divided into a day and night period only.

3.3.2 Annoyance

A number of definitions on annoyance exist, see [38]. In "Genlyd" we decided to follow the definition in ISO 15 666 ([16]):

"Noise-induced annoyance: a person's individual adverse reaction[1)] to noise.

Note 1. The reaction may be referred to in various ways, including for example, dissatisfaction, bother, annoyance, and disturbance due to noise.

Note 2. Community noise annoyance is the prevalence rate of this individual reaction in a community, as measured by the responses to questions specified (below), and expressed in appropriate statistical terms."

This means that noise annoyance (short: annoyance) is an emotional and attitudinal reaction from a person exposed to noise in a given context.

This definition of annoyance is illustrated in Figure 6 from [38].

[1)] Reaction to noise" is defined as emotional response to noise". It includes "annoyance", but also a range of other (psycho-) emotional responses.

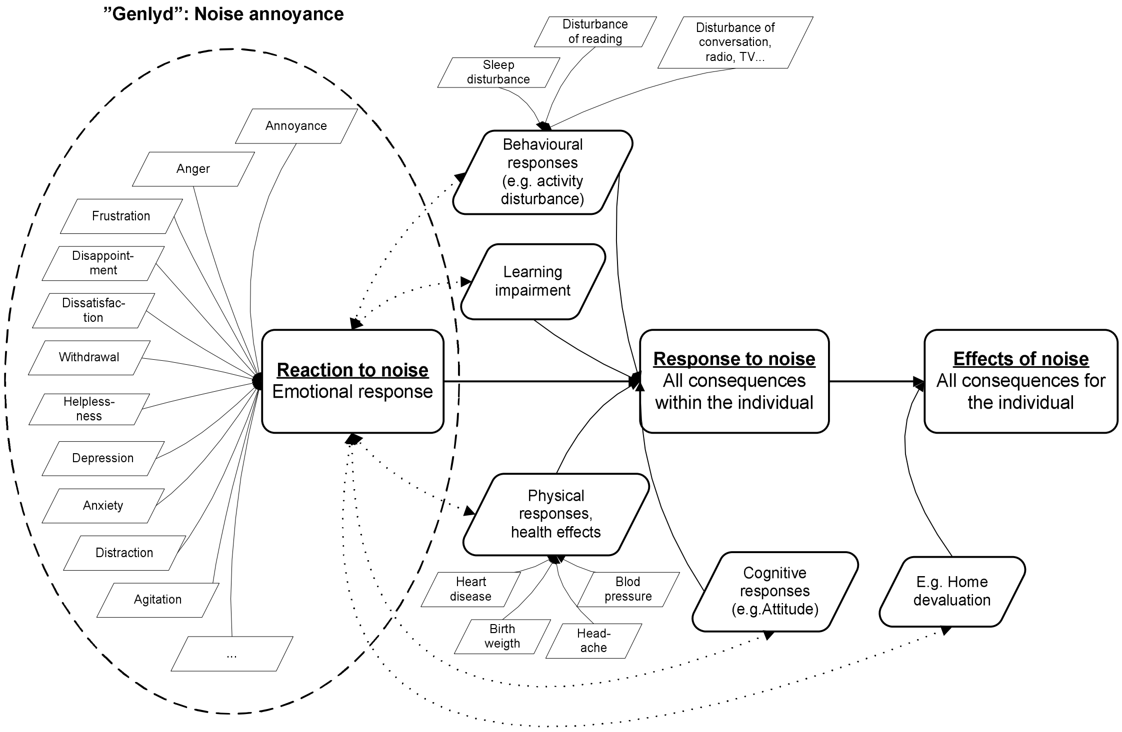

Figure 6
Overview of effects of noise and their "classification".

In [38] three types of annoyance are defined:

- Global annoyance
- Specific annoyance
  - Accumulated specific annoyance
  - Immediate annoyance

The definitions of these concepts are given in the following section.

3.3.3 Global Annoyance

The questions in ISO 15 666 seek to obtain global or generally consistent reactions that allow respondents to express their holistic experiences over time and locations in and around their home, without concern about specific incidents and contexts. The questions do not specify one particular combination of conditions because an overall response that integrates responses over a range of different types of experiences is wanted.

The long-term aspect "Thinking about the last (12 months or so), ..." is chosen to obtain a well defined and stable noise situation. It is known that if the noise situation changes, the response will be affected for a year or so before the response stabilises in the new situation.

3.3.4 Specific Annoyance

It is of interest in the “Genlyd” project to be able to specify the annoyance for a specified stimulus in a specified context for specified persons. We call this “specific annoyance”.

With regard to the time aspect we differentiate between the accumulated annoyance and the immediate annoyance. The immediate annoyance is used for a situation when the noise is present during or immediately before the evaluation of that particular noise.

So we define two types of specific annoyance:

Accumulated specific annoyance**:** The annoyance for a specified stimulus in a specified context for specified persons integrated over time and experiences.

Immediate annoyance[2)]***:*** The annoyance for a specified stimulus in a specified context for specified persons when the noise actually is present during or immediately before the evaluation of that particular noise.

See Figure 19 for an illustration of these definitions.

Accumulated specific annoyance may be relevant for the following examples:

– Conversations inside a home affected by traffic noise

– Working next to a noisy printer

– Neighbour usually rehearses drums every evening

Immediate annoyance may be relevant for the following examples:

– Aircraft passing while you are talking in a phone

– Passing a pneumatic drill on the pavement

– Irrelevant speech while you are working in an office

The global annoyance – as defined in ISO 15 666 – is the accumulated specific annoyance integrated over a range of contexts and over a range of locations at home (e.g. at the balcony, in the kitchen, in the bedroom).

[2)] The word ”specific” is redundant in this connection because the immediate annoyance will always be for a specific situation.

The accumulated specific annoyance is the immediate annoyance and the connected experiences integrated over time.

3.4 Community, Group or Individual Annoyance

Usually the community noise annoyance is expressed as the prevalence rate of the individual reaction for groups of persons exposed to the same noise level. These groups are illustrated as horizontal layers in Figure 7. Each horizontal layer is exposed to the same noise level. For each layer a point on a dose-response curve may be drawn. Usually the percentage of e.g. highly annoyed is plotted as a function of the noise level, see e.g. Figure 22. In this form, other noise characteristics (than the noise level), the context variables and the personal characteristics are averaged.

The influence of the context and personal moderators may also be of interest. In the case of context, the groups may be obtained by vertical "slices" parallel with the paper. For the influence of personal moderators as e.g. noise sensitivity or fear, the groping should be in vertical slices perpendicular to the paper.

See [10] and [27] for a more thorough description of these issues.

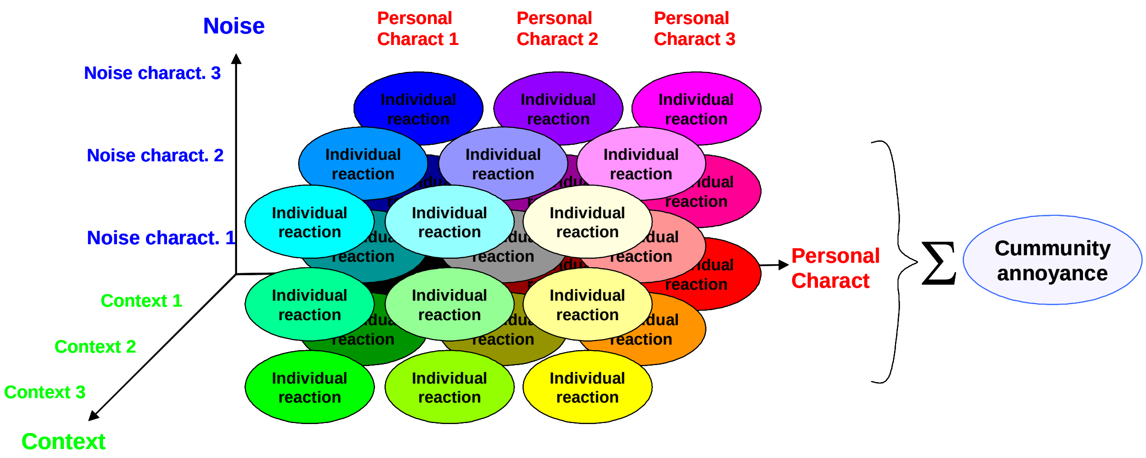

Figure 7
Illustration of the relation between individual, group and community annoyance.

The general way of working in the "Genlyd" model is to find the average relation between the sound exposure (usually expressed by the level) and the annoyance and then take the other noise characteristics (than the noise level), the context and the personal characteristics into account as moderators to the average relation (the dose-response curve) between noise exposure and annoyance.

3.5 Reactions to Changes in the Noise Situation

The effects of changes in the noise situation are more complicated to understand than the relations in an unchanged (stable) situation. Therefore the “Genlyd” model is based so far on a stable noise situation.

When changes occur in the noise exposure, the relations between noise exposure and annoyance do not necessarily follow the normal dose-response curves. It is known that a small decrease in the noise exposure does not necessarily infer a change in the annoyance. It has also been seen that mentioning e.g. in the press that the noisy activities may increase will in some cases increase the annoyance regardless whether a level increase has actually happened or not.

3.6 Annoyance Reduction

Annoyance reduction is reduction of the annoyance obtained by changing the noise characteristics or the context.

For environmental noise, it is normally the stable long-term effect of annoyance reducing measures that interests.

As pointed out in Sections 3.5 and 7.7.2.4 a direct relation between noise changes and annoyance reaction may not be expected.

Annoyance reduction may be obtained by other measures than reducing the perceived noise level from the source.

In Section 5 different scales for annoyance are given. The annoyance reduction may be described as a decrease of the annoyance in terms of these scales.

4. Measurement of Annoyance

In “Genlyd” project the reference for annoyance is the self-reported noise annoyance. Self-reporting means that the reaction is expressed by the exposed persons as the answer to a question.

For assessment of noise annoyance by means of social and socio-acoustic surveys the question and answering scales should be in accordance with ISO 15 666, “Thinking about the last (… 12 months or so…), when you are here at home, how much does noise from (… noise source…) bother, disturb, or annoy you?” – The respondents give their answers on semantic and numerical categorical scales.

The answers should express the spontaneous subjective feelings about the noise. Therefore it is recommended not to bother (at least not in the beginning of an interview) the respondents with a complete list of too many conditions (e.g. room in a home, location on the property, season of the year, day of week, hour of day, window opening conditions, activity during exposure, number of noise events ...). This may lead the respondent towards objective assessments of the noise and away from subjective feelings about exposures.

In “Genlyd” we operate with annoyance measurements in other situations than socio-acoustic surveys. In these cases the question should be formulated according to the following structure:

[Reference to the time frame], [reference to the context], how much does [reference to the sound source and/or sound characteristic] bother, disturb, or annoy you?

The question may address the annoyance accumulated over time or the immediate annoyance, where the noise is present in connection with the evaluation situation.

All relevant variables of the noise characteristics, the context, and the persons shall be reported. Inspiration to this can be found in ISO 15666.

The intention of the question formulated above is to be able to measure the annoyance for a specific person of a specific stimulus in a specific context. It deviates from the question in ISO 15 666 which intends to measure the accumulated annoyance for a long-term exposure in the home environment of a non-changing noise situation. This deviation may be necessary to obtain practical results within a limited time frame, but the consequences for the validity of annoyance measurements by this question will be thoroughly considered whenever used.

5. Scales for Annoyance

In “Genlyd” we operate with the same categorical scales as ISO 15 666, i.e. a verbal scale and a numerical scale. The words of the verbal scale are (Danish translations in parentheses):

– Not at all (Slet ikke)

– Slightly (Lettere)

– Moderately (Moderat)

– Very (Kraftigt)

– Extremely (Ekstremt)

... annoyed.

The process of translating these words into Danish is described in [21] and [22].

The numerical scale is an 11-point categorical scale from 0 to 10:

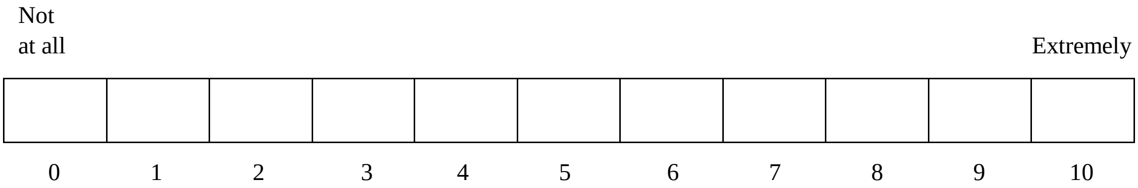

Figure 8
The 11-point categorical scale from 0-10 according to ISO 15 666.

It is common practice to convert the (average) annoyance scores on the verbal and numerical to a 0-100 point scale. The response may also be expressed as ([4]):

– The percentage of highly annoyed (%HA)is the percentage of people giving an answer above 72 (the top 27-29%) of the response scale, i.e. the verbal categories Very (kraftigt) and Extremely (Ekstremt) and the numerical categories 8, 9 and 10

– The percentage of (at least) annoyed (%A)is the percentage of people giving an answer above 50, i.e. the verbal categories Moderately (Moderat), Very (kraftigt) and Extremely (Ekstremt) and the numerical categories 5 to 10

– The percentage of (at least) little annoyed (%LA) is the percentage of people giving an answer above 28, i.e. the verbal categories Slightly (lettere) and above and the numerical categories 3 to 10.

In some cases it may be relevant to compare the values from the numerical categorical annoyance scale to a common reference of sound pressure levels in dB. This can be done by referring to the L_{den} of road traffic noise giving the same average response on the annoyance scale.

Reference can be given to the dB-scale for L_{den} of road traffic noise in the following way:

> The annoyance of this ...(noise, stimulus) in this ...(specify context) for ...(specify the (group of) person(s) corresponds to the average annoyance reaction you will get from persons living in homes with L_{den} of xx dB outdoor (on the most exposed facade) from road traffic noise.

To conclude: The annoyance for a certain noise exposure in a specified situation may be expressed in by the following annoyance descriptors:

- AS: The average response on the ISO 15 666 eleven point scale (average annoyance score)
- EA: Estimated annoyance = AS*10
- % HA: The percentage of highly annoyed
- % A: The percentage of annoyed
- % LA: The percentage of slightly annoyed
- $L_{den,AeqR}$: The annoyance equivalent road noise level, i.e. the outdoor L_{den} in dB of road traffic noise giving the same average annoyance response as found for the actual combination of noise exposure, context and persons.

5.1 The Relation between Annoyance Score and Percentage Annoyed

The community annoyance is often expressed as the percentage of little annoyed (%LA), annoyed (%A) or highly annoyed (%HA). For the purpose of this project it is of interest to know the relation between the percentage annoyed and the average annoyance score (AS) on the 11 point numerical scale given in ISO 15 666.

Data for this is found in Figure 9, where both the annoyance score and the % highly annoyed are found for aircraft noise in a Swiss study. The data are based on 2052 personal interviews in 58 residential areas.

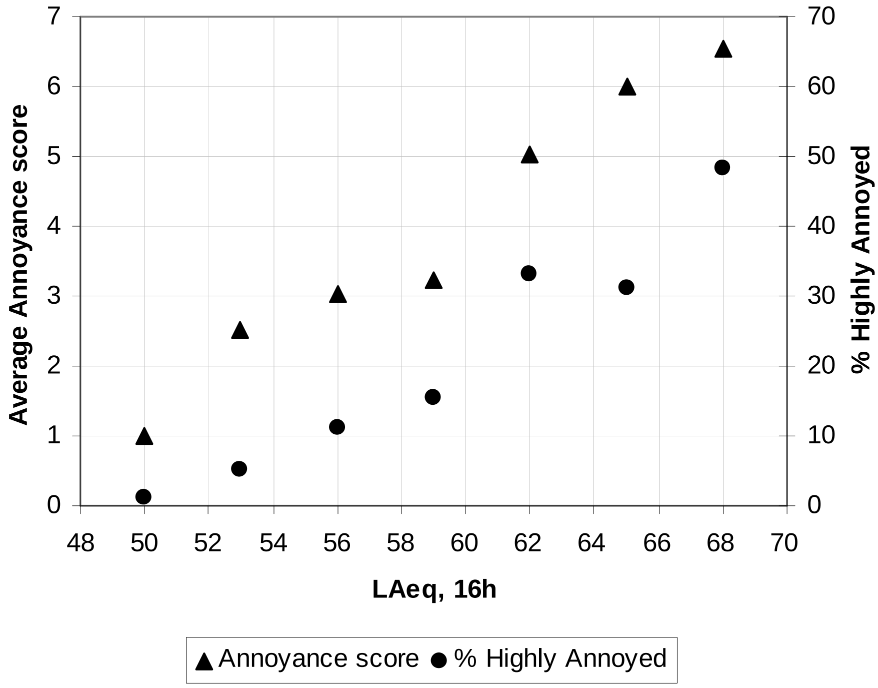

Figure 9
Dose response curves from "Lärmstudie 90"for aircraft noise at Zürich and Geneva with 2052 personal interviews in 58 residential areas. The Annoyance scale ia a 11 point numerical scale (0-11). The percentage of Highly Annoyed is the top 3 responses on the annoyance score [10].

By displaying the same data in another way the relation between annoyance score and % highly annoyed can be found for this study, see Figure 10.

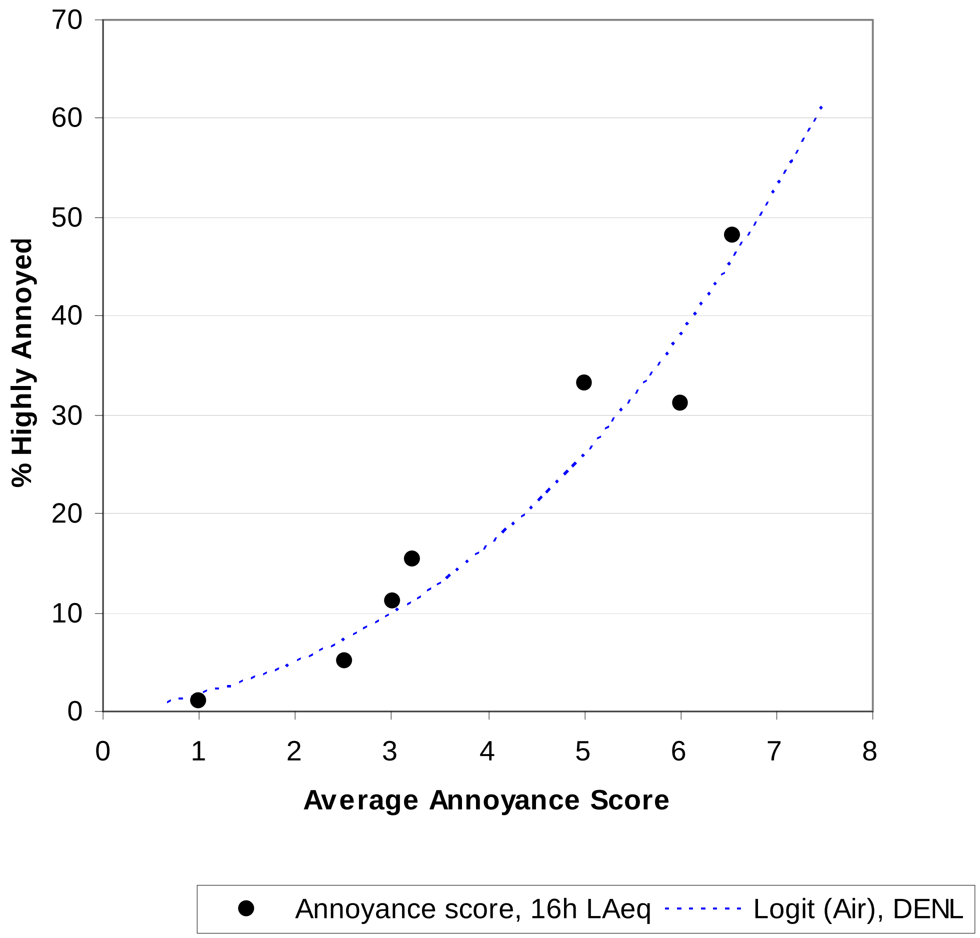

Figure 10
Filled circles: Lärmstudie 90, same data as in Figure 9 displayed with the % highly annoyed (%HA) as function of the average annoyance score (AS).
Dotted line: Logistic approximation for the same relation according to section 7.2.3.

The good correspondence shown in Figure 10 between the "Lärmstudie 90" and the logistic approximation indicate that the logistic function is in correspondence with the dose-relationship in practice.

5.2 Relation between L_{den} of Road Traffic Noise and the Annoyance from Other Sources

It may be of interest for comparison purposes to find the levels of road noise which causes the same degree of annoyance.

Reference may be given to the L_{den} in dB of road traffic noise in the following way:

- The annoyance of this ... (noise, stimulus) in this ...(specify context) for ...(specify the (group of) person(s) corresponds to the percentage of (highly/-/little) annoyed persons you will get from people living in homes with L_{den} of xx dB outdoor (on the most exposed facade) from road traffic noise.

From Equation 3 and the equations in Section 7.2 it can be shown that the annoyance equivalent road noise level can be found from:

$$Lden_{AeqR} = \frac{s_s}{s_r}(E_s - f_s) + f_r \qquad \text{Equation 1}$$

where the general meaning of the symbols are defined in Section 6.1 in Equation 3 and:

- $L_{den,AeqR}$ is the annoyance equivalent road noise level
- s_s is the slope of the logistic annoyance function for the source s
- s_r is the slope of the logistic annoyance function for the road noise
- E_s is the exposure of the source (e.g. L_{den})
- f_s is the fifty percent annoyance value for the source s
- f_r is the fifty percent annoyance value for road noise

The results are shown in Figure 11.

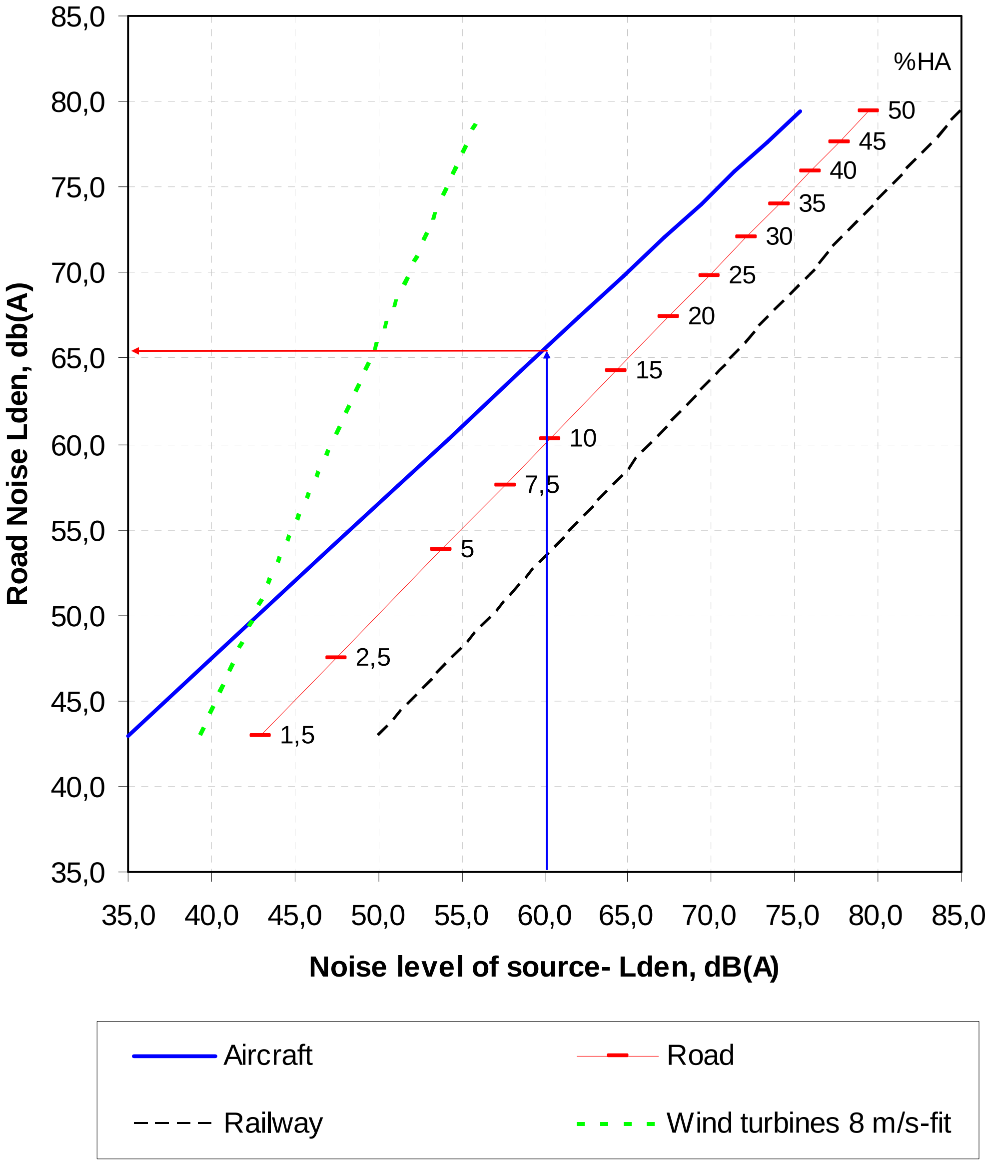

Figure 11
Annoyance equivalent road noise, $L_{den,AeqR}$,(y-axis) based on the same percentage of highly annoyed (%HA). From the noise level of the actual source on the x-axis the $L_{den,AeqR}$, can be found. This is illustrated for aircraft noise by the arrows.

