FAMOS
a CEDR project

Non-acoustic factors that affect the annoyance response

20-10-2020
TG

Deliverable 1.2 Preliminary prioritized list of modifiers

FORCE TECHNOLOGY

LÄRMKONTOR GmbH

SINTEF

Contents

Photo front cover: Hans Bendtsen

1 Preface

This report has been produced as a part of the FAMOS project. FAMOS responds to the questions of the Conference of European Road Directors (CEDR) call in 2018 on Noise and Nuisance: Psycho-Acoustics: Improved Understanding of People's Subjective Reactions to Road Noise.

WHO has estimated that about 1.2 million healthy life-years are lost annually in Europe due to road traffic noise. About half of these can be related to the subjective element: annoyance. This is a huge challenge for the National Road Administrations. Analyses of results from noise surveys reveal that only about 1/3 of the variance in the annoyance response is caused by the noise level itself, whereas the other 2/3 are determined by so-called non-acoustic factors. This means that the annoyance response can be altered within wide limits without doing any changes to the actual noise level. So, when road administrations have used all the technically feasible and economically possible measures, the noise impact can still be reduced by making changes in the non-acoustic factors known to moderate the annoyance response.

FAMOS will quantify how different factors modify people's subjective reactions to road traffic noise. The project will use scientific methods to find, extract and analyze data from existing annoyance surveys. The most promising findings will be tested experimentally by the use of questionnaire studies, listening testing in the laboratory and soundscape measurements/sound walks. The results will be used to develop a handbook on how "moderators" can be used by road administrations to reduce noise annoyance.

FAMOS is the acronym for "FActors MOderating people's Subjective reactions to road noise". The project is carried out over two years and started in December 2019. The project consortium consists of three partners:

- Force Technology in Denmark (Project leader)
- LÄRMKONTOR in Germany
- SINTEF in Norway

This report has been produced within Work Package WP 1 of the project, which deals with "Moderator search and qualification" and is led by the SINTEF. This report presents the main results of a large international literature study on noise annoyance surveys as well as a prioritized list of moderators. The report has been produced by Truls Gjestland from SINTEF as deliverable D.1.2 of the FAMOS project. The report has been reviewed by Torben Holm Pedersen from FORCE and Sebastian Eggers from LÄRMKONTOR. The work is financed by CEDR.

2 Introduction

Results from social surveys on noise annoyance from road traffic noise reveal that there is a large spread in the annoyance response. The annoyance is assumed to be proportional to the cumulative noise exposure, but at equal noise exposure levels the