When the $L_{den,AeqR}$ is stated it should be mentioned which annoyance measure it is based on (%HA, %A, %LA or EA as defined in Section 5).

6. Functions and Methods Used in the Model

6.1 The Logistic Function

The basic idea behind the “Genlyd” annoyance model is that if all moderators are constant then a more intense stimulus (e.g. louder perceived noise) will result in a larger annoyance.

According to Section 5 the annoyance is measured on a scale from 0 (not at all annoyed) to 10 (extremely annoyed).

The following anticipations are made:

– There is a linear relation between the noise exposure in dB and the response on an unlimited (open) answering scale allowing answers lower than 0 and higher than 10 (the “underlying ideal” response).

– The underlying individual answers follows the normal distribution.

From this it is possible to calculate the “actual” mean values of the answers on a 0-10 scale by assigning the value 0 to all answers below 0 and assigning the value 10 to all answers above 10. The calculated “actual” average response is shown in Figure 12 together with an approximated logistic curve.

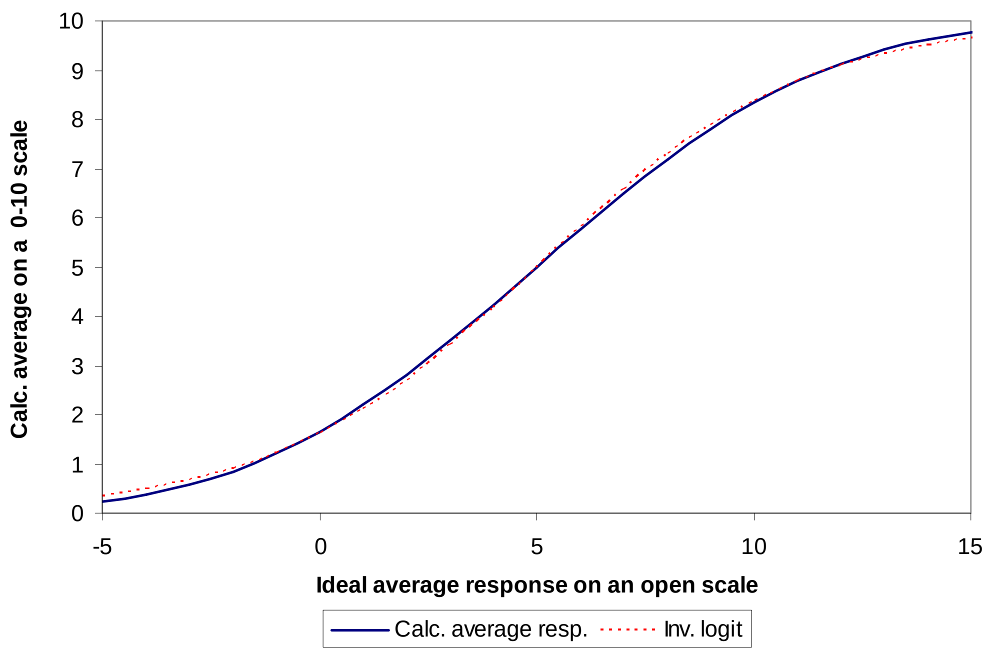

Figure 12
The calculated average response on a 1-10 closed 11-point categorical scale calculated from an “ideal” linear response on an open scale (normal distributed data with a standard deviation of 4.2). Approximation with a logistic (inverse logit) function with a slope of 0.33 is also shown.

The “S”-curve reflects that when the perceived intensity of the noise is below a certain level, the noise annoyance will be 0 (This must be true, at least if this “certain level” is the hearing or masking threshold) and when the perceived loudness exceeds a level where the annoyance is extreme it will still be extreme.

The logistic function (or the inverse logit function) has the properties that correspond to the situation described above. It is simple to use and as it is seen from Figure 12 it is very close to the calculated theoretical response function based an a “limited” normal distribution.

The logistic function in the fundamental form (also called the sigmoid function) is described by:

$$y = \frac{1}{1+e^{-x}}$$ Equation 2

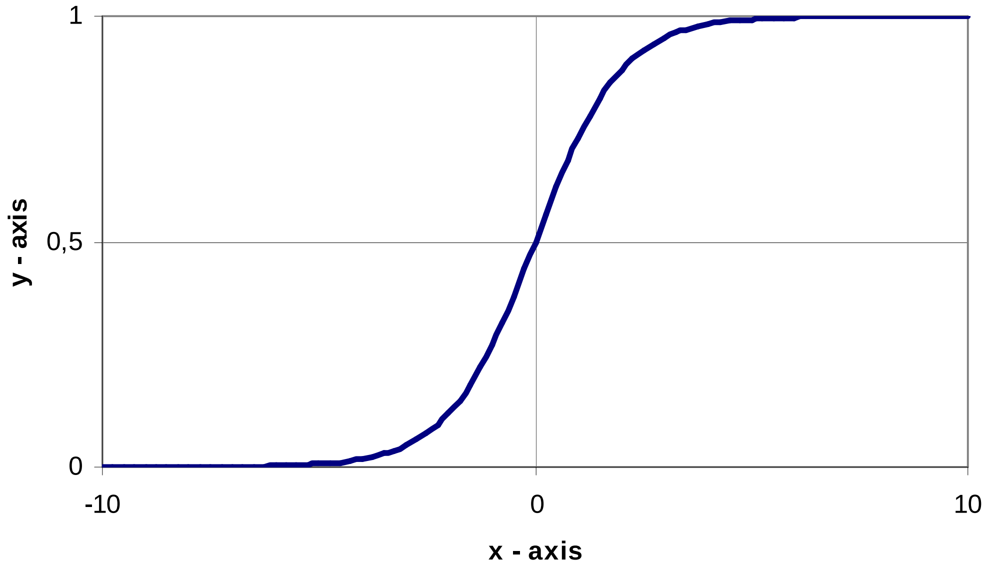

Figure 13
Graph of the logistic function (inverse logit function) in the fundamental form.

A more general form of the logistic function for our purpose is given by:

$$A = \frac{u}{1+e^{-s(E-f)}}$$ Equation 3

where

- *A* is a measure for the annoyance response
- *u* is the **u**pper limit of *A (10 for the ann. score, 100 for the percentage annoyed)*
- *s* is the **s**lope of the inverse logit function
- *E* is a measure for the noise **E**xposure
- *f* is the value of E for a **f**ifty percent annoyance response

A cumulative normal distribution function can be approximated by a logistic function as follows:

f = mean value of the normal distribution

s = 1,7 / (the standard deviation of the normal distribution)

If we want to know the exposure E that corresponds to e certain annoyance A, this can be found from Equation 4:

$$E = f - \frac{\ln(\frac{u}{A} - 1)}{s}$$ Equation 4

6.2 The Logit Function

The logit function or the logit transformation y_t of a variable y is described by:

$$y_t = \ln(\frac{y}{1-y})$$ Equation 5

If we use the logit transformation on Equation 3, we get:

$$A_t = \ln(\frac{A}{u-A}) = s(E-f) = sE - sf$$ Equation 6

Here we have a linear relationship between the transformed annoyance response A_t and the exposure E given by the slope s and the intercept –sf.

An example of the use of the logit transformation on data from a listening test is given in Figure 14.

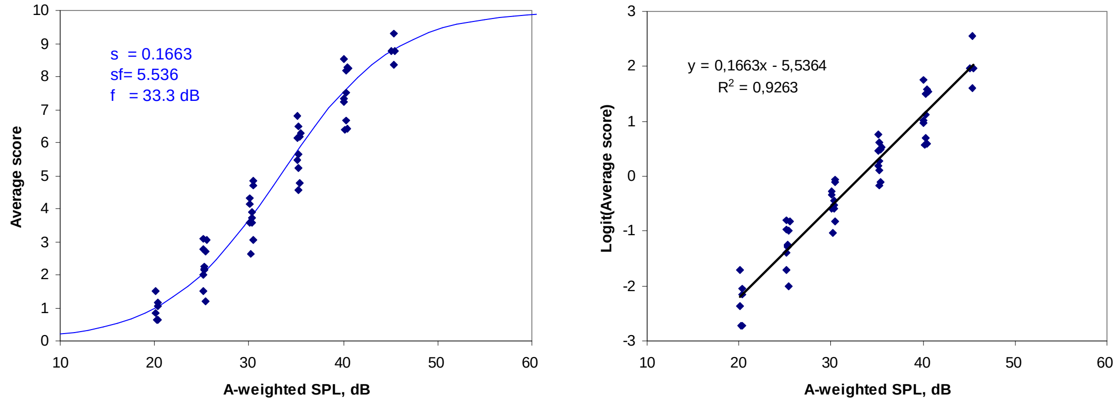

Figure 14
Example on logit transformation of data. Left: Raw data and the logistic function derived from the transformed data in the right figure. For the transformed data the fraction of explained variance, R2 = 0.93. Data is taken from [36].

From Figure 14 it is seen that the variance of transformed data in the different level groups seems to be the same. This indicates that ordinary linear statistical models such as (multiple) linear regression may be used for the transformed data. This is illustrated in Equation 7, from [46].

$$y = \frac{1}{1 + e^{-(a + bx_1 + cx_2 + \ldots)}} \Rightarrow y_t = \ln\left(\frac{y}{1 - y}\right) = a + bx_1 + cx_2 + \ldots \qquad \text{Equation 7}$$

6.3 Logistic Regression

The data obtained when using the procedure described in ISO 15 666 is categorical in ordered categories, either in the categories “Not at all” – “Slightly” – “Moderately” – “Very” – “Extremely” or as numeric categories in the 11 point 0-10 answering scale.

For this type of data ordinal logistic regression analysis is useful. As the result of this type of analysis the constants and coefficients between the logit transformed annoyance variables and the independent variables (the L_{den}, the noise sensitivity etc.) may be obtained.

This type of analysis is described in [19] and [46], and the ordinal logistic data analysis in the “Genlyd” project is performed with the SigmaXL plug-in for Excel.

More information on logistic regression, logistic function and logit function can be found in [19], [32] and [35].

6.4 Influence of Moderators on the Fifty Percent Value, f

For each type of source a norm curve is defined, which describes the average relation between the exposure and the community annoyance, see Section 7.2. A number of moderators may change the (horizontal) position of the curve for s specific situation, i.e. a change in the value of f for that situation. This can be described as:

$$f = f_{norm} + \Delta f_{fear} + \Delta f_{noise\_sens} + \Delta f_{tonepenalty} + \Delta f_{impulsepenalty} + \cdots \qquad \text{Equation 8}$$

where

- f_{norm} is the f-value of the norm curve
- Δf_{fear} is the change in f caused by fear
- $\Delta f_{noisesens}$ is the change in f caused by noise sensitivity
- $\Delta f_{tonepenalty}$ is the change in f caused by prominent tones
- $\Delta f_{impulsepenalty}$ is the change in f caused by prominent impulses
- ... additional terms for other moderators (including noise characteristics)

As a first approximation it is anticipated that the terms are additive (without limitations on the maximum and minimum sum), independent and without interaction (no interaction terms in the equation). The assumption of independence between terms (and independence of the noise level), is a first approximation and may not be fully correct in all cases.

The background for the values of the Δf-terms may be specified in two different ways:

1. As a displacement in dB
2. As an increased annoyance (caused by e.g. noise sensitivity)

6.4.1 Δf-Terms with Background in a Change in dB

The implementation of the first type is straightforward. A tone or impulse penalty specifies an addition in dB to the measured sound pressure level. This addition is believed to correspond to the extra annoyance these noise characteristics cause.

A penalty of x dB is implemented as a Δf value of –x dB

6.4.2 Δf-terms with Background in a Change in Annoyance

If the effect of a change in an independent variable is expressed as an extra (percentage of) annoyance or as an extra percentage of annoyed caused by this variable, such numbers has to be converted to a Δf value in dB to be incorporated in the model.

If the information is found on basis of multiple linear regression analysis, the unlinear effects at the extremes of the s-shaped dose-response curves are often avoided by excluding the extreme data from the analysis. The conversion from annoyance may therefore be made with basis in the middle part of the dose-response curves. As the slope of the curves depends on the source, the conversion will be source dependent.

As we now work with a linear approximation to the (middle part of the) norm (subscript norm) dose-response curve this can be described as:

$$A_{norm} = a \cdot E + b_{norm} \qquad \text{Equation 9}$$

where A_{norm} is the norm-annoyance, a is the slope of the line, E is the exposure and b is the intercept.

When e.g. noise sensitivity causes a change in the response A, the changed linear approximation can be described as:

$$A = a \cdot E \quad + b_{norm} + \Delta b \qquad \text{Equation 10}$$

where Δb is the extra annoyance caused by e.g. noise sensitivity (in which case Δb is a function of the noise sensitivity).

From Equation 9 and Equation 10 we find that the Δf-value (e.g. $\Delta f_{noise\ sens}$) can be expressed as:

$$\Delta f = \frac{-\Delta b}{a} \qquad \text{Equation 11}$$

Now we need to find the slope, a for the linear approximations to the dose response curves. From Equation 3 (and with the same notation) we find that the average slope between two points on the dose-response curve x units to each side of the value f is:

$$a = \frac{\dfrac{u}{1+e^{-s(f+x-f)}} - \dfrac{u}{1+e^{-s(f-x-f)}}}{(f+x)-(f-x)} \Rightarrow a = \frac{u}{2x}\left(\frac{1}{1+e^{-sx}} - \frac{1}{1+e^{sx}}\right) \qquad \text{Equation 12}$$

It is seen that the slope a for the linear approximation depends on x. The slope a for the linear approximation depends also on s, which is the parameter for the slope of the logistic curve. a and s should not be confused.

The results for different sources and annoyance descriptors are shown in Table 1.

	% LA	% A	% HA	AS, EA
Air	2.47	2.47	2.54	1.86
Road	2.47	2.52	2.80	1.96
Rail	2.52	2.66	2.91	2.05
Industry	2.24	2.49	2.96	2.01
Shunting	2.26	2.16	2.27	1.81
Seasonal	2.61	3.05	3.00	2.42
Wind turbines	4.64	4.58	4.40	4.43

Table 1
The average slopes, a (unit: % XA/dB) for a linear approximation to the norm curves in the range ±5 dB around the value for 50% annoyed (f).

It should be noted that the values in Table 1 are larger than 1,4 EA/dB, which is the value used to translate the estimated of extra annoyance into an equivalent change in DNL in [26]. The value 1.4 is obtained by linear regression on real data, which presumably have their point of gravity at a lower point of the dose-response curve, where the slope is lower than the slopes at the 50% value which are stated in Table 1.

The formulas for the Δf-values for different effects (moderators) will be given in Section 7.

6.5 Averaging of Results from Different Studies

If different studies exist of the annoyance effect for a specific type of source one way of combining the information is to pool all data from the studies and calculate the average annoyance. The effect of this procedure is illustrated in Figure 15. It is seen that the result will be an average curve with a systematic lower slope than found in the individual studies.

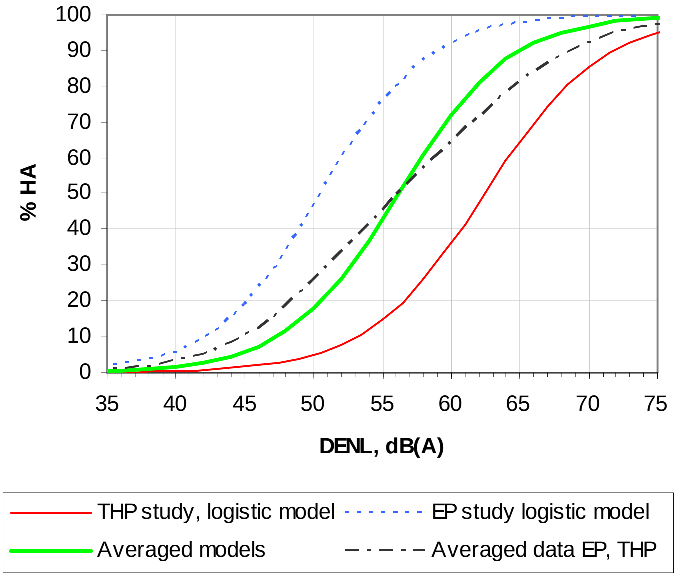

Figure 15
The logistic functions for two studies and the combined results by either averaging the models or the data. The slopes of the curves for the logistic model for the two studies are 0.26 and 0.23 with a mean slope of 0.25 while the slope of the curve based on the pooled data is 0.19. The data is the percentage of highly annoyed derived from the studies in [37] and [41].

A low slope may also be the result of integration over a number of (known or unknown) specific situations, so it may be taken as the community response in general when these situations are not specified or known.

For a specific situation a more steep slope of the curve is expected. This steeper slope may be expected for single studies in and in specific situations where the context and maybe also the personal variables either are specified or the range of these variables limited. In such cases another procedure than pooling the data should be used. In such cases the slopes and the fifty percent values for the logistic functions will averaged. This procedure will result in a response as shown by the steepest of the middle curves in Figure 15. The slopes found in each of the studies will only be changed to the average slope and not to a systematic to lower value. The averaging of the fifty percent values results in a horizontal displacement of the response curves.

6.6 The Slope of the Logistic Function

We have seen that when the results from many observations under different conditions are pooled, the slope becomes less steep. We also know that e.g. noise sensitivity and fear for the source has a significant influence on the annoyance. When such effects are averaged (i.e. by pooling data from a large group of persons with e.g. different noise sensitivity) we get a resulting curve, which is less steep than the individual dose response curves. If we can "correct" the individual data for the influence of e.g. noise sensitivity (by a horizontal displacement of the individual curves) so the resulting curves for a specific noise sensitivity should be steeper than the averaged curve.

To enlighten what slopes we can expect, the slopes of the dose response curves for different sources are shown in Figure 16.

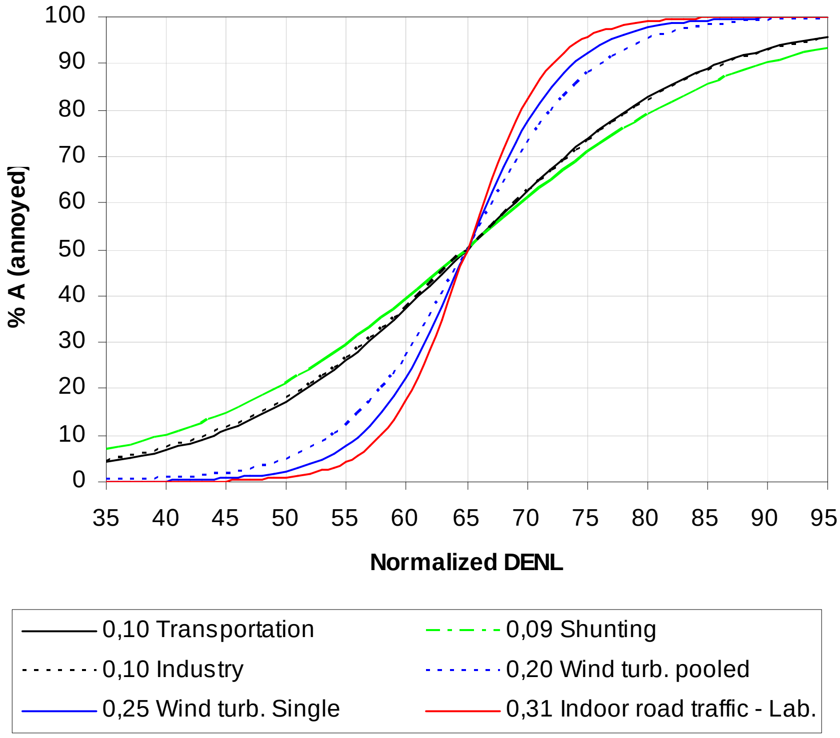

Figure 16
Examples of slopes s for the logistic approximations to the percentage of annoyed (% A) for different noise sources and for different studies. The f-values for the shown curves are normalised.

As a rule of thumb: At the 10-percent level, 10·s equals the increase in the percentage annoyed per dB.

The slopes for the % HA and % LA are very similar to the % A shown in Figure 16, but the slopes for the % EA are lower, see Table 2.

Noise source / study	**s**
Aircraft	0.0754
Road	0.0795
Railway	0.0832
Industry	0.0816
Shunting yard	0.0730
Seasonal industry	0.0986
Wind turbines, pooled data	0.1903
Wind turbine single studies	0.2392
Indoor traffic, Laboratory listening test	0.1660

Table 2
Examples of slopes s of the logistic approximations to the expected annoyance (%EA) for different noise sources and for different studies.

6.6.1 Slopes for a Specified Group of Persons and a Specified Context

In Section 6.5 the problem of averaging results from different studies were described. A similar problem exists when we want to calculate the dose-response curve for e.g. a group of persons with specific noise sensitivity. The norm curves are the average of many persons response, each of these having e.g. different noise sensitivities. Figure 17 shows that the norm curve has a lower slope than the individual curves.

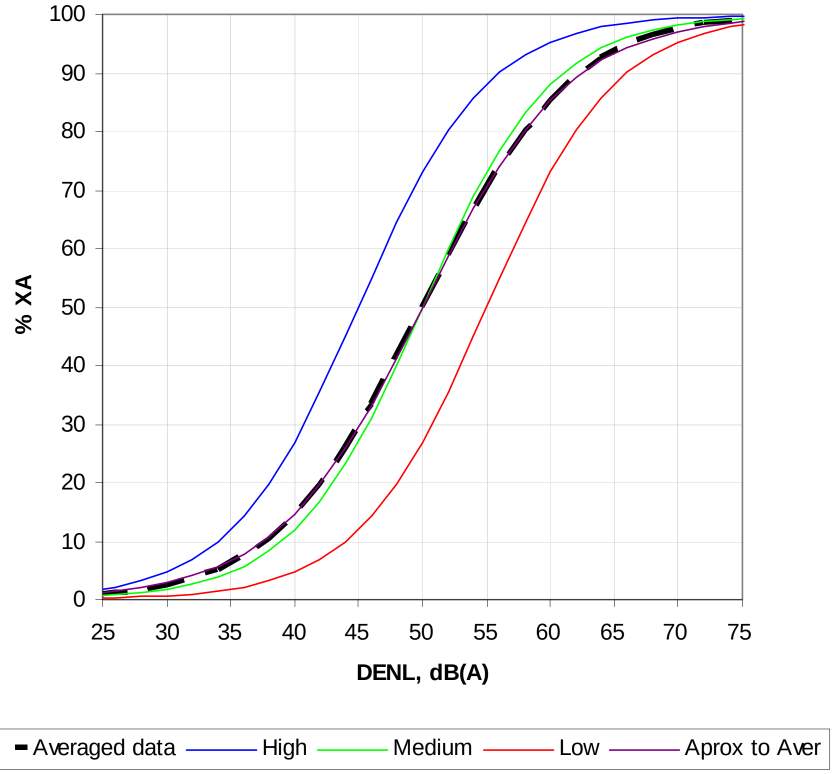

Figure 17
Illustration showing that the dose-response function for averaged data (over the response curves for persons with e.g. low, medium and high noise sensitivity) has a lower slope than the individual dose response functions. The f-values for high, medium and low are 45, 50 and 55 dB, the slopes are s= 0.2. The slope for the averaged curve is 0.176 or 14% lower.

The norm curves are in general expected to have a low slope because they also "include" the result of uncertainties of the (outdoor and corresponding different indoor) levels the persons are exposed to and other undefined effects.

The relation between the slopes of the individual curves and the slope of the averaged curve depends both on the slopes of the norm curve and on the difference in f values, Δf, for the involved curves. For a specific situation a reasonable and heuristic approach is to describe the slope of the dose-response curve as:

$$s = s_{norm} \cdot s_1 \cdot s_2 \cdot ...s_n \cdot s_{n+1...} \ , \ (\text{if } s_1 \cdot s_2 \cdot ...s_i \cdot s_{n+1...} > 3 \text{ then } s_1 \cdot s_2 \cdot ... \cdot s_{n+1...} = 3)$$ Equation 13

where

– s is the slope of the dose-response curve for a specific situation

– s_{norm} is the slope for the actual norm curve (depending of the sound source (aircraft, road traffic...) and the annoyance descriptor (%LA, %A...) see Section 7.2.

– s_n is a factor specifying the increase in slope due to specification of the nh'th moderator (e.g. specifying the noise sensitivity or the fear connected to the source or etc.)

The modification of the norm curve slope is limited to a factor 3. From Figure 16 it is seen that this value represent the factor between surveys in the field and results in a laboratory experiment where the stimuli and many modifying factors are supposed to be the same for the participants.

The following procedure has been used to find the values of s_n corresponding to the n'th moderator:

The Δf values for the classes: lowest, medium and highest (e.g. corresponding to the values 16, 50 and 84 for the midpoints if there are three categories low, medium and high on a 0-100 scale) are found. How the Δf values are calculated may be found under the sections for the individual moderators in Section 7. The difference between the medium & low class and between the medium & high class is denoted Δf_d.

The dose-response curves for the tree classes are constructed and the curve for the average data is computed. By linear regression of the logit transformed annoyance data the parameters for the logistic function that best approximates the curve for the averaged data has been found (see Sections 6.1 and 6.2).

The relations (depending on the slope of the norm curve s_{norm}) between the factors s_n and the Δf_d values are shown in Table 3.

	The difference Δf_d in dB					
s_{norm}	**0**	**1**	**3**	**5**	**7**	**9**
0.05	1	1.000	1.004	1.010	1.020	1.031
0.1	1	1.002	1.014	1.040	1.064	1.111
0.2	1	1.006	1.049	1.138	1.242	1.379
0.3	1	1.010	1.099	1.262	1.500	1.775

Table 3
The factor s_n specifying the increase in the slope of the dose-response curve (relative to the norm slope) for a moderator with the difference of Δf_d between the medium & low class and between the medium and the high class, i.e. a difference of $2\Delta f_d$ between the low and the high class.

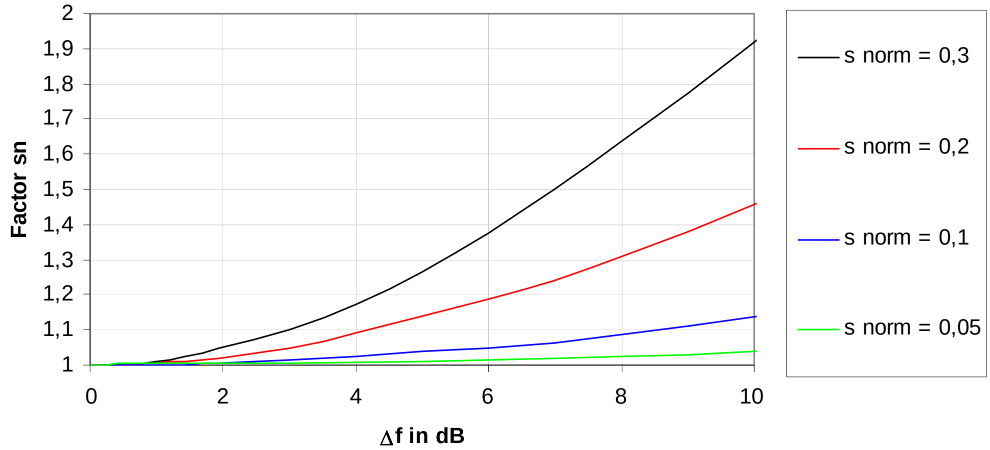

Figure 18
The factor s_n specifying the increase in the slope of the dose-resonse curve (relative to the norm slope, s_{norm}) for a moderator with the difference of Δf_d between the medium & low class and between the medium & high class, i.e. a difference of $2\Delta f_d$ between the low and the high class.

7. The "Genlyd" Annoyance Model

7.1 General Overview

In the succeeding sections a model for annoyance caused by noise from a specified sound source is described. The model quantifies the annoyance response from a basic dose-response model (the norm curve) with moderators caused by context, personal and acoustic variables. The main emphasis is laid on environmental noise, but the model is thought as a general model which is open for other types of noise, e.g. irrelevant speech in open-plan offices. The focus of the report is the annoyance from one type of noise source at a time, while models for source combinations (e.g. road and aircraft noise) in general are not included. Although the model in the first place is intended for only one primary source, masking phenomenon's are included in the mind set for some specific sources.

7.1.1 The Fundamental Model

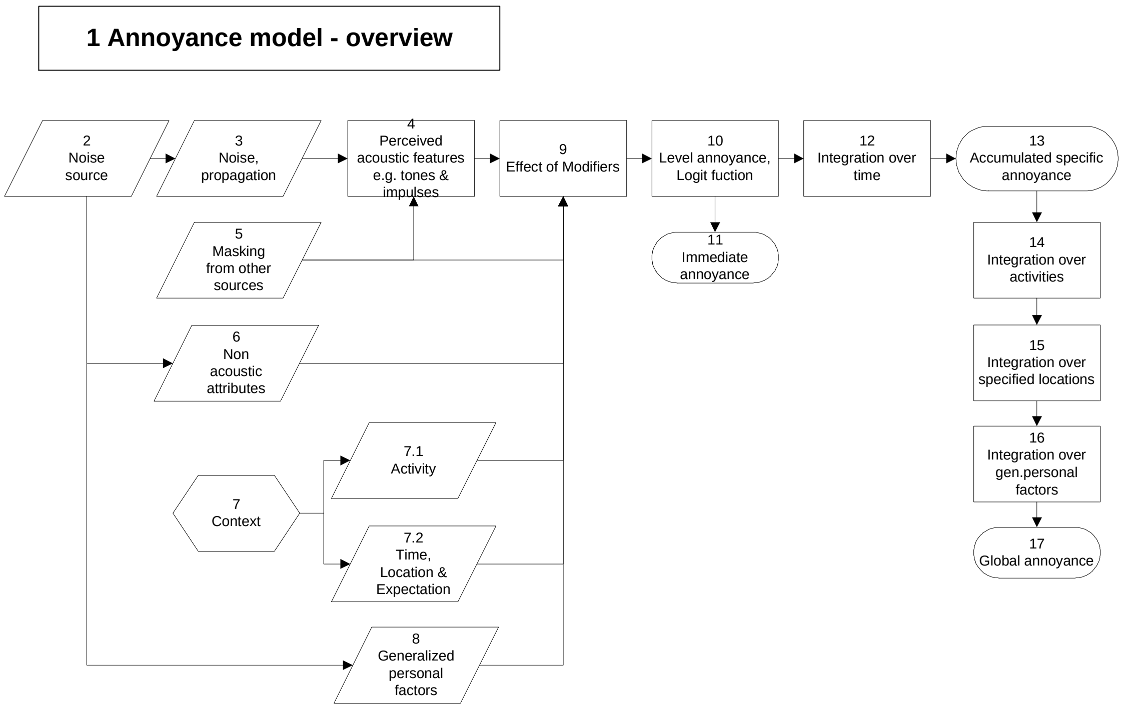

Figure 19
Overview of the elements and their relation in the "Genlyd" annoyance model.

The content and effects of the items in Figure 19 are explained in the subsections of section 7. The numbers of the subsections in this section follows the numbering of the elements given in Figure 19

7.1.2 Reliability of Data and Results

The model is based on information from a number of different sources and references. Some of these are well documented and widely accepted correlations between the noise and the annoyance, other sources are not so well documented, and in the extreme, hypothesis based on general observations and common sense may be included.

We want to gather as much information as possible and combine it into a tool giving guidance on the expected annoyance in different situations as a tool for persons that are not experts on annoyance.

If we want to include information which is not fully documented and well established or information which in some sense has a relatively large uncertainty, we need to mark data with a "reliability indicator". This shall give an indication of the quality of the data behind the different parts of the model.

The reliability indicator is quantifying the reliability on a percentage scale (0-100%) as follows:

100%	Information from well documented and widely accepted references from reviewed scientific journals or solid reports of similar quality, based on a number of references showing the same or similar results
80%	Information from well documented and widely accepted references from reviewed scientific journals or solid reports of similar quality
60%	Data and information based on documented and published (e.g. conference papers, books, articles) investigations, based on a number of references showing the same or similar results. References from this group may be upgraded if the authors are represented in the two upper groups.
40%	Data and information from non published single investigations documented in non public available sources. Data from DELTA's own listening test is located in this group until they are published and compared to possible other findings in literature and conference papers
20%	Generally accepted opinions on the connections between issues of significance for the "Genlyd" project (noise, annoyance, context, persons). Documentation may exist, but is not located or presently available. Personal correspondence or conversations may be used as reference
10%	Hypotheses based on general observations and common sense, accepted as plausible by a number of "Genlyd" project participants with relevant background.

Table 4
Reliability scale for data contributing to a dose response curve.

7.1.3 Calculation of Overall Reliability

The overall reliability indicator for a dose response curve is the weighted average of the indicators of the intermediate model parameters involved in the actual computation of annoyance. The weighting factors shall be in accordance with the relative significance influence of the intermediate models on the final result. This is obtained by the following formulas for calculating the overall reliability:

Equation 14 is fabricated to give a reasonable expression for the reliability of the resulting 50% value, f, for the dose-response curve after changing the norm curve with the moderator, Δfn:

$$\mathrm{Rel}_n \text{ of f} = (0.8 + 0.2 \cdot \mathrm{Rel}_{fn})^{\Delta fn} \qquad \text{Equation 14}$$

"Rel_n of f" is the reliability of the n'th moderator for f. The value of Rel_{fn} for Δfn is defined by Table 4 (Rel_{fn} shall be inserted in Equation 14 as a value in the range 0-1). Δfn is the actual magnitude in dB of he n'th moderator. The formula is illustrated in Figure 20.

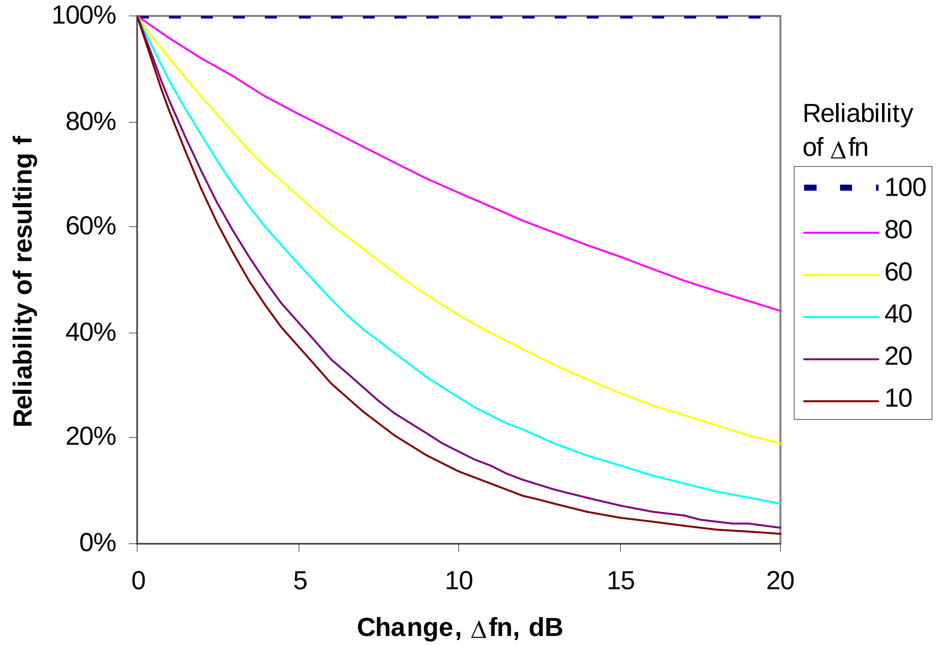

Figure 20
Illustration of Equation 14.

Correspondingly Equation 15 is fabricated to give a reasonable expression for the reliability of the resulting slope, s, for the dose-response curve after changing the norm curve with the moderator (factor), s_n:

$$\mathrm{Rel}_n \text{of } s = (0.8 + 0.2\mathrm{Rel}_{sn})^{30 \log sn} \qquad \text{Equation 15}$$

“Rel_n of s” is the reliability of the n’th factor for resulting slope s. The value of Rel_{sn} for s_n is defined by Table 4 (Rel_{sn} shall be inserted in Equation 14 as a value in the range 0-1. s_n is the magnitude of the n’th moderator (factor). The formula is illustrated in Fig***u***re 21.

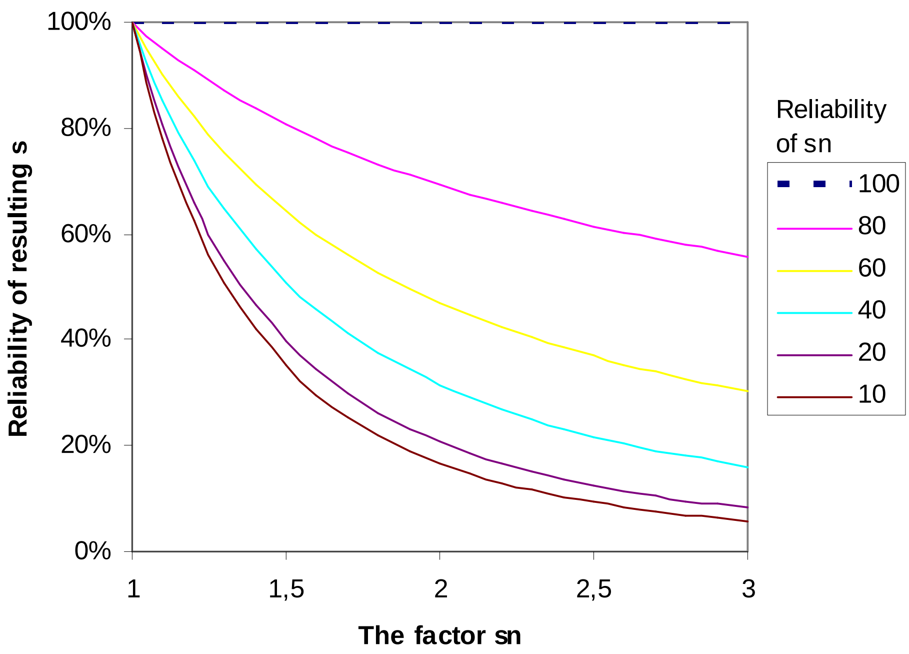

Figure 21
Illustration of Equation 15.

The reliability Rel_{total} for the dose-response curve with a number of moderators is then defined as:

$\mathrm{Rel}_{total} = \mathrm{Rel}_{norm}$* ($\mathrm{Rel}_1$ of f)*(Rel_1 of s) * (Rel_2 of f)*(Rel_2 of s) * (Rel_3 of f)*(Rel_3 of s)...

where Rel_{norm} is the reliability of the norm curve.

7.1.4 Validity Range

The model may within a certain range be based on data with a stated reliability as described in the former section. In some cases it may be of interest to go beyond this range, to extrapolate the model. It will be indicated in which range the model is based on actual data and observations and in which range the model is extrapolated.

7.2 Noise Source

7.2.1 Norm Curves for Global Annoyance

For each type of noise source it has been the intension to define the most reliable norm curve as the basis for introducing the effect of moderators. The norm curve gives the relation between the general exposure (expressed e.g. as L_{den}-values) and the annoyance reaction. The norm curve represent an average situation for sound characteristics, context and personal factors, which is relevant for the actual source. Examples of norm curves are shown in Figure 22.

When a moderator has a specific value it may change the norm curve. To be able to introduce a change, both the specific value of the moderator and the average value of this moderator for the norm curve must be known. Even if the specific value equals the average value a change in the norm curve may be introduced, namely a steeper slope for the curve in a specific rather than average situation, see Section 6.6.1.

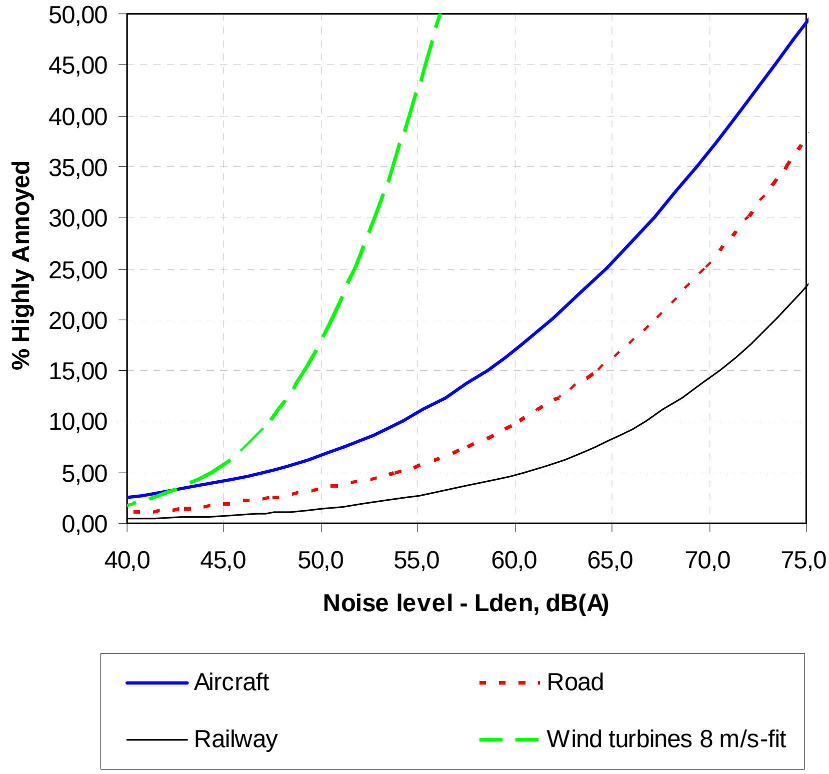

Figure 22
Norm curves (logistic approximation) for the relation between noise level(L_{den}) and % Highly Annoyed from [4]and [24] . The wind turbine data are found by combining data from [37] and [38] and correcting from L_{Aeq}-values to L_{den} by adding 6.4 dB to the L_{Aeq}.

The norm curves in Figure 22 are based on L_{den}-values. Similar curves exist for L_{dn}-values. The average relations between Lden and DNL are according to [4]:

- Aircraft: $L_{den} = L_{dn} + 0.6$
- Road traffic: $L_{den} = L_{dn} + 0.2$
- Railway: $L_{den} = L_{dn}$

The relations for a specific case depend on the distribution of the noise in the day, evening and night period for the actual situation.

The norm curves predict the global long term annoyance reaction (see Section 3.3.3) valid for the entire population. They are a suitable basis for policy making and when exposure limits for dwellings and noise abatement measures are discussed.

Community noise sources may in some respects deviate from other sources in the sense that:

– the sound emission is not confined to areas owned by the source administrators

– they are ever-present or repetitious rather that temporary

– individual respondents rarely can do anything about them

The norm curves do not predict the actual annoyance for particular individuals or groups. They do not take local circumstances into account nor is reactions to changes in the exposure considered.

7.2.2 Approximations to norm curves and data

In [4] both estimates and approximations to these estimates are given by third order polynomials. Within the level range of 45-75 dB these polynomial approximations are acceptable, but their fundamental properties deviate from the s-shaped function of the general dose-response relationship. Outside a limited range the third order polynomials are not usable, see Figure 23. They may e.g. give values below 0 and above 100%.

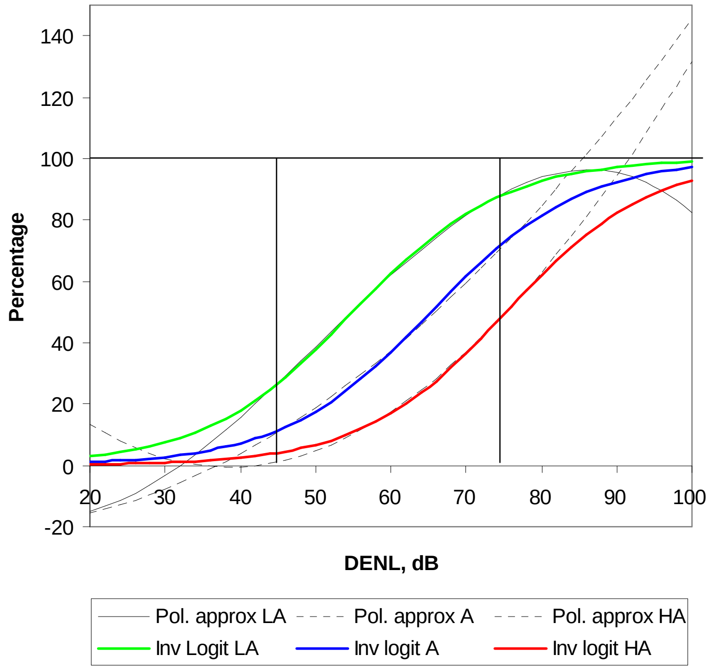

Figure 23
Comparison of different approximations to the estimated norm curves for aircraft noise. LA =% little annoyed, A = % annoyed, HA = % Highly annoyed. Thick lines are logistic approximations thin lines are third order polynomial approximations. The estimated data and the approximations are valid in the range 45-75 dB L_{den}.

The logistic approximations (see Section 6.1) are in agreement with the fundamental properties of the dose-response reaction and extrapolations outside the restricted range are likely to give probable results.

The agreement with the estimated values for transportation noise (based on [4]) for the logistic approximation is in line with or better than the polynomial approximation, see Table 5.

Deviations in %-point		**Logistic approx.**		**Polynomial approx.**	
		Mean	**Max**	**Mean**	**Max**
% LA	Air	0.3	0.7	0.5	1.0
	Road	0.2	0.5	0.6	0.9
	Rail	0.4	0.7	0.7	1.7
% A	Air	0.3	0.7	1.2	2.2
	Road	0.4	0.9	0.7	1.4
	Rail	0.5	0.8	0.4	0.9
% HA	Air	0.6	1	0.4	1.9
	Road	0.5	1.0	0.6	1.1
	Rail	0.3	0.5	0.1	0.2

Table 5
Absolute values of the deviations from estimated values in [4] in the range 45-75 dB L_{den}. The logistic and polynomial approximations are stated in the succeeding sections. The models in the "Genlyd" project will be based on logistic approximations.

7.2.3 Aircraft

The third order polynomial and the logistic approximations to the norm curves as defined in Section 7.2.1 for aircraft noise are given in Table 6 and Figure 24.

Third order polynomial approximation	
%LA	$-6.158 \times 10^{-4} (L_{den} - 32)^3 + 3.410 \times 10^{-2} (L_{den} - 32)^2 + 1.738 (L_{den} - 32)$
%A	$8.588 \times 10\text{-}6 (L_{den} - 37)^3 + 1.777 \times 10^{-2} (L_{den} - 37)^2 + 1.221 (L_{den} - 37)$
%HA	$-9.199 \times 10\text{-}5 (L_{den} - 42)^3 + 3.932 \times 10^{-2} (L_{den} - 42)^2 + 0.2939 (L_{den} - 42)$
%EA	$-8.786 \times 10^{-5} (L_{den} - 32)^3 + 1.439 \times 10^{-2} (L_{den} - 32)^2 + 1.120 (L_{den} - 32)$

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.101	55.0
% A	0.101	65.3
% HA	0.104	75.3
EA (from approximated curves)	0.0754	65.2

Table 6
Aircraft noise. Third order polynomial approximations (upper table) and logistic approximation (lower table) to the estimated curves giving the percentage of "Little Annoyed" (% LA), Annoyed (% A), Highly Annoyed (% HA) and Estimated Annoyance (EA). The Average Annoyance Score, AAS = (% EA) / 10.

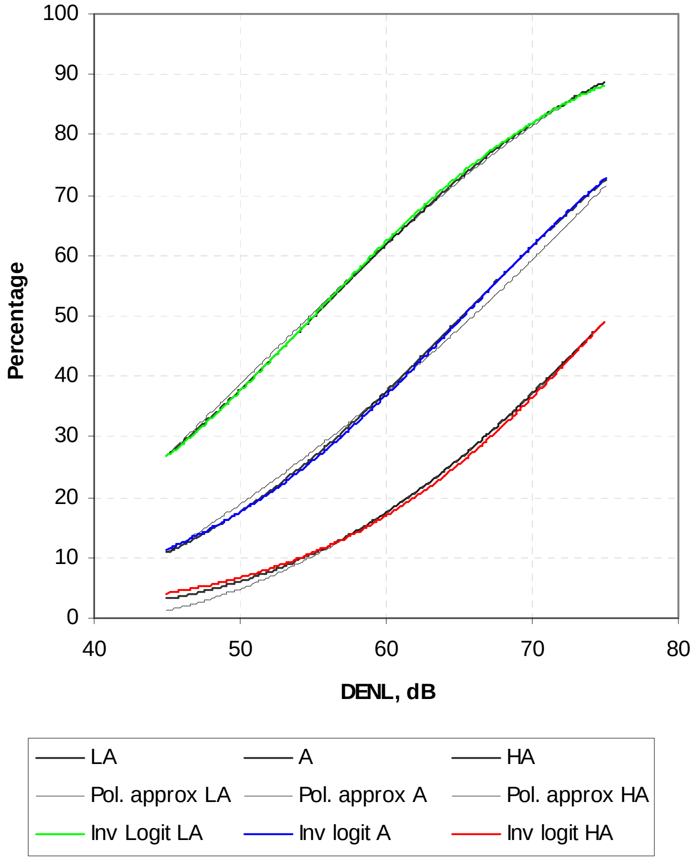

Figure 24
Aircraft noise. Estimated and approximated curves for the percentage of Highly Annoyed (HA), Annoyed (A) and Little Annoyed (LA) for aircraft noise.

The norm curves are valid in the range 45-75 dB L_{den}. In this range the reliability is set to 100% according to Section 7.1.2.

The data are based on 27,081 observations in 19 studies.

7.2.4 Road Traffic

The third order polynomial and the logistic approximations to the norm curves as defined in Section 7.2.1 for noise are defined in Table 7 and Figure 25.

% LA	$-6.235 \times 10^{-4} (L_{den} - 32)^3 + 5.509 \times 10^{-2} (L_{den} - 32)^2 + 0.6693 (L_{den} - 32)$
% A	$1.795 \times 10^{-4} (L_{den} - 37)^3 + 2.110 \times 10^{-2} (L_{den} - 37)^2 + 0.5353 (L_{den} - 37)$
% HA	$9.868 \times 10^{-4} (L_{den} - 42)^3 - 1.436 \times 10^{-2} (L_{den} - 42)^2 + 0.5118 (L_{den} - 42)$
EA	$-9.154 \times 10^{-5} (L_{den} - 32)^3 + 2.307 \times 10^{-2} (L_{den} - 32)^2 + 0.537 (L_{den} - 32)$

Logistic approximation: $\%XA = \dfrac{100}{1 + e^{-s(DENL - f)}}$	s	f
% A	0.101	60.7
%	0.103	70.7
% A	0.115	79.4
EA (from approximated curves)	0.0795	70.4

Table 7
Road noise. Third order polynomial approximations (upper table) and logistic approximation (lower table) to the estimated curves giving the percentage of Little Annoyed (% LA), Annoyed (% A), Highly Annoyed (% HA) and Estimated Annoyance (EA). The Average Annoyance Score, AAS = EA/10.

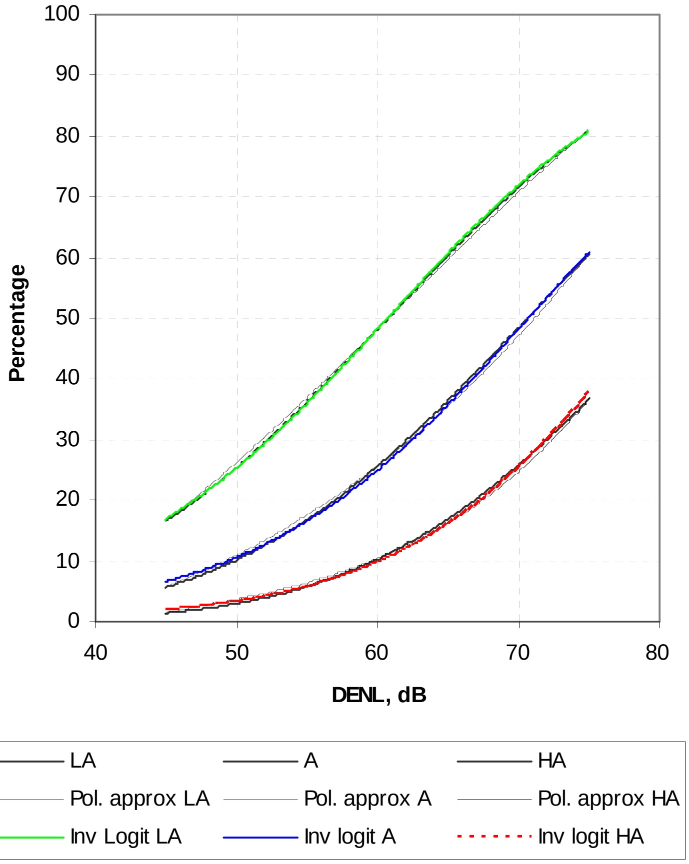

Figure 25
The percentage of annoyed for road traffic noise.
Valid in the range 45-75 dB L_{den}.

The norm curves are valid in the range 45-75 dB L_{den}. In this range the reliability is set to 100% according to Section 7.1.2.

The data are based on 19,172 observations in 26 studies.

7.2.5 Railway Traffic

The norm curves as defined in Section 7.2.1 for railway noise are defined in Table 8 and Figure 26.

% LA	$-3.229 \times 10^{-4} (L_{den} - 32)^3 + 4.871 \times 10^{-2} (L_{den} - 32)^2 + 0.1673 (L_{den} - 32)$
% A	$4.538 \times 10^{-4} (L_{den} - 37)^3 + 9.482 \times 10^{-3} (L_{den} - 37)^2 + 0.2129 (L_{den} - 37)$
% HA	$7.239 \times 10^{-4} (L_{den} - 42)^3 - 7.851 \times 10^{-3} (L_{den} - 42)^2 + 0.1695 (L_{den} - 42)$
EA	$-5.045 \times 10^{-6} (L_{den} - 32)^3 + 2.068 \times 10^{-2} (L_{den} - 32)^2 + 0.234 (L_{den} - 32)$

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.103	66.0
% A	0.109	76.0
% HA	0.120	85.0
EA (from approximated curves)	0.0832	75.3

Table 8
Railway noise. Third order polynomial approximations (upper table) and logistic approximation (lower table) to the estimated curves giving the percentage of Little Annoyed (% LA), Annoyed (% A), Highly Annoyed (% HA) and Estimated Annoyance (EA). The Average Annoyance Score, AAS = EA/10.

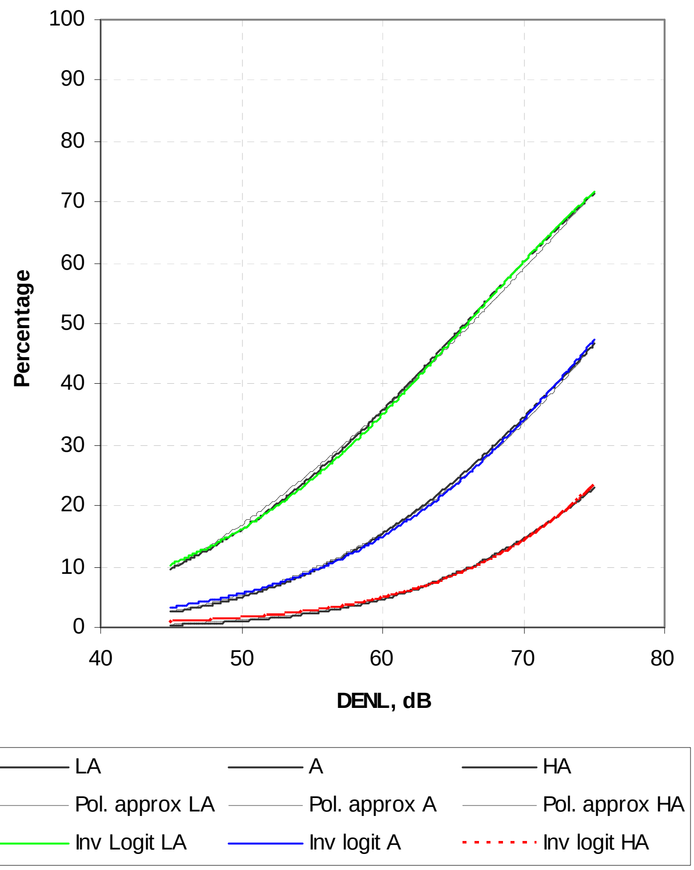

Figure 26
The percentage of annoyed for railway noise.
Valid in the range 45-75 dB L_{den}.

The norm curves are valid in the range 45-75 dB L_{den}. In this range the reliability is set to 100% according to Section 7.1.2.

The data are based on 7,632 observations in 8 studies.

7.2.6 Wind Turbines

Two studies of wind turbine noise is the basis for the norm curves, a Swedish study [36] and a Danish study [41]. The Swedish study showed a considerably lower response at the same noise levels, see Table 9 for a comparison.

LA_{eq} at 8 m/s in dB	< 30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	> 40.0
S. Slightly annoyed	0	14	35	39	50	56
S. Rather annoyed	0	0	18	13	28	44
S. Very annoyed	0	0	8	6	20	36
DK. Slightly annoyed	0	0	0	8	9	25
DK. Annoyed	0	0	0	2	5	13
DK. Highly annoyed	0	0	0	0	5	9

Table 9
Comparison of the (cumulative) percentage annoyed in two studies of wind turbine noise: Swedish [36] and Danish [41].

In both studies the noise exposure is an estimate for the equivalent level for a (hypothetical) time period with continuous performance at downwind conditions 8 m/s at 10-m height. The studies give no indications if this represents the real noise exposure. In the Swedish study there are no measurements of the prominence of tones in the noise. Generally the noise level from wind turbines increase approximately 1 dB per 1 m/s increase in wind speed and for modern wind turbines the prominence of the tones is in the low range of adjustment according to ISO 1996-2 [15] or below.

The data from [36] and [41] have been reanalyzed with ordinal logistic regression. Furthermore the exposures expressed as L_{Aeq}-values are converted to L_{den} by adding 6.4 dB under the assumption that there is no change in level during the evening and the night. The results from these analyses are shown in Table 10.

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	S s	S f	DK s	DK f	Average s	Average f
% LA	0.263	50.6	0.235	62.4	0.249	56.2
% A (S = “Rather annoyed”)	0.263	48.1	0.235	58.6	0.249	53.1
%HA (S = “Very annoyed”)	0.263	44.1	0.235	54.6	0.249	49.1
EA	-	-	0.226	58.2	0.239	52.7

Table 10
Wind turbine noise, results of ordinal logistic regression. The results of each of the studies from Sweden (S) and Denmark (DK) are shown together with average values of slopes, s and 50% L_{den}-values, f, for the percentage of Little Annoyed” (%LA). Annoyed (% A, Highly Annoyed (% HA) and Estimated Annoyance (EA). The average annoyance score AAS = EA/10.

With background in the considerations in Section 6.5 it is decided that the norm curve for wind turbine noise shall be based on the pooled data (i.e. giving a lower slope than averaging the slopes of the two dose-response curves) of the Swedish and the Danish study. The resulting figures are given in Table 11.

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.201	49.1
% A	0.198	53.3
% HA	0.189	56.3
EA	0.190	52.9

Table 11
Norm curves for wind turbine noise. The curves are based on averaged data and gives the percentage of Little Annoyed (% LA), Annoyed (% A), Highly Annoyed (% HA) and Estimated Annoyance (% EA). The average annoyance score AAS = EA/10.

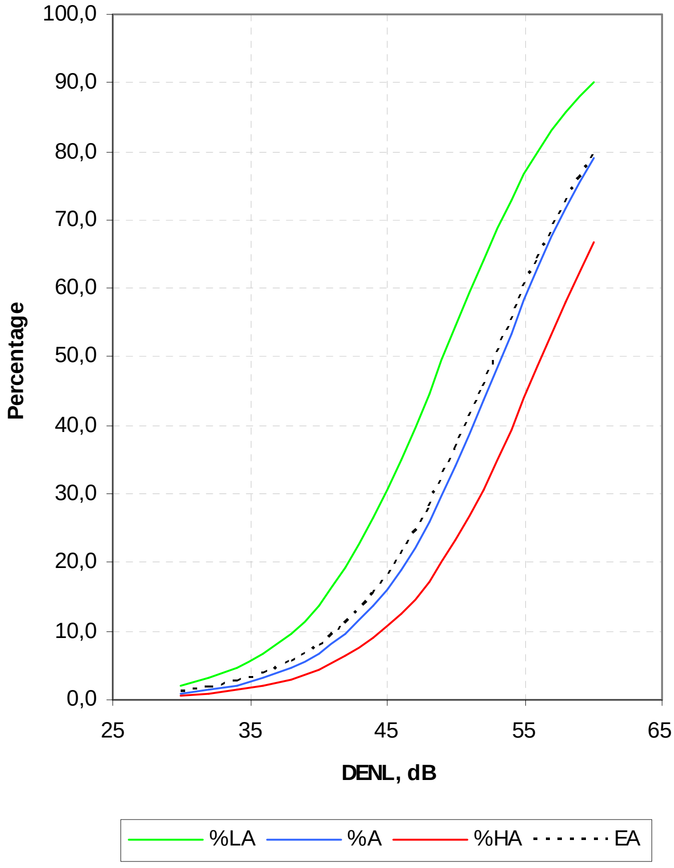

Figure 27
The percentage of annoyed for wind turbine noise.
L_{den}-values for a wind speed of 8 m/s, noise.
Valid in the range 35-50 dB L_{den}.

The norm curves are valid in the range 35-50 dB L_{den}. In this range the reliability is set to 70%. It is less that 80% according to Section 7.1.2 due to the fact that the exposure is based on noise data for the wind speed 8 m/s and not the actual average wind speed.

The Swedish study is based on 351 observations from 5 locations. The Danish study represents 200 respondents on 10 locations. In total 551 observations from 15 locations.

7.2.7 Industrial Noise

The norm curves as defined in Section 7.2.1 for industrial noise are defined in Table 12 and Figure 26.

% LA	$0.02815 \times L_{den}^2 - 1.130 \times L_{den} + 11.477$
% A	$0.03270 \times L_{den}^2 - 2.121 \times L_{den} + 36.854$
% HA	$0.02523 \times L_{den}^2 - 1.886 \times L_{den} + 36.307$
EA	$0.02332 \times L_{den}^2 - 1.172 \times L_{den} + 17.247$

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.0913	62.0
% A	0.1018	69.6
% HA	0.1219	74.8
EA	0.0816	69.8

Table 12
Industrial noise. Second order polynomial approximations (upper table) and logistic approximations to these (lower table) giving the percentage of "Little Annoyed" (% LA). Annoyed (% A. Highly Annoyed (% HA) and Estimated Annoyance (EA). The average annoyance score AAS = EA / 10.

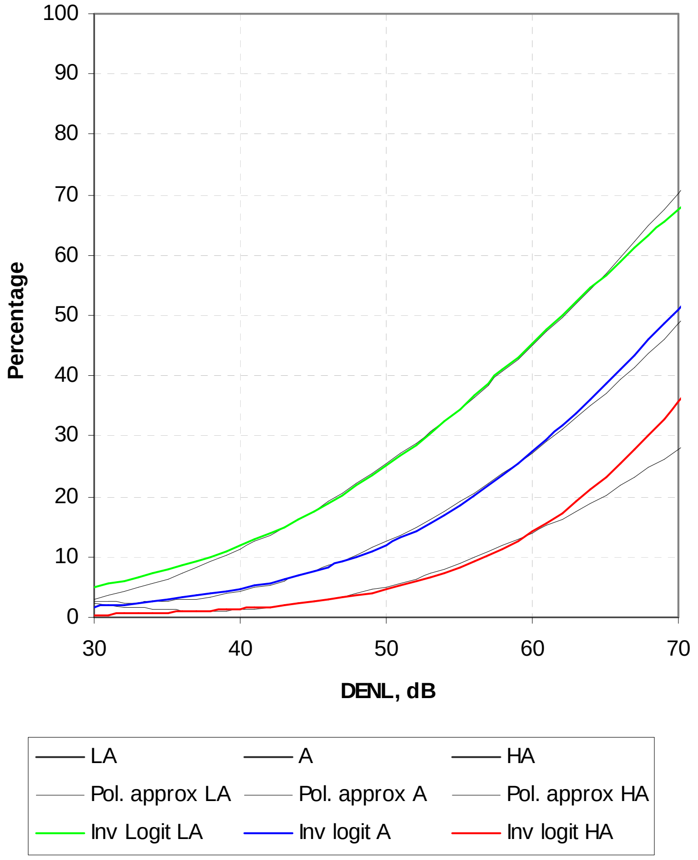

Figure 28
The percentage of annoyed for industrial noise.
Valid in the range 35-65 dB L_{den}.

The norm curves are valid in the range 35-65 dB L_{den}. In this range the reliability is set to 80% according to Section 7.1.2. Information about the prominence of audible tones and impulsive sounds are not available.

The data are based on 1.242 observations near 6 industries in 1 study ([24]).

7.2.8 Seasonal Industry

The norm curves as defined in Section 7.2.1 for seasonal industrial noise (industry not in operation the whole year) are defined in Table 13 and Figure 29.

% LA	$0.03096 \times L_{den}^2 - 2.146 \times L_{den} + 30.156$
% A	$0.02124 \times L_{den}^2 - 1.635 \times L_{den} + 32.137$
% HA	$0.01091 \times L_{den}^2 - 0.887 \times L_{den} + 18.123$
EA	$0.02017 \times L_{den}^2 - 1.390 \times L_{den} + 25.476$

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.1069	71.9
% A	0.1258	77.1
% HA	0.1237	85.7
EA	0.0986	77.8

Table 13
Seasonal industrial noise. Second order polynomial approximations (upper table) and logistic approximations (lower table) to these giving the percentage of "Little Annoyed" (%LA). Annoyed (%A. Highly Annoyed (%HA) and Estimated Annoyance (EA). The Average Annoyance Score AAS = EA / 10. (Based on approximated values).

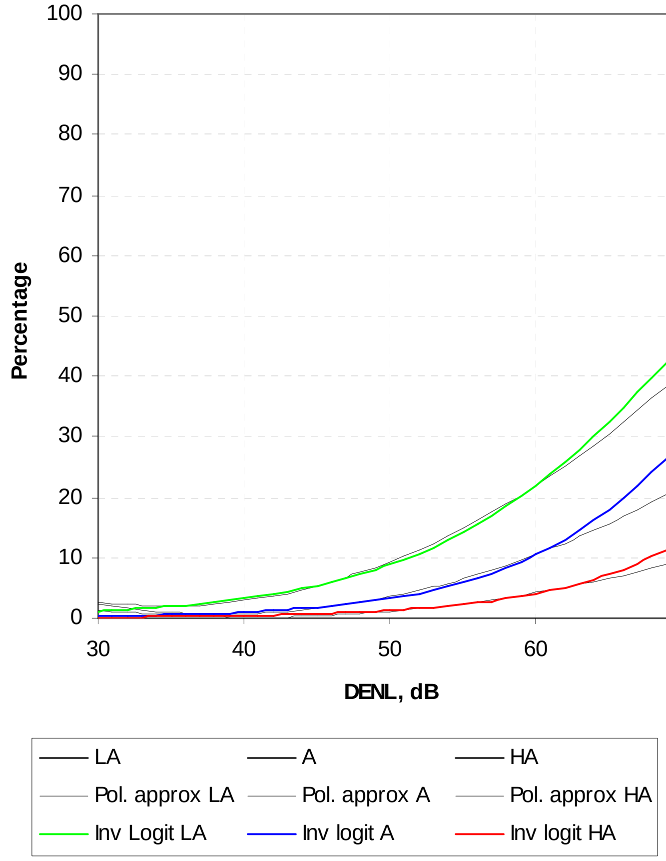

Figure 29
The percentage of annoyed for seasonal industrial noise.
Valid in the range 35-65 dB L_{den}.

The norm curves are valid in the range 35-65 dB L_{den}. In this range the reliability is set to 80% according to Section 7.1.2. Information about the prominence of audible tones and impulsive sounds are not available.

The data are based on 421 observations near 3 industries in 1 study ([24]).

7.2.9 Shunting Yard

The norm curves as defined in Section 7.2.1 for shunting yard noise are defined in Table 13 and Figure 29.

% LA	$-0.0253 \times L_{den}^2 + 4.659 \times L_{den} - 110.52$
% A	$0.01265 \times L_{den}^2 + 0.722 \times L_{den} - 27.629$
% HA	$0.02980 \times L_{den}^2 - 1.367 \times L_{den} + 16.980$
EA	$0.007308 \times L_{den}^2 - 0.972 \times L_{den} - 25.051$

Logistic approximation: $\%XA = \frac{100}{1+e^{-s(DENL-f)}}$	s	f
% LA	0.0920	46.1
% A	0.0879	54.6
% HA	0.0923	63.3
EA	0.0730	54.6

Table 14
Shunting yard. Second order polynomial approximations (upper table) and logistic approximations (lower table) to these giving the percentage of Little Annoyed (% LA). Annoyed (% A), Highly Annoyed (% HA) and Estimated Annoyance (EA). The average annoyance score AAS = EA / 10.

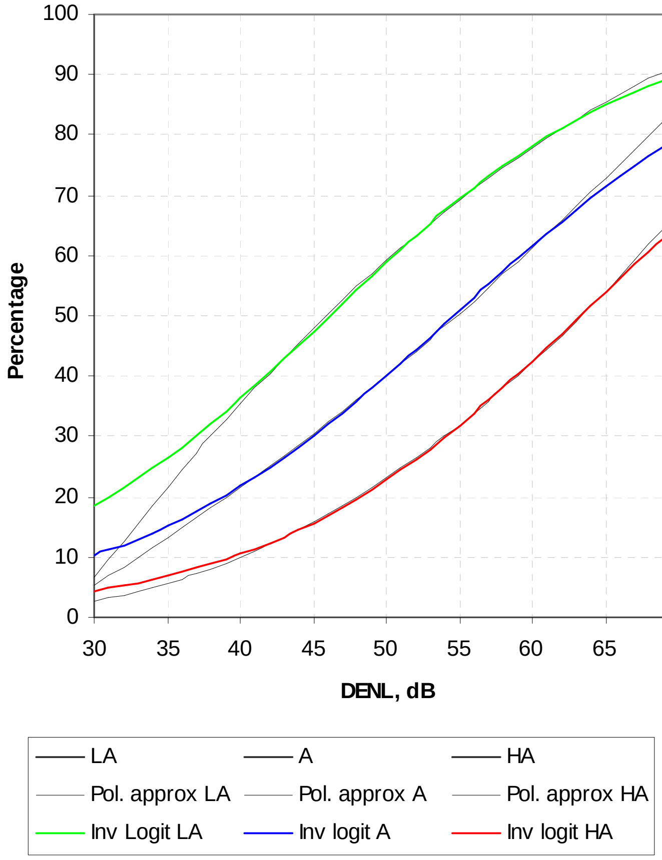

Figure 30
The percentage of annoyed for shunting yard noise.
Valid in the range 35-65 dB L_{den}.

The norm curves are valid in the range 35-65 dB L_{den}. In this range the reliability is set to 80% according to Section 7.1.2. Information about the prominence of audible tones (diesel trains) and impulsive sounds from shunting activities are not available.

The data are based on 212 observations near 2 shunting yards in 1 study [24].

7.2.10 Summary of Norm Curves

The norm curves in the model are described by a logistic function:

$$\%XA = \frac{100}{1 + e^{-s(DENL - f)}}$$

where XA =

LA (Little annoyed)

A (Annoyed)

HA (Highly annoyed)

AS (Average annoyance score (0-10))

EA (Expected annoyance (= 10 × AS))

The constants for different sources are summarised in Table 15.

Constants	**% LA**		**% A**		**% HA**		**AS. EA**	
	s	**f**	**s**	**f**	**s**	**f**	**s**	**f**
Air	0.1010	55.0	0.1010	65.3	0.1040	75.3	0.0754	65.2
Road	0.1010	60.7	0.1030	70.7	0.1150	79.4	0.0795	70.4
Rail	0.1030	66.0	0.1090	76.0	0.1200	85.0	0.0832	75.3
Industry	0.0913	62.0	0.1018	69.6	0.1219	74.8	0.0816	69.8
Shunting	0.0920	46.1	0.0879	54.6	0.0923	63.3	0.0730	54.6
Seasonal	0.1069	71.9	0.1258	77.1	0.1237	85.7	0.0986	77.8
Wind turbines	0.2010	49.1	0.1980	53.3	0.1890	56.3	0.1903	52.9

Table 15
The constants s = slope and f = L_{den}-level for 50% XA for different noise sources.

7.3 Noise Propagation

The noise propagation describes how the sound characteristics of the source are changed during propagation. The general idea of the “Genlyd” model is to take the perceived sound as the starting point. In many cases this is not possible, and the perceived sound is therefore approximated by the sound measured or calculated elsewhere e.g. by the sound at a facade outside peoples homes. Anyway, the calculation of the sound propagation itself has not been the topic for the “Genlyd” model. Only if the sound propagation itself has an effect on the annoyance it will be taken into account.

Sound insulation is part of the sound propagation, [31] describes how the sound insulation has an effect in the annoyance reaction, see Figure 31.

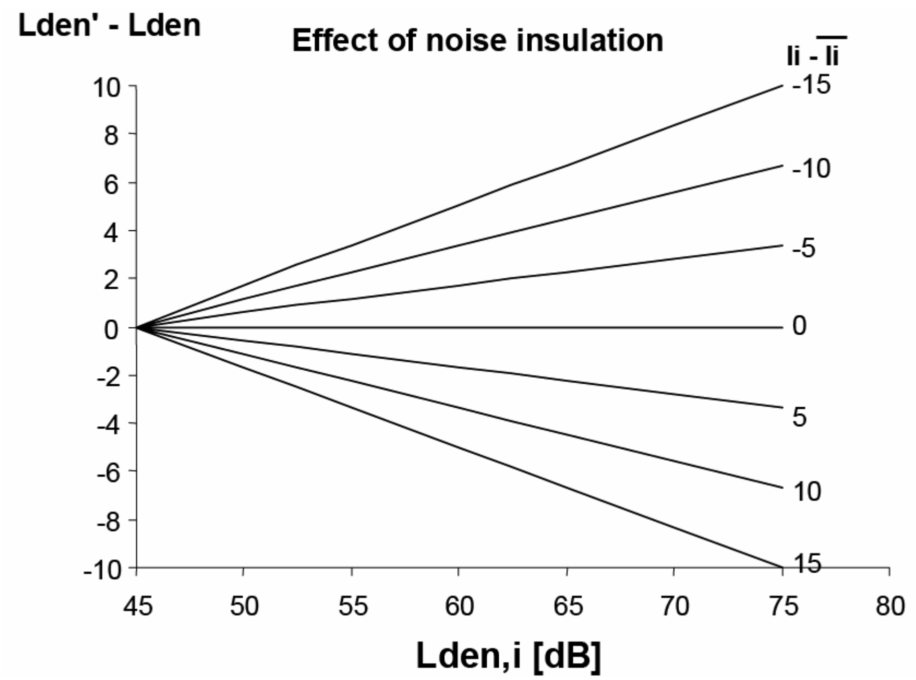

Figure 31
Possible effect of sound insulation on the difference between $L_{den.i}$' and $L_{den.i}$ as function of $L_{den.i}$. $L_{den.i}$' is the L_{den}-value adjusted according to the extra annoyance caused by a facade insulation deviating from the aveage. I_i is the lowest insulation for bed/living room at the most exposed facade [dB]. $\overline{I_i}$ is the average insulation for dwellings[dB]. Index i relates to the source type, Figure from [26].

The effect of the sound insulation is not yet incorporated in the model.

7.4 Perceived Acoustic Features

The sound from a source may have some specific characteristics. These may be changed during the propagation to the receiver. Masking sounds that changes the audibility of the source characteristics may also occur. We will concentrate on the sound at the receiver and the term “Perceived acoustic features” relates to the characteristics of the sound as it is perceived at the “listener” or at the exposed persons.

The sound level or the intensity of the sound will in most cases be the most important variable. Therefore metrics as L_{Aeq} or other metrics derived from this (L_{den}, L_{night} ...) or related to this (e.g. Loudness) is chosen as the primary independent parameter.

Other characteristics of the sound may be regarded as moderators for the average dose-response curves (the norm curves) which describes the general relations between sound level and the annoyance.

Many characteristics may be relevant. but data for the modifying effect exist only for a few.

7.4.1 Audibility of Tones in Noise

It is generally believed that audible tones in noise increase the annoyance relative to a situation where there are no audible tones in the noise. Data from laboratory experiments exist, but data from surveys has not been found. Anyway it seems that it is a general experience, feeling or hypothesis that prominent tones increases the annoyance corresponding to an increase in the A-weighted equivalent level of 5-6 dB.

In the legislation of many countries a “penalty” of 3-6 dB is added to the measured L_{Aeq} to compensate for the extra annoyance if there are clearly audible tones in the noise.

A method for determining the audibility of tones is published in [39] and the same method appears in ISO/FDIS 1996-2 ([15]). This method finds the audibility of the tones (the level above the masking threshold ΔL_{ta}) and transforms it into an adjustment K_T of 0-6 dB to the measured L_{Aeq}. K_T is used as an input parameter in the model.

According to Section 6.4 the following relation applies:

$$\Delta f_{tonepenalty} = -K_T$$

This means that the dose-response curve is transposed up to 6 dB depending on the prominence of the tones.

As described in Section 6.6.1 the dose-response relationship has a steeper slope for a specific situation –e.g. specific audibility of tones- than the norm curve which represents an average of many different situations for the prominence of tones.

The value of s_n (in this case $S_{tonalpenalty}$) specifying the increase in the slope of the dose-resonse curve (relative to the norm slope) can be found from Table 3. The Δf_d value in this case is 3 dB, because all values in the range 0-6 dB (= $2\Delta f_d$) are considered to be equal probable.

From Table 15 it is seen that the S_{norm}-values for transportation noise and industrial sources all are close to 0.1 while the values for wind turbines are close to 0.2.

Noise source	**Approx s_{norm}**	**S_n**
Transportation and industrial	0.1	1.014
Wind turbines	0.2	1.049

Table 16
The value of s_n (in this case $S_{tonalpenalty}$) specifying the increase in the slope of the dose-response curve (relative to the norm slope) when a specific value for tone adjustment K_T is used in stead of the average for the norm curve.

The tone adjustment may be relevant for many sources. Usually it is not taken into account for transportation noise. In this model it will only be introduced for industrial sources. wind turbines and office equipment.

No documented relations for the effect has been found, but it is so generally accepted that audible tones in noise increase the annoyance that adjustments (of the above mentioned magnitudes) to L_{Aeq} for prominent tones are a part of national legislation and international standards. Therefore the reliability is set to 75%.

7.4.2 Prominence of Impulses in Noise

Prominent impulses in the noise increase the annoyance relative to a stationary noise type with the same level (L_{Aeq}). Data exist, but to a large extent they relates to shooting noise, which until now is not covered by the model. Anyway it seems that it is a general experience that prominent impulses increase the annoyance.

The legislation of many countries includes a "penalty" which is added to the measured L_{Aeq} if there are prominent impulses in the noise. This also holds for the ISO standard 1996-1 ([14]) where adjustment (or penalty) up to 12 dB are added

A method for determining the audibility of tones is published in [40] and the same method appears in Nordtest ACOU 112 [34]. This method finds the prominence of impulses P and transforms it into an adjustment K_I up to 15 dB to the measured L_{Aeq}. Although the underlying prominence metric P gives good correlation with the perceived impulse prominence in listening tests, there is some doubt about the correctness of the adjustment K_I . Until further data is found K_I is used a slightly modified as an input parameter in the model as follows:

According to Section 6.4 the following relation applies:

$$\text{For } K_I \leq 12 \text{ dB: } \Delta f_{impulsepenalty} = -K_I \text{ . For } K_I > 12 \text{ dB: } \Delta f_{impulsepenalty} = -12$$

This means that the dose-response curve is transposed up to 12 dB depending on the prominence of the impulses.

As described in Section 6.6.1 the dose-response relationship has a steeper slope for a specific situation –e.g. specific prominence of impulses- than the norm curve which represents an average of many different situations for the prominence of impulses.

The value of s_n (in this case $S_{impulsepenalty}$) specifying the increase in the slope of the dose-resonse curve (relative to the norm slope) can be found from Table 3. The Δf_d value in this case is set to 3 dB. Although the variation of Δf is up to 12 dB, it is estimated that the ocurrence of 12 dB impulse penalties is not normally used for non explosive sources. As these are rare or maybe not represented at all in the underlying data for the norm curves, it is judged that the majority of adjustments K_I (if any) are in the range 0-6 dB (= $2\Delta f_d$).

From table Table 15 it is seen that the S_{norm} values for transportation noise and industrial sources all are close to 0.1 while the values for wind turbines are approximately 0.2.

Noise source	Approx s_{norm}	S_n
Transportation and industrial	0.1	1.014
Wind turbines	0.2	1.049

Table 17
The value of s_n (in this case $S_{impulsepenalty}$) specifying the increase in the slope of the dose-resonse curve (relative to the norm slope) when a specific value for tone adjustment KT is used in stead of the average for the norm curve.

The impulse adjustment may be relevant for a number of sources. Usually it is not taken into account for transportation noise. In this model it will only be introduced for industrial sources, wind turbines and office equipment.

No documented relations for the effect are found for these sources. Anyway it is generally accepted that prominent impulses increase the annoyance and penalties (or adjustments) are included in national legislation and international standards. There are discussions in the international community about the correct magnitide of the adjustment; therefore the reliability is set to 50%.

7.4.3 Other Acoustic Characteristics of the Sound

Until now only the effect of the noise level, tones and impulses are taken into account. Other chracteristics of the noise may also moderate the annoyance reaction.

- Other metrics for sound intensity than L_{den} (L_{Aeq}, $L_{Amax,F}$, L_{A95}. Loudness. Loudness (N_5) ...)
- Number of events (partly included in metrics as L_{Aeq})
- Duration of the noise (partly included in metrics as L_{Aeq})
- Number and duration of relative calm intervals
- Low frequency content (metric?)
- Sharpness
- Roughness
- Fluctuation strength
- Unbiased annoyance/psykoakoustic annoyance
- Information content (speech. music)
- Potential communication disturbances/difficulties (metrics for this characteristic?)
- Speech intelligibility (Speech interference level (SIL). Articulation index (AI) Speech transmission index (STI. RASTI) Speech intelligibility index (SII)
- Privacy (expressed as 1-STI or by a signal to noise ratio)
- ......

The effect of these noise characteristics has not been found and therefore not included in the model.

7.5 Masking from Other Sources

Several noise sources in the same area or at the same time may increase the total annoyance, but sometimes one source may mask the sound or sound characteristics (e.g.- tones) so the contribution from this is less.

Following types of masking may be relevant:

- For wind turbines the masking effect of wind generated noise in the vegetation around the neighbours' homes may have influence on the annoyance
- Audible tones or impulses may be masked by other sources so that these characteristics will be less prominent or inaudible. The annoyance may be decreased accordingly. (Generally. addition of another (type of) source will not decrease the annoyance. So the validity of decreasing annoyance by masking should be investigated).
- In open-plan offices irrelevant speech may be masked by other noise sources (general "office noise" or "bable noise" from many remote speakers).

The model is prepared for such effects.

7.6 Non-Acoustic Attributes

7.6.1 Non-Acoustical Moderators from Source

There may be a number of non acoustical issues related to the source that may moderate the norm curves. Examples are:

- Smell from noise source
- Dust and air pollution
- Visual impact from noise source (e.g. changed view. disturbance of landscape or shadows)
- Visibility of the sound source (visual screening by e.g. by trees)
- Vibrations from the noise source
- Indirect effects: Generation of more traffic

Especially for wind turbines the visual effects seem to have a significant influence. see [41].

None of these effects are taken into account in the present version of the model.

7.6.2 Non-Acoustical Moderators related to Noise Reduction

There may be other changes in the environmental situation than a mere reduction of the noise exposure when noise reducing arrangements are made. They may be:

- a noise barrier changes the view (positive or negative)
- a noise barrier takes up room avalable for other purposes
- Shadows from a noise barrier
- a more time consuming route to shops. school or work
- Windows with good sound insolation in connection with small attenuated ventilation opening may give less fresh air indoor

Such effects are not taken into account in the present model

7.7 Context

The context is all circumstances and conditions of significance for the annoyance, i.e. the noise source, the situation, the location, the time of day, the surroundings, the working or leisure situation, etc. in this section the emphasis is laid on the context variables at the exposed persons.

7.7.1 Activity

By the activity is meant the present occupation (what is the person doing during the stimulus exposure). For environmental noise types the knowledge is not very specific, so it is normally some average of home activities except for sleep where data for sleep disturbance are found, see Section 9.

For other types of noise, e.g. noise (including irrelevant speech) in open-plan offices, more specific information on the work activity may be specified (e.g. mind work or conversation).

7.7.2 Time, Location and Expectation

7.7.2.1 Time of Day and Day in the Week

Noise events in the evening and at night have more serious effect with respect to annoyance and disturbance than at daytime. This is caused by different vulnerability of activities and different expectations for different parts of the day. For outdoor activities less masking because of lower background noise may also play a role.

With regard to annoyance this effect is considered handled by using L_{den}, where 5 dB are added to the evening levels and 10 dB are added to the night levels. More details can be found in section 3.3.1 and [10].

For the night period sleep disturbances is of special interest. This issue is described in section 9.

Weekends are in the noise legislation of some countries treated with a special penalty. Furthermore the transition period between night and morning is one hour later in the weekend. These effects are not included in the model at the present stage.

7.7.2.2 Seasonal Effects

In [10] it is stated (based on [45]) that when representative samples of the German population -during the summer period (May to September)- are asked about the annoyance due to road traffic noise the percentage of annoyed people is about 70. even if the summer period is not mentioned in the question. If they are asked the same question during the winter period, the response is about 10% less.

If we compare this information with the data in Table 7 and Figure 25 (in the extrapolated area) we find that a 10% decrease in percentage annoyed corresponds to 3 dB less noise.

As the data mentioned are general data (over the whole year) we may anticipate that the seasonal noise sensitivity for road traffic noise can be approximated by

– Northern seasonal sensitivity = 1.5 * cos (month/6*π + π), dB

– Southern seasonal sensitivity = 1.5 * cos (month/6*π), dB

These functions are illustrated in Figure 32.

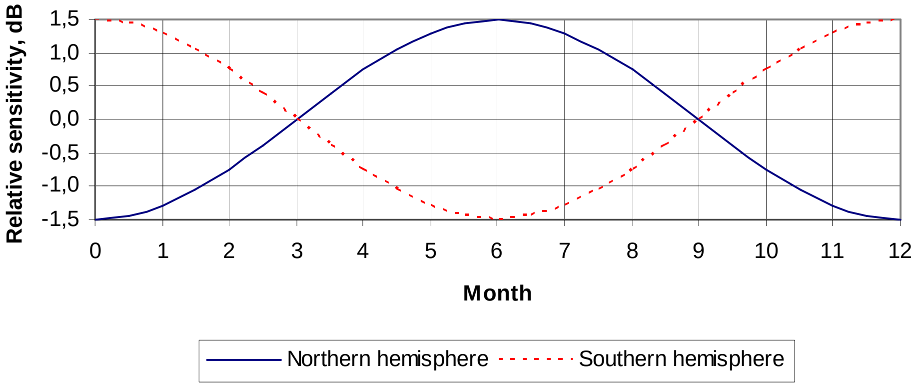

Figure 32
Approximation to seasonal noise sensitivity for road noise.

This seasonal variation will probably be most relevant for countries where the population spend more time outdoors in the summer than in the winter (where they mainly stay indoor with closed windows). This means that this effect probably only is relevant for countries with northern and southern latitudes in the range 30-70 degrees.

Since the observation is made for one type of source (road) in one country. the reliability is set to 25% according to section 7.1.2.

7.7.2.3 Location

The type of location where the persons are exposed to the noise has a major influence on the acceptance of the noise and thereby also on the annoyance. The main groups in the present model are: At home. office and recreational area (park or free nature).

At Home: "Quiet facade"
For the home environment the presence of a quiet side of the dwelling. a quiet facade is known to have significant influence on annoyance. The parameter for this effect is the difference in L_{den} between the most and the least expose facade for a specific source type. This effect is described in [7] and is yet not included in the model

At home: "Ambient noise Levels"
The L_{den}-level on the most and least exposed facade is not the only noise level of significance for the annoyance in the home environment. Also the noise level in the surroundings

is of significance. It is found to be important if there are relatively quiet areas available near the dwelling. This effect is described in [20] but is yet not included in the model.

At home:" Type of area"
In the Danish legislation there are different noise limits for multi-storeyed block of flats. for areas with single-family detached houses and for summer cottage areas. No data has been found for the effect of the area type. and it therefore not included in the model. Maybe the investigations in the effect of soundscape may enlighten this issue.

Recreational area
Two types of quiet areas are relevant: The relatively quiet areas as parks in cities or near residential areas and then the free nature or nature reserve. In the parks relatively high background levels (around L_{Aeq} = 40-45 dB) seem to be acceptable while in the free nature or nature reserve any audible sound not belonging to the nature seem to disturb the experience of "natural silence". Data for these effects have not been found and is not yet included in the model.

At work
Workplace noise differs from noise in the home in the sense that the levels may be higher and that not all noise sources are under control of the individual. The annoyance of workplace noise depends on the type of workplace (Indoor/outdoor work. production plant. office) and the type of work (manual or mind work).

In the "Genlyd" model only the annoyance from irrelevant speech and general background noise (office machines, PC's and ventilation) will be included in the model.

7.7.2.4 Expectation

People's expectations to the noise levels in different situations may influence the annoyance. Expectations that are connected to the type of area – to the acoustic quality of an area. time of day. work or leisure situation are taken into account by these issues.

Effects of expectation not related to the issues described in the other section may be:

- Annoyance may increase if the residents expect the noise to increase ([10] and [11])
- Expectations to the "acoustic" quality (quietness). Residents who expect live in a quiet countryside may be more annoyed than farmers that live and work there. The expectation of a quiet countryside may also play a role for annoyance of wind turbine noise.
- If the noise is known to be of shorter duration (i.e. construction work) the annoyance may be less

Data for the mentioned effects are not found and they are yet not included in the model.

7.8 Generalised Personal Factors

Special characteristics for specified group of persons may cause the responses and reactions to deviate from the general average in a given context. Such characteristics are called personal characteristics.

Personal factors are variables which are closely linked to an individual person or a group and may vary considerable between individuals or groups. Personal characteristics cannot be used for general noise/annoyance evaluations and abatement programs. unless the group of persons considered. is known to deviate from the mean values for the population in general on these factors.

A distinction shall be made between actual properties and perceived properties. The difference may be illustrated by the fact that from a statistical point of view it is safer to travel by airplane than by car. but many people are more nervous for flying because they perceive the risk as greater. For the personal factors it is the perceived or believed factors that counts.

The effect of these factors depends on the factor. Table 18 gives an overview over the magnitudes.

Variable	**Approximate noise level equivalent. dB**
Fear	19
Noise sensitivity	11
Age	5
Dependency on sound source	2
Education	2
Household size	2
Use of noise source	2
Homeownership	2
Occupation	1
Gender	0

Table 18
The approximate maximal noise equivalent effect in dB of the effect on transportation noise for different variables according to [26].

The specific influences on the annoyance of each of the mentioned factors are treated in detail in the succeeding sections. The following sections are mainly based on the information in [26] which is transformed to fit into the general formulas of the present annoyance model.

7.8.1 Fear

Studies on aircraft noise have shown that fear (the subjective feeling rather than the objective risk) of an aircraft crashing in the neighbourhood is related to noise annoyance. The fear variable is the most important non-acoustic variable to be mentioned in aircraft noise studies followed by noise sensitivity. even with stronger correlations than the acoustic variables.

Studies of noise annoyance for other modes of transportation (road and rail) show that fear also have an effect for the annoyance from these sources. although it is less.

The feeling of fear may be measured on a 0-10 scale similar to the scale shown in Figure 8 by using questions as:

- Would you please estimate how much you feel afraid or worried about a possible plane crash in this neighbourhood?
- How concerned are you that a traffic accident will occur near your home?
- When you hear trains go by. how much do feel there is a danger they may crash nearby?

The answers on the 0-10 scale may be transformed into a 0-100 point fear scale.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated in three categories as shown in Table 19.

<table>
<tr><th rowspan="2"></th><th colspan="3">Fear</th><th rowspan="2">Number of Respondents</th></tr>
<tr><th>Low</th><th>Medium</th><th>High (67-100)</th></tr>
<tr><td>Fear. category</td><td>0-32. mean: 16</td><td>33-66. mean: 50</td><td>67-100. mean: 84</td><td></td></tr>
<tr><td>Extra EA. Aircraft</td><td>0</td><td>16.8</td><td>30.2</td><td rowspan="2">14373</td></tr>
<tr><td>Distrib. Aircraft</td><td>63%</td><td>21%</td><td>16%</td></tr>
<tr><td>Extra EA. road</td><td>0</td><td>5.7</td><td>13.5</td><td rowspan="2">2008</td></tr>
<tr><td>Distrib. road</td><td>43%</td><td>19%</td><td>38%</td></tr>
<tr><td>Extra EA. train</td><td>0</td><td>14.4</td><td>43.1?</td><td rowspan="2">1113</td></tr>
<tr><td>Distrib. train</td><td>86%</td><td>13%</td><td>1%</td></tr>
</table>

Table 19
Extra noise annoyance on the EA scale 0-100 for transportation noise relative to the category "low fear". The validity range is 45-75 dB DNL. The High fear value for trains is doubtful (to few respondents) and is excluded from the further analysis.

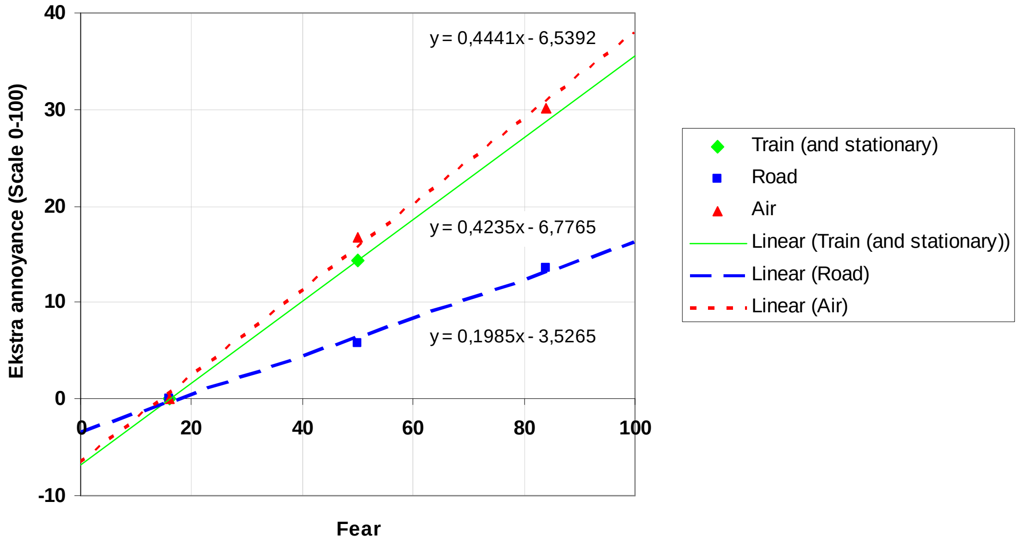

Figure 33
The extra noise annoyance (scale 0-100) caused by fear (scale 0-100) for transportation noise relative to the category "low fear". The (linear) validity range is 45-75 dB DNL

The data from Table 19 is shown in Figure 33.

The deviation. Δb_{fear} . from the mean annoyance score caused by deviations from the mean fear can be described as:

Aircraft: $\Delta b_{fear} = 0.4441 \cdot \text{fear} - 15.11$ Equation 16

Road: $\Delta b_{fear} = 0.1985 \cdot \text{fear} - 9.59$ Equation 17

Railway: $\Delta b_{fear} = 0.4235 \cdot \text{fear} - 6.78$ Equation 18

According to the data in Table 19, the mean fear is: 34 for aircraft, 48 for road traffic and 21 for railways.

Until now we there are found no data for stationary sources, such as industry and wind turbines. We anticipate that the fear pattern of such sources most likely will be closer to the fear properties of railways than to the fear properties of road traffic or aircrafts. As a consequence the extra annoyance caused by fear for stationary sources are calculated according to Equation 18.

From Equation 11 and Equation 19, Δf_{fear} can be found from the different noise sources:

$$\Delta f_{fear} = \frac{-\Delta b_{fear}}{a} \qquad \text{Equation 19}$$

The values of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 33 stems from traffic noise surveys with 1113-14373 respondents (see Table 19). The reliability is high: 80%. At the moment we don't have data for stationary noise sources but it seems reasonable that the effects on Δf are the same for these. The reliability is in these cases are set to 20%.

When a specific fear value is used instead of the average fear value, then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the low and high class of fear is stated in Table 20. The corresponding s_n-values for fear, s_{fear} can then be found from Table 1 by interpolation.

	%LA Δf_d	**%A Δf_d**	**%HA Δf_d**	**AS. EA Δf_d**
Air	6.11	6.11	5.94	8.10
Road	2.73	2.68	2.41	3.44
Rail	5.71	5.41	4.94	7.02
Industry	6.42	5.78	4.87	7.16
Shunting	6.37	6.66	6.35	7.98
Seasonal	5.52	4.73	4.80	5.96
Wind Turb.	3.10	3.14	3.27	3.25

Table 20
The Δf_d values corresponding to half the difference between the low and high class of fear (values 16 and 84 on a 0-100 fear scale).

When a specific fear value is used then the reliability factor Rel_{sn} for fear. Rel_{fear} is set to 20%.

7.8.2 Noise Sensitivity

Noise sensitivity is one of the factors that influence the relationship between noise exposure and reaction. According to [25] the correlation of noise sensitivity with subjective reactions to noise is in the order of 0.3, and it explains in the order of 9% of the variance in the reaction. The difference in noise annoyance between low and high noise sensitive persons (three categories: low. medium and high) was equal to the difference caused by an 11 dB change of the noise exposure (noise metric DNL). There is a weak or no relation between noise exposure and noise sensitivity. This indicates that noise annoyance and noise sensitivity are different factors and not only different ways of measuring noise annoyance.

Operational definitions of noise sensitivity are based on different types of questions:

1. self reported characterization of noise sensitivity
2. self-reported general attitudes toward noise
3. self-reported general reactions to noise in specific situations

A physiological method of measuring noise sensitivity is not available, because there is no theory specifying the relation between a physiological measure and classifications in the basis of answers to noise sensitivity questions. It should be noted that noise sensitive persons do only rate noise as being slightly louder for sound pressure levels above 75 dB [3].

A typical single item question of type 1 is: “In general. how sensitive to noise are you?”, with options “not at all”. “a little”. “moderately”. “considerably” and “extremely”.

In general a scale constructed from multiple items measuring the same attribute is more reliable than the response to a single item.

A questionnaire with a set of 21 noise sensitivity questions has been formulated by Weinstein [47], and a 9-item questionnaire has been formulated by Zimmer and Ellermeier. A comparison of the types of questions in the two questionnaires is given in Table 21.

Type of question	Weinstein	Zimmer/Ellerm.
1. Noise makes you behave different (choices and behaviour)	2	2
2. Noise disturbs you (at work. whwn sleeping or relaxing)	7	4
3. Acceptance of noise (tolerance. habituation)	9	
4. Notice noise (awareness. sensitivity)	2	3
5. Annoyance (annoyance. irritation. bothering)	2	
6. Well being after noise exposure		2

Table 21
Groups (types) and number of questions of each type for the 21 point Weinstein and the 9-item Zimmer/Ellermeier questionnaire for measuring noise sensitivity. Some questions may contribute to two groups.

As the Weinstein questionnaire originally is meant for another purpose it includes questions on noise annoyance. These should be excluded when we want to measure the influence of noise sensitivity on annoyance. Furthermore it includes questions on tolerance. The answers to such question may include other personality traits than noise sensitivity. Questions on annoyance and tolerance are not included in the Zimmer/Ellermeier questionnaire, and therefore we find this more suitable in relation to investigations of the relations between noise exposure and noise annoyance. Anyway, a high correlation (0.79) between the two scales is found, and for both there is a high degree of test-retest stability [48]. The test retest stability is better than for the single item question on noise sensitivity.

A translation from German into English and Danish of the Zimmer/Ellermeier questionnaire is given in appendix 11 and 12. Scores are 0-3 for each question with scales for questions 1, 3, 4, 7 and 9 reversed. The most sensitive persons will obtain a score on 27. The scores shall be multiplied by 100/27 for conversion to a 0-100 noise sensitivity scale. According to [25] the mean noise sensitivity is 47. This value is used for the further computations.

It should be noted that the influence on annoyance stated below stems from single item measurements of noise sensitivity.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 22.

	Noise sensitivity		
	Low	**Medium**	**High (67-100)**
Sensitivity category	0-32 (mean: 16)	33-66 (mean: 50)	67-100 (mean: 84)
Extra annoyance	0	6.8	16.0
Distribution	46%	32%	22%

Table 22
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "low sensitivity". The data are based on 15171 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean sensitivity based on the figures in the table is 42.

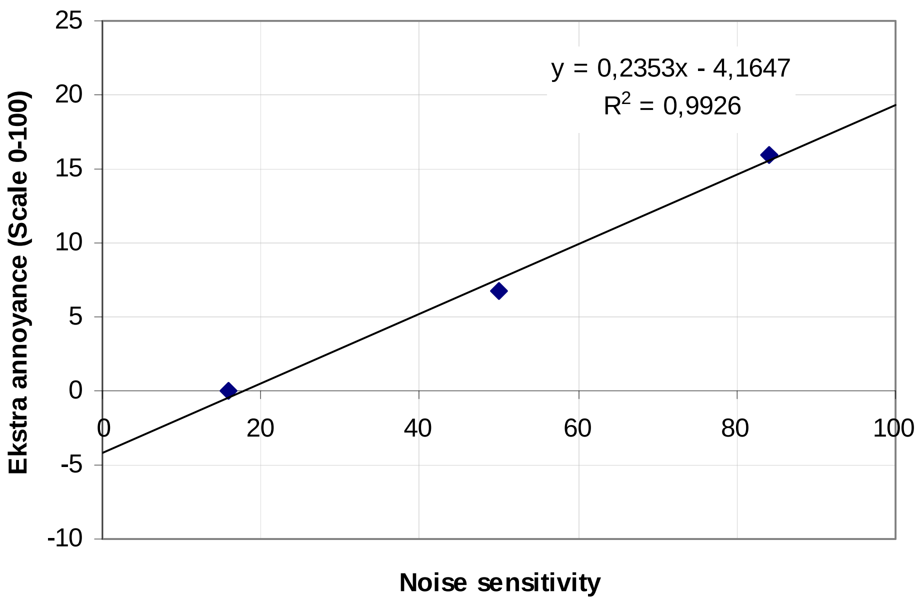

Figure 34
The extra noise annoyance (scale 0-100) caused by noise sensitivity (scale 0-100) for transportation noise relative to the category "low sensitivity". The data are based on 15171 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 22 is shown in Figure 34. It is seen from the figure. that the extreme difference in annoyance caused by different noise sensitivity is 23.5 on the 0-100 scale.

The deviation, $\Delta b_{noise\ sens}$. from the mean annoyance score caused by deviations from the mean noise sensitivity can be described as:

$$\Delta b_{noise\ sens} = 0.2353 \cdot \text{noise sensitivity} - 11.06 \quad \text{Equation 20}$$

From Equation 11 and Equation 20, $\Delta f_{noise\ sens}$ can be found:

$$\Delta f_{noisesens} = \frac{-\Delta b_{noisesens}}{a} = \frac{-0{,}2353 \cdot \text{noisesensitivity} + 11{,}06}{a} \quad \text{Equation 21}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 34 stems from traffic noise surveys with in total 15171 respondents. The reliability is high: 80%. At the moment we don't have data for other noise sources but it seems reasonable that the effects on Δf are the same for other sources and situations. The reliability in these cases is set to 20%.

When specific noise sensitivity is used instead of the average then the slope of the does-response curve is increased. see Section 6.6.1.

The Δf_d values corresponding to half the difference between the low and high class of noise sensitivity is stated in Table 23. The corresponding s_n values for noise sensitivity. $s_{noise\ sens}$ can then be found from Table 1 by interpolation.

	%LA	**%A**	**%HA**	**AS. EA**
	Δf_d. dB	**Δf_d. dB**	**Δf_d. dB**	**Δf_d. dB**
Air	3.24	3.24	3.15	4.29
Road	3.24	3.18	2.86	4.08
Rail	3.18	3.01	2.75	3.90
Industry	3.57	3.21	2.71	3.98
Shunting	3.54	3.70	3.53	4.43
Seasonal	3.06	2.63	2.67	3.31
Wind Turb.	1.72	1.75	1.82	1.81

Table 23
The Δf_d values corresponding to half the difference between the low and high class of noise sensitivity (values 16 and 84 on a 0-100 noise sensitivity scale).

When specific noise sensitivity is used then the reliability factor Rel_{sn} for noise sensitivity. $Rel_{noise\ sens}$ is set to 20%.

According to [25] there is an interaction between the noise level and the noise sensitivity. This interaction is not included in the model.

7.8.3 Age

Age has an effect on annoyance. It is not a linear function so it will not appear in data if linear regression is used as a tool.

The scale for age is simply the age of the persons in years.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 28.

	Age						
	10-19	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70+**
Mean of cat	15	25	35	45	55	65	75
Extra Ann	-5.6	-1.5	0	0.4	-0.7	-2.1	-4.2
Distribution	3%	18%	20%	19%	17%	15%	8%

Table 24
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "30-39". The data are based on 42496 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean age based on the figures in the table is 45.6 years.

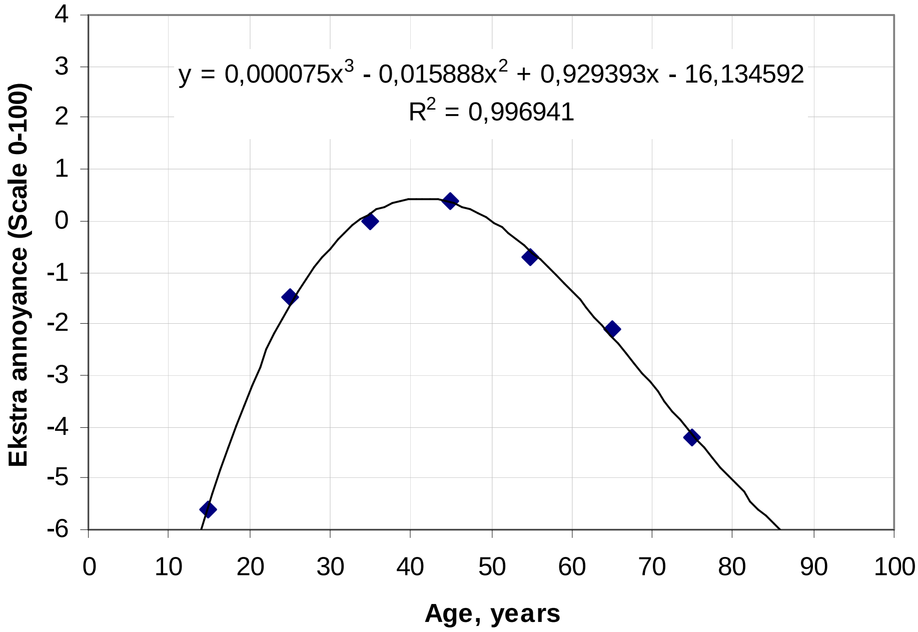

Figure 35
The extra noise annoyance (scale 0-100) caused by age for transportation noise relative to the category "30-39". The data are based on 42496 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 24 is shown in Figure 35. It is seen from the figure. that the extreme difference in annoyance caused by age is 4.6 on the 0-100 scale.

The deviation, Δb_{age}, from the mean annoyance score caused by deviations from the mean age of 45.6 years can be described as:

$$\Delta b_{age} = 0.000075*(age)^3-0.0159*(age)^2+0.929*age-16.415$$ Equation 22

From Equation 11 and Equation 22, Δf_{age} can be found:

$$\Delta f_{age} = \frac{-\Delta b_{age}}{a} = \frac{-0.000075 \cdot age^3 + 0.0159 \cdot age^2 - 0,929 \cdot age + 16.415}{a}$$ Equation 23

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 37 stems from traffic noise surveys with in total 42496 respondents. The reliability is high: 80%. At the moment we don't have data for other noise sources than transportation, but it seems reasonable to assume that the effects on Δf is of the same magnitude as for other sources and situations. The reliability is in these cases set to 20%.

When a specific age group is used instead of the average then the slope of the dose-response curve is increased, see Section 6.6.1.

The Δf_d-values corresponding to half the difference between 20 and 40 years of age is stated in Table 29. The corresponding s_n-values for age, s_{age},can then be found from Table 3 by interpolation.

	%LA Δf_d	**%A Δf_d**	**%HA Δf_d**	**AS. EA Δf_d**
Air	0.75	0.75	0.73	0.99
Road	0.75	0.73	0.66	0.94
Rail	0.73	0.70	0.64	0.90
Industry	0.82	0.74	0.63	0.92
Shunting	0.82	0.86	0.82	1.02
Seasonal	0.71	0.61	0.62	0.77
Wind Turb.	0.40	0.40	0.42	0.42

Table 25
The Δf_d-values corresponding to half the difference between 20 and 40 years according to Equation 23.

When a specific age group is used then the reliability factor Rel_{sn} for age. Rel_{age} is set to 20%.

7.8.4 Dependency on Noise Source

Persons who are economically dependent on the transport activities that cause the noise seem to be slightly less annoyed by the noise from it.

The question behind the data in Table 26 ("Are you or anyone in the family employed at this time at ...) gives only two answering categories: Yes or no. Anyway the underlying variable may be continuous; If the one or more persons are employed the family may be more or less dependent. Therefore this variable is treated like other continuous variables as e.g. noise sensitivity in this model. The answer "Yes" is set to the average of the interval 50-100 on the 0-100 dependency scale. For the answer "No" we must anticipate that there is no direct dependency, so we must anticipate the value is zero for most of the respondents and a higher value for only a few who may be indirectly dependent. In the table the "No" is set to zero.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 26.

	Dependency	
	No	**Yes**
Dependency	0	50-100 (mean: 75)
Extra annoyance	0	-3.6
Distribution	91%	9%

Table 26
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "No". The data are based on 21516 respondents. The (linear) validity range is 45-75 dB DNL

The weighted mean dependency based on the figures in the table is 6.8.

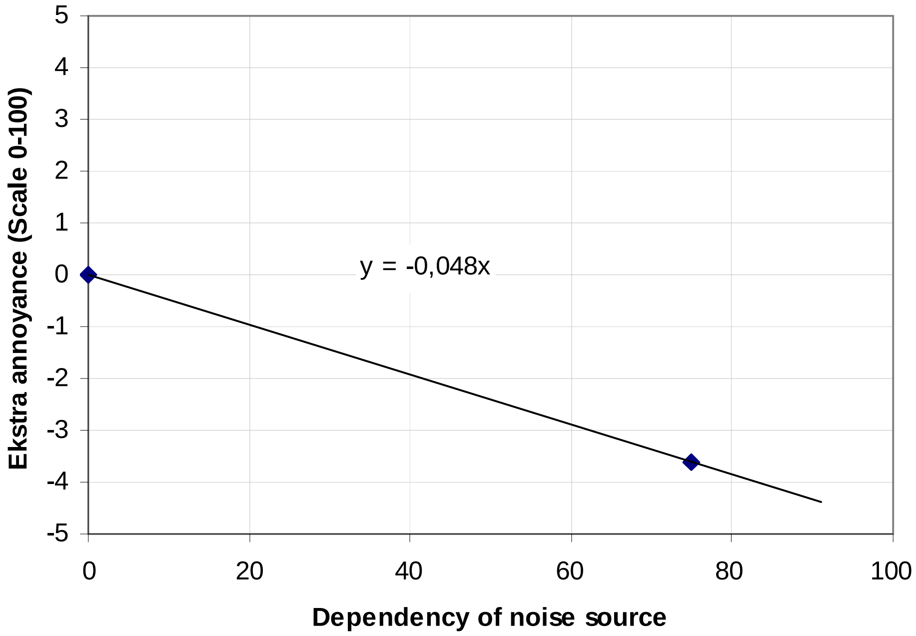

Figure 36
The extra noise annoyance (scale 0-100) caused by dependency (scale 0-100) for transportation noise relative to the category "Medium". The data are based on 21516 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 26 is shown in Figure 36. It is seen from the figure. that the extreme difference in annoyance caused by different dependency is 4.8 on the 0-100 scale.

The deviation, $\Delta b_{dependency}$, from the mean annoyance score caused by deviations from the mean dependency can be described as:

$$\Delta b_{dependency} = -0.048 \cdot \text{dependency} + 0.32 \qquad \text{Equation 24}$$

From Equation 11 and Equation 34, $\Delta f_{dependency}$ can be found:

$$\Delta f_{dependency} = \frac{-\Delta b_{dependency}}{a} = \frac{0.048 \cdot \text{dependency} - 0.32}{a} \qquad \text{Equation 25}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 36 stems from traffic noise surveys with in total 21516 respondents on the dependency. The reliability is high: 80%. At the moment we don't have data for other noise sources than transportation so in lack of data we will assume that the effects on Δf is of the same magnitude the for other sources and situations. The reliability is in these cases set to 10%.

When a specific dependency is used instead of the average then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the "No" and "Yes" dependency is stated in Table 27. The corresponding s_n values for dependency. $s_{dependency}$ can then be found from Table 1 by interpolation.

	%LA Δf_d	**%A** Δf_d	**%HA** Δf_d	**AS. EA** Δf_d
Air	0.73	0.73	0.71	0.97
Road	0.73	0.71	0.64	0.92
Rail	0.71	0.68	0.62	0.88
Industry	0.80	0.72	0.61	0.89
Shunting	0.80	0.83	0.79	1.00
Seasonal	0.69	0.59	0.60	0.74
Wind Turb.	0.39	0.39	0.41	0.41

Table 27
The Δf_d values corresponding to half the difference between the "NO" and "Yes" category of dependency (values 0 and 75 on a 0-100 dependency scale).

When a specific dependency is used then the reliability factor Rel_{sn} for dependency. $Rel_{dependency}$ is set to 20%.

According to [41] the effect of an economical interest in the running of a wind turbine on the annoyance of the noise is only at the border of being significant. This effect is not included in the model.

7.8.5 Education

The education level is divided into four categories:

1st: competed primary school

2nd: Completed secondary school. high school

High: Completed higher education that does not lead to a first university degree

University: University first degree and postgraduate level

These four categories are transformed into a 0-100 education level scale.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 28.

	Education			
	1st	**2nd**	**High**	**University**
Education level	0-24 (mean: 12)	25-49 (mean: 37)	50-74 (mean: 62)	75-100 (mean: 87.5)
Extra annoyance	-1.0	0	0.7	2.3
Distribution	35%	45%	11%	9%

Table 28
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "2nd level". The data are based on 32254 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean education level based on the figures in the table is 36.

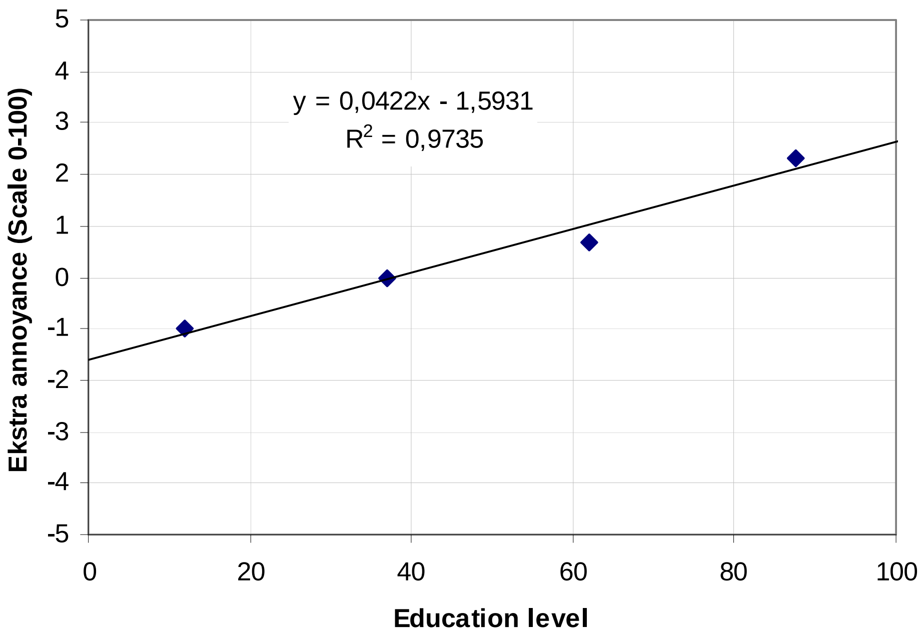

Figure 37
The extra noise annoyance (scale 0-100) caused by education level (scale 0-100) for transportation noise relative to the category "2nd". The data are based on 32254 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 28 is shown in Figure 37. It is seen from the figure. that the extreme difference in annoyance caused by different level of education is 4.2 on the 0-100 scale.

The deviation. $\Delta b_{education}$. from the mean annoyance score caused by deviations from the mean education can be described as:

$$\Delta b_{education} = 0.0422 \cdot \text{education} - 1.5931 \qquad \text{Equation 26}$$

From Equation 11 and Equation 26, $\Delta f_{education}$ can be found:

$$\Delta f_{education} = \frac{-\Delta b_{education}}{a} = \frac{-0.0422 \cdot \text{education} + 1.5931}{a} \qquad \text{Equation 27}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 37 stems from traffic noise surveys with in total 32254 respondents. The reliability is high: 80%. At the moment we don't have data for other noise sources than transportation but it seems reasonable that the effects on Δf is of the same magnitude the for other sources and situations. The reliability is in these cases set to 20%.

When a specific education is used instead of the average then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the "1st" and the University class of education is stated in Table 29. The corresponding s_n values for education. $s_{education}$ can then be found from Table 3 by interpolation.

	%LA Δf_d	**%A** Δf_d	**%HA** Δf_d	**AS. EA** Δf_d
Air	0.64	0.64	0.63	0.86
Road	0.64	0.63	0.57	0.81
Rail	0.63	0.60	0.55	0.78
Industry	0.71	0.64	0.54	0.79
Shunting	0.70	0.74	0.70	0.88
Seasonal	0.61	0.52	0.53	0.66
Wind Turbines	0.34	0.35	0.36	0.36

Table 29
The Δf_d values corresponding to half the difference between the "1st" and the University class of education (values 12 and 87.5 on a 0-100 education scale).

When a specific education is used, then the reliability factor Rel_{sn} for education, $Rel_{education}$, is set to 20%.

7.8.6 Household Size

The number of persons in a household has a weak an effect on annoyance. It is not a linear function so it will not show up if linear regression is used as a tool.

The scale for household size is simply the number of persons ind the household.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 28.

	Household size				
	1	**2**	**3**	**4**	**5+**
Extra Ann	-2.7	0	0.1	-0.6	-0.5
Distribution	14%	30%	20%	19%	17%

Table 30
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "2". The data are based on 27241 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean household size based on the figures in the table is 3.0 persons.

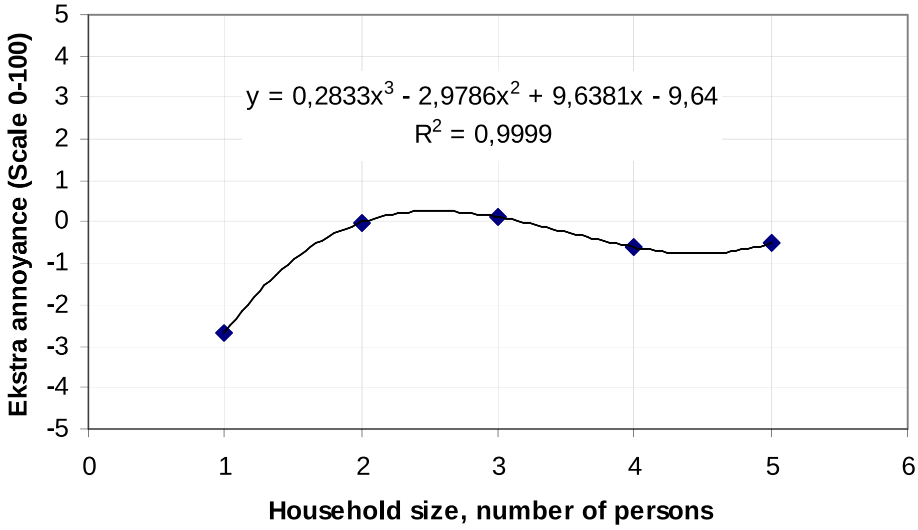

Figure 38
The extra noise annoyance (scale 0-100) caused by household size for transportation noise relative to the category "2". The data are based on 27241 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 30 is shown in Figure 38. It is seen from the figure, that the extreme difference in annoyance caused by household size is 2.7 on the 0-100 scale.

The deviation, $\Delta b_{\text{household size}}$, from the mean annoyance score caused by deviations from the mean household size of 3.0 persons can be described as:

$$\Delta b_{\text{household size}} = 0.2833*(\text{household size})^3 - 2.9786*(\text{household size})^2 + 9.6381*(\text{household size}) - 9.74 \qquad \text{Equation 28}$$

The relation will hold for the range 1-5 persons. For more than 5 persons the value 5 is used. Non integer input values are relevant for the average number of persons in a group of households.

From Equation 11 and Equation 28, $\Delta f_{\text{household size}}$ can be found:

$$\Delta f_{\text{age}} = \frac{-\Delta b_{\text{age}}}{a} = \frac{-0.2833 \cdot \text{householdsize}^3 + 2.9786 \cdot \text{householdsize}^2 - 9.6381 \cdot \text{householdsize} + 9.74}{a}$$

Equation 29
The equation is valid for household size 1-5. For household size > 5, household size = 5.

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 38 stems from traffic noise surveys with in total 27241 respondents. The reliability is high: 80%. At the moment we don’t have data for other noise sources than transportation but it seems reasonable to assume that the effects on Δf is of the same magnitude for other sources and situations. The reliability is in these cases set to 20%.

When a specific household size group is used instead of the average then the slope of the does-response curve is increased, see section 6.6.1.

The Δf_d values corresponding to half the difference between household sizes of 1 and 3 persons of is stated in Table 29. The corresponding s_n-values for household size, $s_{household\ size}$, can then be found from Table 1 by interpolation.

	% LA Δf_d	**% A** Δf_d	**% HA** Δf_d	**AS, EA** Δf_d
Air	0.57	0.57	0.55	0.76
Road	0.57	0.56	0.50	0.72
Rail	0.56	0.53	0.48	0.69
Industry	0.63	0.56	0.48	0.70
Shunting	0.62	0.65	0.62	0.78
Seasonal	0.54	0.46	0.47	0.58
Wind turbines	0.30	0.31	0.32	0.32

Table 31
The Δf_d values corresponding to half the difference between household sizes of 1 and 3 persons according to Equation 29.

When a specific household size group is used, then the reliability factor Rel_{sn} for household size, $Rel_{household\ size}$, is set to 20%.

7.8.7 Use of Noise Source

Persons who often use a specific means of transportation are slightly less annoyed by the noise from it.

The question about the use of transportation is: "Looking back at the last 12 month. how many times have you ..." The answers could be given in a number of categories: Never. seldom. ...or the categories could be associated with the number of times the mean of transportation has been used. The answers in the categories are then transformed into an 0-100 scale for use of the mean of transportation

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 22.

	Use of noise source			
	Not	**Low**	**Use**	**High**
Use category	0-24 (mean: 12)	25-49 (mean: 37)	50-74 (mean: 62)	75-100 (mean: 87.5)
Extra annoyance	0	-0.9	-1.3	-2.2
Distribution	40%	13%	29%	18%

Table 32
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "no use". The data are based on 16800 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean use of sound source based on the figures in the table is 43.

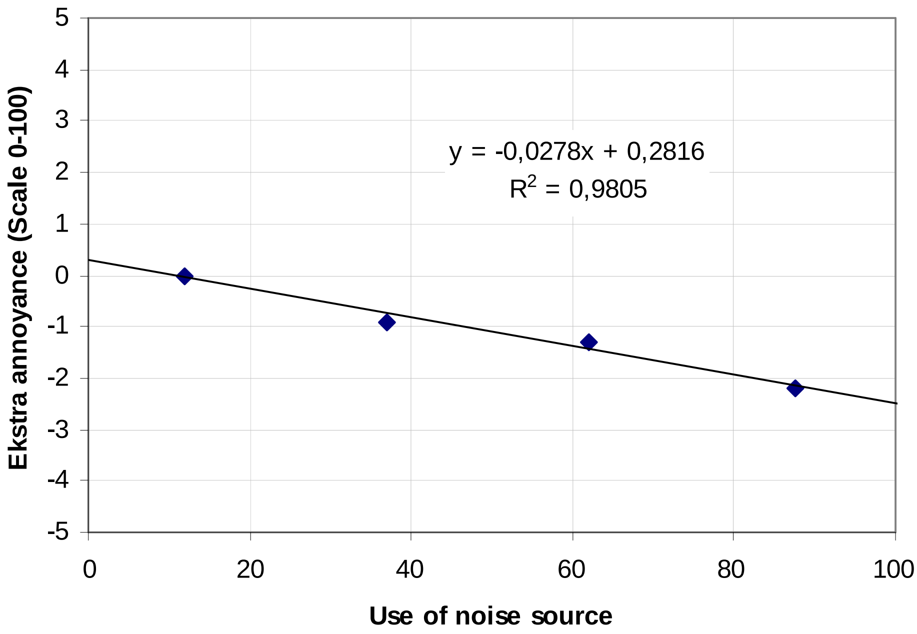

Figure 39
The extra noise annoyance(scale 0-100) caused by use of sound source (scale 0-100) for transportation noise relative to the category "not used". The data are based on 16800 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 32 is shown in Figure 39. It is seen from the figure. that the extreme difference in annoyance caused by different use of sound source is 2.8 on the 0-100 scale.

The deviation. Δb_{use} . from the mean annoyance score caused by deviations from the mean use of sound source can be described as:

$$\Delta b_{use} = -0.0278 \cdot \text{use of sound source} + 0.2816 \qquad \text{Equation 30}$$

From Equation 11 and Equation 20, Δf_{use} can be found:

$$\Delta f_{use} = \frac{-\Delta b_{use}}{a} = \frac{0.0278 \cdot use - 0.2816}{a} \qquad \text{Equation 31}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 39 stems from traffic noise surveys with in total 16800 respondents. The reliability is high: 80%. At the moment we don't have data for other noise sources but it seems reasonable that the effects on Δf are the same for other sources and situations. The reliability is in these cases set to 20%.

When a specific use of sound source is used instead of the average then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the "not used" and high class of use of sound source is stated in Table 33. The corresponding s_n values for use of sound source. s_{use} can then be found from Table 3 by interpolation.

	%LA Δf_d	**%A Δf_d**	**%HA Δf_d**	**AS, EA Δf_d**
Air	0.42	0.42	0.41	0.56
Road	0.42	0.42	0.38	0.53
Rail	0.42	0.39	0.36	0.51
Industry	0.47	0.42	0.35	0.52
Shunting	0.46	0.49	0.46	0.58
Seasonal	0.40	0.34	0.35	0.43
Wind turbines	0.23	0.23	0.24	0.24

Table 33
The Δf_d-alues corresponding to half the difference between the "not used" and high class of use of sound source (values 12 and 87.5 on a 0-100 use of sound source scale).

When a specific use of sound source is used, then the reliability factor Rel_{sn} for use of sound source. Rel_{use} is set to 20%.

7.8.8 Home Ownership

People who own their home are more concerned about noise than other. This has a (small) effect on the annoyance. As illustrated in Figure 6 this effect may be caused by concern about devaluation of the home.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 34.

	Home ownership	
	Renter	**Owner**
Home ownership	0	100
Extra annoyance	0	2.3
Distribution	44%	56%

Table 34
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "Renter ". The data are based on 33343 respondents. The (linear) validity range is 45-75 dB DNL.

The weighted mean home ownership based on the figures in the table is 56. corresponding to that 56% own their home.

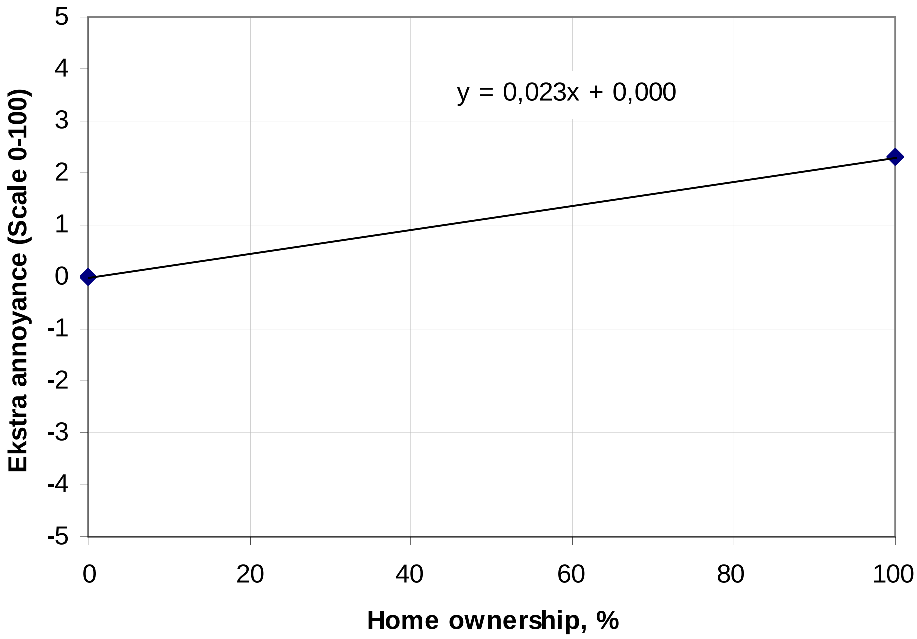

Figure 40
The extra noise annoyance (scale 0-100) caused by home ownership for transportation noise relative to the category "Renter"(=0). The data are based on 33343 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 34 is shown in Figure 40. It is seen from the figure. that the extreme difference in annoyance caused by different home ownership is 2.3 on the 0-100 scale.

The deviation, $\Delta b_{home\ ownership}$, from the mean annoyance score caused by deviations from the mean home ownership can be described as:

$$\Delta b_{home\ ownership} = 0.023 \cdot \text{home ownership} - 1.29 \qquad \text{Equation 32}$$

From Equation 11 and Equation 32, $\Delta f_{home\ ownership}$ can be found:

$$\Delta f_{hom\,eownership} = \frac{-\Delta b_{hom\,eownership}}{a} = \frac{-0.023 \cdot hom\,eownership + 1.29}{a} \qquad \text{Equation 33}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 40 stems from traffic noise surveys with in total 33343 respondents on the home ownership. The reliability is high: 80%. At the moment we don't have data for other noise sources than transportation but it seems realistic to assume that the effects on Δf is of the same magnitude the for other noise sources. The reliability is in these cases set to 20%.

When a specific home ownership is used instead of the average ownership then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the "Renter" and "Owner" is stated in Figure 28. The corresponding s_n values for home ownership. $s_{home\ ownership}$ can then be found from Table 1 by interpolation.

	%LA Δf_d	%A Δf_d	%HA Δf_d	AS, A Δf_d
Air	0.47	0.47	0.45	0.62
Road	0.47	0.46	0.41	0.59
Rail	0.46	0.43	0.39	0.56
Industry	0.51	0.46	0.39	0.57
Shunting	0.51	0.53	0.51	0.64
Seasonal	0.44	0.38	0.38	0.48
Wind Turb.	0.25	0.25	0.26	0.26

Table 35
The Δf_d values corresponding to half the difference between the "Renter" and "Owner" category of home ownership (values 0 and 100 on a 0-100 home ownership scale)

When a specific home ownership is used, then the reliability factor Rel_{sn} for home ownership, $Rel_{home\ ownership}$, is set to 20%.

7.8.9 Occupation

The occupational status is not self evident and involves a subjective judgment. Three categories are used: Low. medium and high. The status is determined for the member with the highest status in the household. Unemployed persons were excluded for the analysis.

These three categories are transformed into a 0-100 occupational status scale.

In [26] the extra annoyance (on the expected annoyance EA 0-100 scale) is estimated as shown in Table 36.

	Occupational status		
	Low	**Medium**	**High**
Occupational status	0-32 (mean: 16)	33-66 (mean: 50)	67-100 (mean: 84)
Extra annoyance	-0.9	0	0.7
Distribution	24%	42%	34%

Table 36
Extra noise annoyance (scale 0-100) for transportation noise relative to the category "2nd". The data are based on 27018 respondents. The (linear) validity range is 45-75 dB DNL

The weighted mean occupational status based on the figures in the table is 53.

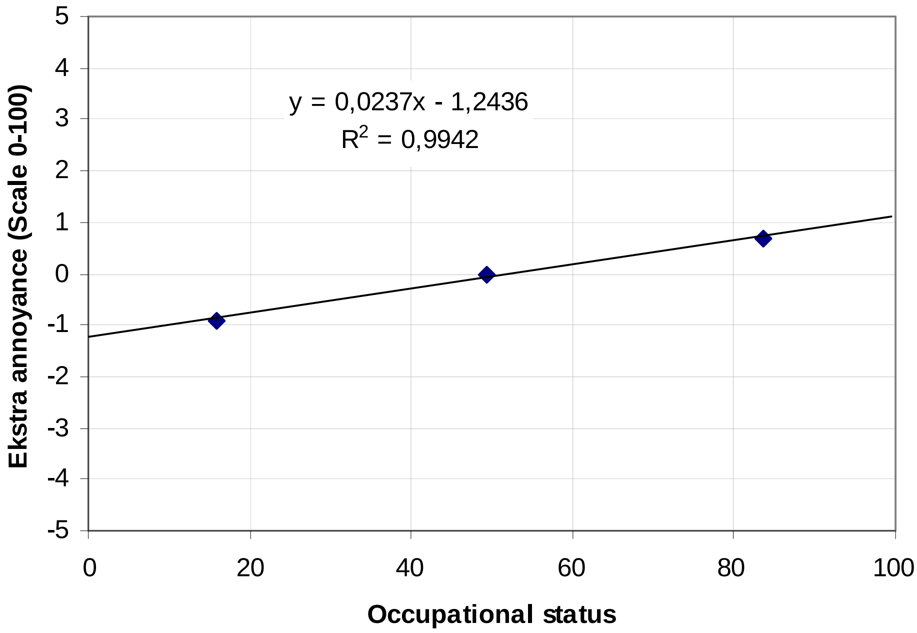

Figure 41
The extra noise annoyance (scale 0-100) caused by occupational status (scale 0-100) for transportation noise relative to the category "Medium". The data are based on 27018 respondents. The (linear) validity range is 45-75 dB DNL.

The data from Table 36 is shown in Figure 41. It is seen from the figure that the extreme difference in annoyance caused by different occupational status is 2.4 on the 0-100 scale. This is less than the effect of education, which may be caused by the more accurate and unambiguous classification of the education level.

The deviation, $\Delta b_{occupation}$, from the mean annoyance score caused by deviations from the mean occupational status can be described as:

$$\Delta b_{occupation} = 0.0237 \cdot \text{occupational status} - 1.2436 \qquad \text{Equation 34}$$

From Equation 11 and Equation 34, $\Delta f_{occupation}$ can be found:

$$\Delta f_{occupation} = \frac{-\Delta b_{occupation}}{a} = \frac{-0.0237 \cdot \text{occupation} + 1.2436}{a} \qquad \text{Equation 35}$$

The value of a can be found in Table 1 for different noise sources and for different parameters for annoyance.

The data in Figure 41 stems from traffic noise surveys with in total 27018 respondents on the occupational status. The reliability is high: 80%. At the moment we do not have data for other noise sources than transportation but it seems reasonable that the effects on Δf is of the same magnitude the for other sources and situations. The reliability is in these cases set to 20%.

When a specific occupational status is used instead of the average then the slope of the does-response curve is increased, see Section 6.6.1.

The Δf_d values corresponding to half the difference between the low and high occupational status is stated in Table 37. The corresponding s_n values for occupational status. $s_{occupation}$ can then be found from Table 3 by interpolation.

	%LA Δf_d	**%A** Δf_d	**%HA** Δf_d	**AS. EA** Δf_d
Air	0.33	0.33	0.32	0.43
Road	0.33	0.32	0.29	0.41
Rail	0.32	0.30	0.28	0.39
Industry	0.36	0.32	0.27	0.40
Shunting	0.36	0.37	0.36	0.45
Seasonal	0.31	0.26	0.27	0.33
Wind Turb.	0.17	0.18	0.18	0.18

Table 37
The Δf_d values corresponding to half the difference between low and high category of occupational status (values 16 and 84 on a 0-100 occupational status scale).

When a specific occupational status is used then the reliability factor Rel_{sn} for occupational status. $Rel_{occupation}$ is set to 20%.

7.8.10 Gender

Men and women react in a similar way to transportation noise. so the gender has no effect on noise annoyance.

7.8.11 Control

The perceived control over the sound source. (i.e. if the person exposed to the noise has control over the source or is the user of it) may have a major influence on the annoyance.

So far the model is based on surveys on the reaction to environmental noise where the individual respondents rarely can do anything about the noise sources.

As no data are found for the influence of the possibility of controlling the noise source it it not part of the model although it is believed to be an important moderator in general.

7.8.12 Attitude

The attitude to the sound source may be seen as a number of reasons each of which may moderate the annoyance. It is chosen to synthesise these reasons into one moderator called attitude.

It is the thought that a questionnaire may be constructed to cover the issues mentioned in this section. The answers may then be combined into a single number after the same principles as used for the noise sensitivity questionnaire (see 11 Appendix).

The attitudinal issues may be social or personal. Social and general characteristics are linked to noise situations shared to a considerable degree between the individuals of a society: railway systems are generally evaluated more positively that airline systems. because they are perceived as being less dangerous to the general public. Social characteristics are thought to be the result of a social development shared by larger groups of the society. Some factors will appear both as social and as personal factors. Social characteristics can be used for general annoyance evaluations and for noise/annoyance abatement programs.

Social attitudinal factors are such as:

- social evaluation of the source being unhealthy
- the source is important and useful for the society
- Will the source spoil the nature or the wild life
- the source is giving less air pollution (wind power)
- Does the noise source fit in the history of the area?

For airport noise the the correlation coefficients of annoyance with importance of the noise has found to be 0.15 to -0.28 i.e. a fraction of explained variance R^2 = 2-8% [10]. For wind turbines the significance of wind power for the annoyance was R^2 = 13% [41].

Mainly personal attitudinal factors are:

- Attitude to the specific sound source in the specific neighbourhood (Do I want it here? NIMBY – Not In My Back Yard)
- Fear of or belief that the noise source has harmful effects. the most important non acoustic moderator according to [10]
- Feeling that the noise annoyance is preventable
- Did we have influence on the planning process?
- Detailed knowledge about the sound source
- Perceived fairness of the authorities or the source owners in the planning process

– Trust or misfeasance to source authorities (noise abatement programs will be more efficient in reducing the annoyance if the inhabitants trust the authorities [10]).

More information may be found in [17] and [44].

As it seen above a number of different issues are relevant for the attitude so a sound source. It may be difficult to find the influence for each of these on the dose-response curve. Therefore one single number (e.g. ranging from 0 to 100) that describes the attitude to a sound source may be more useful. An untested draft for a questionnaire on attitude is given in 13 Appendix.

The attitudinal factor is not yet part of the model.

7.8.13 Personal Situation and Personal Capabilities

The annoyance is also likely to be moderated by the person situations such as the stress level (on the workplace and at home) the persons coping capacity and the satisfaction with residential aspects and with life in general.

No data for these effects have been found and it is not included in the model.

7.9 Effect of Moderators

In box 9 in Figure 19 the combined effect of the moderators are expressed as horizontal displacements and as a change in the slope of the norm curves described in section 7.2. The magnitude of each of these effects are described and quantified in sections 7.3to 7.8

7.10 Level-Annoyance Logistic Function

In box 10 in Figure 19 the specific logistic functions are defined. Information on this can be found in sections 6 and 7

7.11 Immediate Annoyance

The immediate annoyance is defined in Section 3.3.4 as the annoyance of a specified stimulus in a specified context for specified persons when the noise actually is present during or immediately before the evaluation of that particular noise.

It is typically the immediate annoyance (potential) which is measured in experiments (see remark in Section 3.2).

7.12 Integration over Time

Box 12 in Figure 19 represents integration over time of the immediate annoyance.

7.13 Accumulated Specific Annoyance

The accumulated specific annoyance is defined in Section 3.3.4 as the annoyance of a specified stimulus in a specified context for specified persons integrated over time and experiences.

7.14 Integration over Activities

A part of the context is the activities of the exposed persons. How annoyed a persons are depends on the task or leisure situation. Sleep is also a sort of activity.

For the home situation we are normally interested in the annoyance averaged over different home activities. Sleep disturbance is an exception from this. For an office situation we may want to distinguish between mind work and manual work.

The activity is part of the context.

7.15 Integration over Specified Locations

For the home situation the context may be indoor (e.g. in rooms facing a noisy road or the opposite. a room behind the "silent facade"). or outdoor in a garden or at a balcony. The noise exposure at different locations at home is usually not the same.

When we integrate over the specified locations "At home" we get the average response for home locations.

7.16 Integration over generalised personal factors

This box in Figure 19 represents an integration over the personal factors specified in Section 7.8.

7.17 Global Annoyance

The global annoyance (for environmental noise also called the community response to noise) is defined in Section 3.3.3 as the average response of large groups of persons at certain noise levels. The global annoyance expresses the average holistic experiences of a large group of persons over time, activities and locations without reference to specific incidents and contexts.

The norm curves in section 7.2 express the global annoyance.

8. Overview of Effects and Parameters in the Model

Table 38 gives an overview of most of the factors and moderators of relevance for the annoyance reaction mentioned in the preceding sections.

Sources Road Air Train Wind turbines Industry Seasonal industry Shunting yard Neighbors Irrelevant speech Office equipment Ringing phones **Locations** At home Office Recreational (park) Recreational (free nature) **Activities** Average home activities Sleeping Conversation Average office activities Mental work Manual work **Time of day** Day Evening Night Average, L_{den} **X-parameters** L_{den} L_{Night} L_{Aeq} $L_{Amax.F}$ Privacy **Y-parameters** AS EA % HA % A % LA $L_{den,AeqR}$ ASD ESD % HSD % SD % LSD	**Sound propagation** ***Sound insulation*** Facade To neighbours **Perceived acoustic attributes** ***Source related*** $L_{Amax.F}$ Tones. Dlta or K_T Impulses. P or K_I Number of events Duration per event Calm intervals Background noise level Information content Low frequency content Whirr of wings Loudness Sharpness Roughness Fluctuation strength ***Masking*** Office appliances Babble noise Wind noise in vegetation ***Speech intelligibility*** STI? **Non acoustic factors** ***Source related*** Smell & air pollution Visual impact in general Visibility of source from home Size (visual angle) Vibrations Generation of more traffic ***Working environment*** Comfort ***Noise barrier*** Visual appearance of noise barrier ***Time of year*** Average (default) January February March …	**Location** ***Type of area*** Average Town Multi-storeyed suburb Detached housing Industrial ***Home ownership*** Renter Owner ***In or out*** Average Indoor stay Outdoor stay ***Sound Scape*** Silent side Neighbourhood levels ***Office data*** Reverberation time Size Number of persons **Personal Moderators** ***Personal factors*** Fear Noise sensitivity Age Dependency on sound source Education Household size Use of noise source Occupation Gender ***Expectations*** Acoustic quality Expected duration Expected noise increase ***Control*** Perceived control over sound source ***Attitude to source*** Importance of the source Attitude to such sound sources Attitude to the specific sound source Learning impairment Influence on planning Trust to source administrators Appropriateness of source in area Perceived health risk Visual disturbance ***Situation and coping*** Stress level and satisfaction Coping capacity

Table 38
Overview of factors and moderators of relevance for annoyance.

9. Sleep Disturbance

If the noise levels are high enough, awakenings will occur. Mainly three types of sleep disturbance are reported in the literature:

- Behavioural awakenings: awakenings that are followed by an action (like pressing a button) from the sleeper.
- Sleep stage changes, found from EEG patterns
- Increased motility (body movements during sleep)
- Self-reported (chronic) sleep disturbances

The reference for this report (and the model) will be the self reported sleep disturbance.

9.1 Indicator for Night Time Noise

According to [6] the L_{Aeq} value for the night outdoors at the most exposed facade. L_{night} is chosen as indicator for the night time noise level.

L_{night} do not include reflections of the façade for which they are assessed so that they describe the incident sound at the façade. L_{night} is defined as the A-weighted "average" sound level. over a year for the period 23 – 7h (he lenght of the night time should minimum be 8 hours) at the façade of a dwelling with the highest L_{den}.

For mapping purposes L_{night} shall be determined at the facade at a height of 4 meters. For more detailed evaluations at the position of the bedroom.

9.2 Scales for Sleep Disturbance

Different categories (of severeness) of self reported sleep disturbance may be expressed on a 0-100 scale in a similar way as described noise annoyance and phenomenon's related to that. see sections 5 and 7. Similar to annoyance, sleep disturbance can be expressed as follows [29]:

- %HSD. the percentage of highly sleep disturbed is the percentage of people giving answers in categories above 72 (the top 27-29%) of the response scale
- %SD. the percentage of sleep disturbed is the percentage of people giving an answer in categories above 50
- %LSD The percentage of (at least) lowly sleep disturbed is the percentage of people giving an answer in categories above 28

9.3 Norm Curves for Sleep Disturbance

For each type of noise source norm curve for sleep disturbance may be found. The norm curve gives the relation between the general exposure (expressed e.g. as L_{night}-values) and the sleep disturbance. The norm curve represents an average situation. which is relevant for the actual source. Examples of norm curves are shown in Figure 22.

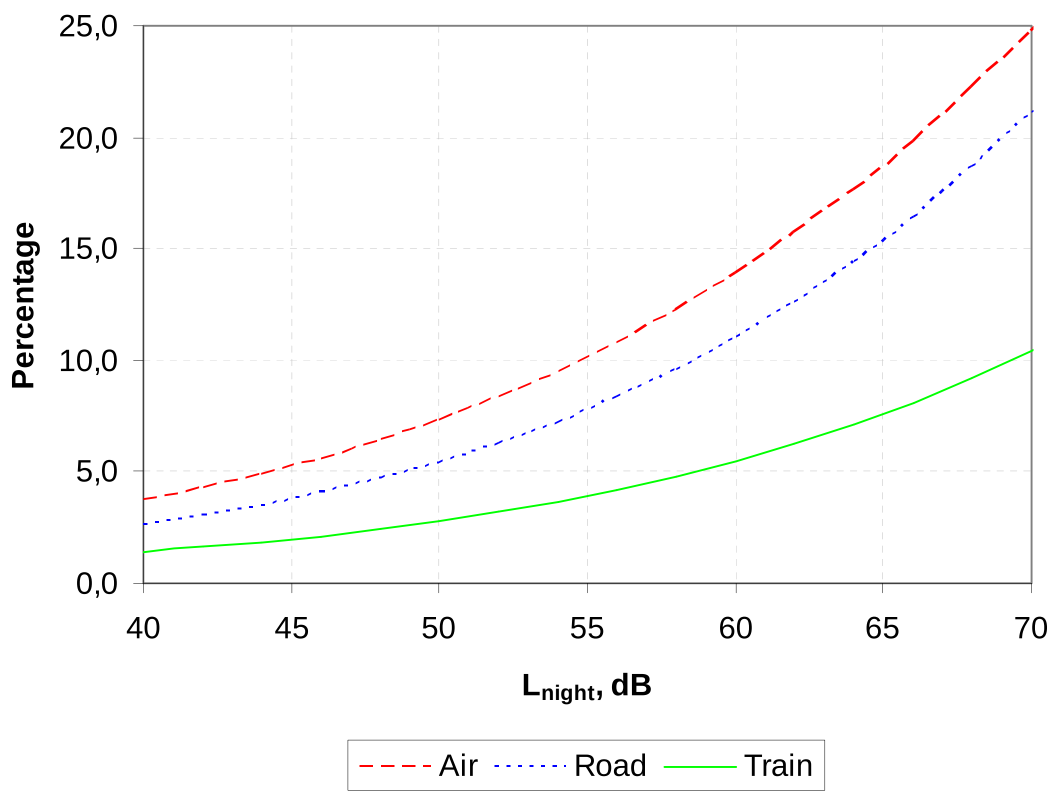

Figure 42
Norm curves for the relation between Noise level (L_{night}) and % Highly sleep disturbed as for aircraft, road and train noise according to [6].

The norm curves describe the general chronic sleep disturbance. They are a suitable basis for policy making and when exposure limits for dwellings and noise abatement measures are discussed.

The norm curves do not predict the actual sleep disturbance for particular individuals or groups. They do not take local circumstances into account.

9.4 Approximations to Norm Curves and Data

In [6] the sleep disturbance is described by second order polynomials. Within the level range of 40-70 dB (which is extrapolated from data in the range 45-65 dB). These polynomial approximations are acceptable in a limited range. but their fundamental properties deviate from the s-shaped function of the dosis response relationship. see Section 7.2.2. Outside a limited range the the order polynomials are not usable. as they may give values below 0 and above 100%

The logistic approximations (see Section 6.1) are in agreement with the fundamental properties of the dose response reaction and extrapolations outside the restricted range are likely to give probable results.

The difference between values for sleep disturbance calculated from second order polynomials (based on [6]) and the logistic curves is shown in table Table 39. It is seen that within the range where data exist (45-65 dB) the differences are insignificant.

Differences in %-point		**Mean**	**Max**
% LSD	Air	0.2	0.3
	Road	0.2	0.4
	Rail	0.1	0.3
% SD	Air	0.2	0.3
	Road	0.2	0.4
	Rail	0.1	0.2
% HSD	Air	0.2	0.3
	Road	0.2	0.3
	Rail	0.1	0.2

Table 40
Absolute values of the differences between polynomial curves in [6] and the logistic curve in the range 45-65 dB L_{night}. The logistic and polynomial curves are stated in the succeeding sections.

The models in the "Genlyd" project are based on the logistic curves.

9.5 Aircraft

The polynomial curves from [6] and the logistic norm curves for sleep disturbance as defined in Section 9.1 to 9.3 are given for aircraft noise in Table 41 and Figure 43.

Second order polynomial approximation	
%LSD	$4.465-0.411*L_{night}+0.01395*L_{night}^{2}$
%SD	$13.714-0.807*L_{night}+0.01555*L_{night}^{2}$
%HSD	$18.147-0.956*L_{night}+0.01482*L_{night}^{2}$

Logistic curve: $\%XSD = \frac{100}{1+e^{-s(L_{night}-f)}}$	s	f
%LSD	0.0632	73.5
%SD	0.0667	79.8
%HSD	0.0715	85.5

Table 41
Aircraft noise. Second order curves and logistic norm curves (lower table giving the pecentage of “Lowly sleep disturbed” (%LSD). “Sleep disturbed” (%´SDA. “Highly sleep disturbed” (%HSD).

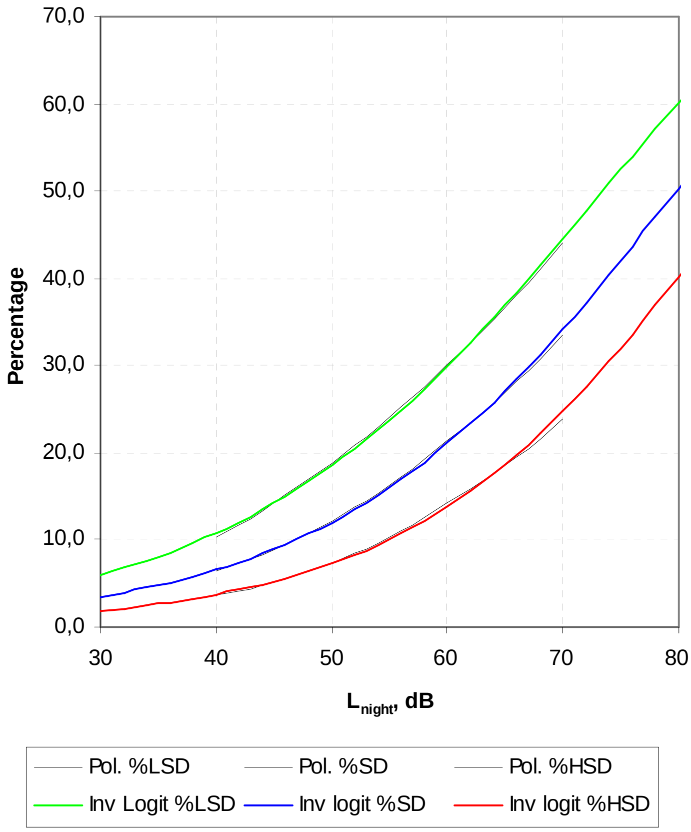

Figure 43
Aircraft noise.Estimated and approximated curves for the percentage of highly sleep disturbe (%HSD) sleep disturbed (%SD) and Little annoyed (%LSD) for aircraft noise.

The norm curves are valid in the range 40-70 dB L_{night}. In this range the reliability is set to 75%. The reason for not setting the reliability to 100% is a remark in [6] that states that the variance is large compared to the variance found for rail and road traffic. Therefore it is recommended that the responses calculated for aircraft noise are considered as indicative only.

The data are based on 7.394 observations in 7 studies.

9.6 Road

The polynomial curves from [6] and the logistic norm curves for sleep disturbance as defined in Section 9.1 to 9.3 are given for road noise in Table 42 and Figure 44.

Second order polynomial approximation	
%LSD	$-8.4+0.16* L_{night} +0.0108* L_{night}{}^{2}$
%SD	$13.8-0.85* L_{night} +0.0167* L_{night}{}^{2}$
%HSD	$20.8-1.05* L_{night} +0.01486* L_{night}{}^{2}$

Logistic curve: $\%XSD = \frac{100}{1+e^{-s(L_{night}-f)}}$	s	f
%LSD	0.0634	66.4
%SD	0.0693	77.7
%HSD	0.0770	87.1

Table 42
Road noise. Second order curves and logistic norm curves (lower table giving the percentage of "Lowly sleep disturbed" (%LSD). "Sleep disturbed" (%´SDA. "Highly sleep disturbed" (%HSD)

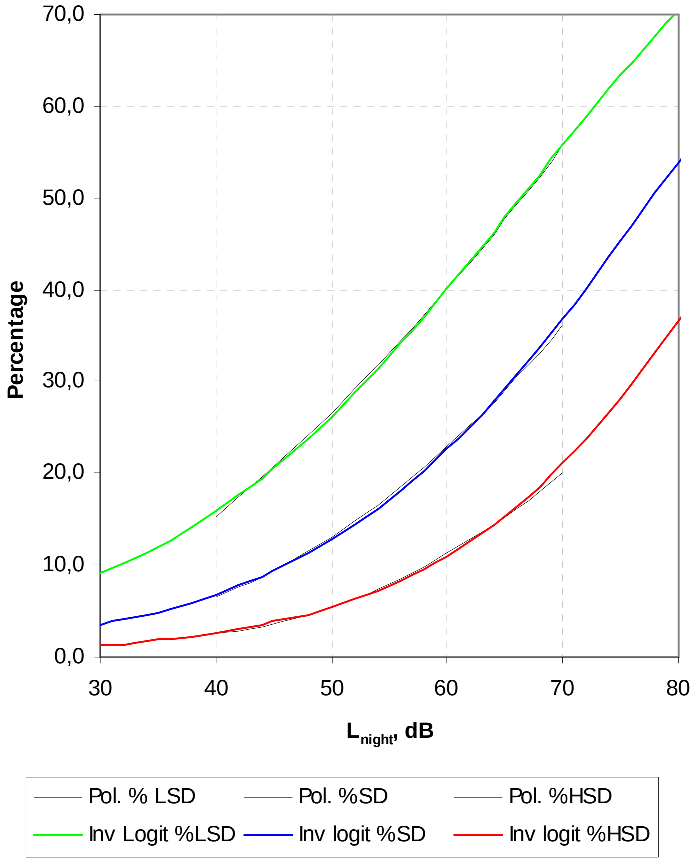

Figure 44
Road noise. Estimated and approximated curves for the percentage of highly annoyed (HA) annoyed (A) and Little annoyed (LA) for road noise.

The norm curves are valid in the range 40-70 dB L_{night}. In this range the reliability is set to 100% according to Section 7.1.2.

The data are based on 8.459 observations in 14 studies.

9.7 Train

The polynomial curves from [6] and the logistic norm curves for sleep disturbance as defined in Section 9.1 to 9.3 are given for train noise in Table 43 and Figure 45.

Second order polynomial approximation	
%LSD	$4.7\text{-}0.31^* L_{night} +0.01125^* L_{night}{}^2$
%SD	$12.5\text{-}0.66^* L_{night} +0.01121^* L_{night}{}^2$
%HSD	$11.3\text{-}0.55^* L_{night} +0.00759^* L_{night}{}^2$

Logistic curve: $\%XSD = \dfrac{100}{1+e^{-s(L_{night}-f)}}$	s	f
%LSD	0.0556	78.3
%SD	0.0624	90.4
%HSD	0.0700	100.7

Table 43
Train noise. Second order curves and logistic norm curves (lower table giving the pecentage of "Lowly sleep disturbed" (%LSD). "Sleep disturbed" (%´SDA. "Highly sleep disturbed" (% HSD).

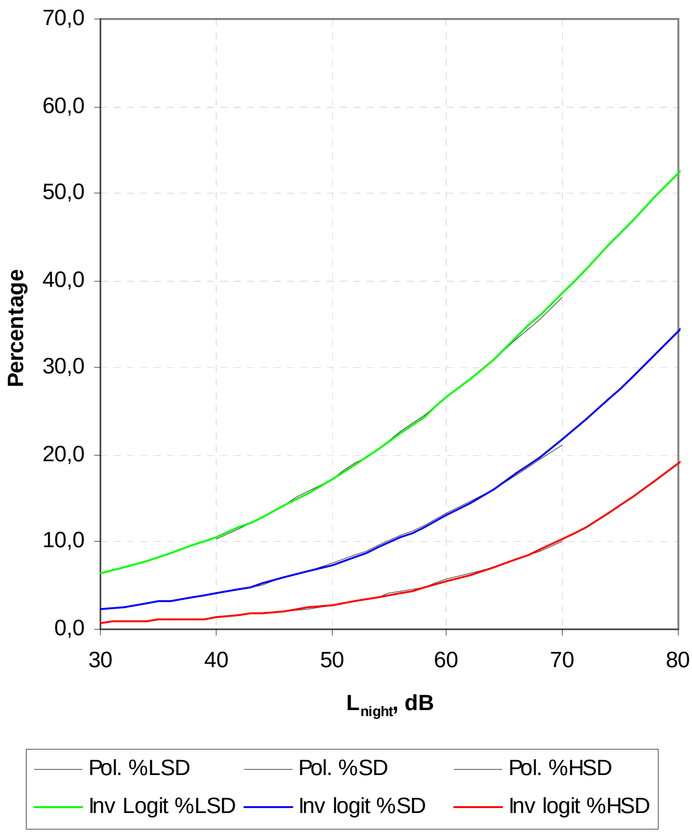

Figure 45
Train noise. Estimated and approximated curves for the percentage of highly annoyed (HA) annoyed (A) and Little annoyed (LA) for train noise.

The norm curves are valid in the range 40-70 dB L_{night}. In this range the reliability is set to 100% according to Section 7.1.2.

The data are based on 4.098 observations in 7 studies.

9.8 Moderators for Sleep Disturbance

The norm curves in the preceding sections are based on L_{night} .the outdoor night time noise exposure at the most exposed facade of a dwelling. L_{night} is not the only acoustical factor that influences sleep disturbance. The norm curves may be modified by factors as:

– the actual noise exposure at the facade of the bedroom
– the difference between outdoor and indoor noise levels of bedrooms (sound insulation)
– influence from day-time noise

The sound insulation in this case should be determined under the premise that the windows are partially open.

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11. Appendix – Zimmer/Ellermeier 9-Item Noise Sensitivity Questionnaire in English

On the following pages, we will ask for your opinion with respect to a variety of sounds. Please try to imagine the situation presented in each statement, and indicate to which extent you agree with it. We are interested in **your own personal assessment** of the topics presented here, so there are no „right“ or „wrong“ answers.

Please give your opinion spontaneously by marking that answering option which best reflects your opinion. The answering options are: Agree fully, Rather agree, Rather disagree, or Disagree fully.

Please answer all statements in turn, always marking a single option only.

If you are unsure as to which option to mark please choose that option which comes closest in reflecting your opinion.

Thank you for your participation!

	Agree fully	**Rather agree**	**Rather disagree**	**Disagree fully**
1. It is no fun keeping up a conversation while the radio is on.				
2. I tend to notice disturbing sounds later than do other persons.				
3. I avoid noisy pastimes such as going to soccer matches or fairs.				
4. I wake up at the slightest sound.				
5. Even in noisy surroundings. I am able to work quickly and with concentration.				
6. On doing my shopping in the city. I hardly hear the street noise.				
7. After having passed an evening in a noisy pub I feel drained.				
8. When I want to fall asleep, hardly any sound can disturb me.				
9. On weekends I like to be in quiet places.				

12. Appendix – Zimmer/Ellermeier 9-Item Noise Sensitivity Questionnaire in Danish

Hvordan har du det med støj?

Nedenfor vil vi spørge om din mening om forskellige former for støj. Svar venligst på udsagnene i rækkefølge uden at springe nogen over og afkryds kun ét svar for hvert.

Forestil dig for hvert udsagn, at du er i den beskrevne situation, og angiv, i hvilken grad du er enig. Vi er interesseret i **din helt personlige bedømmelse** af de præsenterede udsagn, så der er ingen ”rigtige” eller ”forkerte” svar.

Angiv din mening spontant uden at overveje for længe og marker den svarmulighed, der bedst afspejler din mening. Svarmulighederne er: ”Helt enig”, ”Forholdsvis enig”, ”Forholdsvis uenig” eller ”Helt uenig”.

Hvis du er usikker på, hvilket svar du skal krydse af, så vælg det, der kommer tættest på at afspejle din mening.

	Helt enig	**Forholds-vis enig**	**Forholds-vis uenig**	**Helt uenig**
1. Det er ikke særligt sjovt at tale med hinanden, når radioen også kører.				
2. Jeg bemærker forstyrrende støjkilder senere end andre gør.				
3. Jeg undgår støjende begivenheder som f.eks. fodboldkampe eller byfester.				
4. Jeg vågner ved den mindste lyd.				
5. Selv i støjende omgivelser kan jeg arbejde hurtigt og koncentreret.				
6. Når jeg er i byen for at købe ind. lægger jeg ikke mærke til gadelarmen.				
7. Efter at have tilbragt en aften i støjfyldte lokaler, føler jeg mig flad.				
8. Når jeg lægger mig til at sove, kan næsten ingen lyde forstyrre mig.				
9. Jeg foretrækker at tilbringe weekenden i fredelige omgivelser.				

Tak for din deltagelse!

13. Appendix – Untested Sketch to an Attitude Questionnaire

On the following page, we will ask for your attitude to (sound source). Please consider each statement, and indicate to which extent you agree with it. We are interested in **your own personal assessment** of the topics presented here, so there are no „right“ or „wrong“ answers.

Please answer all statements in turn, always marking a single option only.

If you are unsure as to which option to mark, please choose the option which comes closest in reflecting your opinion.

Thank you for your participation!

	Agree fully	**Rather agree**	**Rather disagree**	**Disagree fully**	**Disagree fully**
1. The ...(source) is important for the society					
2. Such ... (sources) increase the pollution					
3. The ...(source) should not be placed/operating so close to my residence					
4. Such sources do not belong in an area like this					
5. My/the citizens views are taken into account in a fair way when planning this ...(source)					
6. I believe that the ...(source administrators) are making/have made great efforts to minimise noise and other negative effects					
7. The ...(source) will decrease(s) the value of my residence					
8. The ...(source) is unhealthy and/or dangerous for people living here					
9. The ... (source) disturbs the landscape and/or the nature					

Scoring 0-3 points. 3 is in favour of the noise source. Attitude scaling = points * 100/27.

14. Appendix – Results of the “Genlyd” Project

14.1 Reports and Notes

Many of the documents listed below are intended as internal, and some of them are preliminary reports. Finalising, proofreading and layout have not been prioritised in all reports, and they are therefore not suitable for publication (marked as “Draft”). Some of the reports shall be seen as steps towards an understanding of the matters and do not necessarily represent the final recognition of problems and their solutions.

- ***Litteratur om støjgene*** *(Literature collection on noise annoyance)*
  Internal note, March 2004, 11 pages, Birger Plovsing
  A note with titles and links to relevant articles, summaries and literature

- ***Proposal for a tool and scales for measuring annoyance of noise***
  Internal Technical Note AV 1328/04, June 2004, 24 pages, Torben Holm Pedersen
  Describes loudness functions and suggests a similar scale ”Molestia” for annoyance

- ***Selection of annoyance scales for further testing***
  Internal Report, draft, September 2004, 28 pages, Preben Kvist
  Describes different types of scales used for perceptive and affective evaluations, among these scales for annoyance

- ***Genlyd – Lytteforsøg, procesbeskrivelse (Listening test process description)***
  Teknisk Notat, draft, AV 1590/04, 25 sider, juni 2004, Lise-Lotte W. Tjellesen

- ***Genlyd – Lytteforsøg. praktiske eksempler (Listening test, practical examples)***
  Teknisk Notat, draft, AV 1589/04, 29 sider, juli 2004, Lise-Lotte W. Tjellesen

- ***Genlyd – Listening test procedures***
  Technical Note, draft, AV 1590/04uk, Sept. 2005, 84 pages, Lise-Lotte W. Tjellesen
  Overview and reference for procedures for performing listening tests

- ***Translation of Questions and Scales in ISO 15666 into Danish.***
  Technical Report, AV 1340/05, draft, October 2005, 23 pages, Preben Kvist
  Describes the selection and translation process and results

- ***Genlyd – Building acoustics - Annoyance from traffic noise indoor***
  Internal report, draft, February 2006, 99 pages, Dan Brøsted Pedersen
  Detailed results on ”Reduction of annoyance from traffic noise indoor by windows”

- ***Dokumentation af lytteforsøg (Documentation of listening test)***
  Internal note, draft, Feb. 2005, 18 pages, Lise-Lotte W. Tjellesen
  Describes details of the listening test for the Building acoustics project

- ***Genlyd - Noise Annoyance - Concepts and Definitions***
  Technical Note AV 1500/04, 2005 rev. 2006, 23 pages, Torben Holm Pedersen.
  Defines relevant concepts for the interaction between the physical noise/sound and the human perception and affect. Describes the effects of noise in general and gives a definition of annoyance. relevant to the “Genlyd” project.

- ***Annoyance and performance test in an office environment***
  Technical Note, draft, February 2006, 18 pages, Preben Kvist
  Describes the test setup for annoyance and performance measurements in office environment. Results and data processing not yet reported.

- ***Test af noiseLAB plug-in til toneanalyse***
  Technical Note, draft, March 2006, 22 pages, Birger Bech Jessen
  Describes test of the software module for analysis of audible tones in noise

- ***Verifikation af noiseLAB plugin til beregning af impulsers tydelighed***
  Technical Note, AV 1269/04, draft, 8 pages, Preben Kvist
  Describes test of the software module for analysis of the prominence of impulses in noise

- ***Kravspecifikation for genedemonstrator (Requirement specification for annoyance demonstrator)***
  September 2006, 34 pages, Carsten Ryom Pedersen
  Describes the requirements to a piece of software for annoyance calculations according to the model

- ***Genlyd – Field vs. Laboratory – Statistical Analysis***
  Technical Note, draft, December 2006, 23 pages, Søren Ludvig Jørgensen
  Analysis of socio acoustic results from field survey of annoyance from traffic noise

- ***Genlyd - Measurements of internal and external noise from road traffic at 3 sites in Copenhagen***
  Technical Note, under preparation, Claus Backalarz
  Describes the noise measurements for the field vs. laboratory annoyance study

- ***Report on surveys of traffic noise***
  Report 2006, Social Research Institute
  The results from the field interviews on annoyance from traffic noise

- ***Annoyance from sounds in open-plan offices***
  Technical Note, under preparation, Jan Voetmann and T. Holm Pedersen
  The results of a literature study and a model for annoyance from irrelevant speech and masking noises (bable noise, ventilation and office equipment) are described.

- ***Genlyd - Laboratory study on sound from wind turbines***
  Technical Report, draft, March 2007, 90 pages, Søren Vase Legarth
  Describes the results of listening tests with simultaneous presentation of pictures. A metric for the wosh of wings is developed.

- ***”The Genlyd annoyance model”***
  Technical Report, March 2007, 135 pages, Torben Holm Pedersen
  Reference report which describes the annoyance model, the background and the underlying mathematical methods and formulas

14.2 Papers

Some of the “Genlyd” results were presented at Euronoise 2006 in Tampere. Finland:

- ***Translation into Danish of the questions and modifiers for socio-acoustic surveys***
  Preben Kvist and Torben Holm Pedersen

- ***Physical and psychoacoustic metrics for the reduction of indoor traffic noise annoyance by windows***
  Dan Brøsted Pedersen, Torben Holm Pedersen, and Preben Kvist

- ***Model for Noise Annoyance***
  Torben Holm Pedersen

Some results were also presented at a meeting arranged by the Reference Laboratory for noise measurements (DELTA) for the approved noise measurement laboratories (6 March 2007).

14.3 Developed Software Tools

Tone and impulse plug-ins
As a tool for quantification of noise annoyance with regard to the noise characteristics, two software modules are developed. The modules are able to measure the prominence of tones and impulses according to the methods described in the [15] and [34] (see also [39] and [40]). The modules are plug-ins for the noise analysis software noiseLAB from DELTA.

Wav-import

This module makes it possible to import and analyse sound files in the wav-format. The sound files for the Genlyd listening tests were all in that format, so this plug-in for noise-LAB made an efficient analysis possible.

”Annoyance demonstrator”

This piece of software calculates the annoyance from a number of sound sources with regard to a few moderators.

“Annoyance calculator”

With the experience from the Annoyance demonstrator software, a requirement specification was made for a more comprehensive piece of software. This software will calculate the annoyance according to the models described in this report. A program according to the requirement specifications exists at present as a first and untested version.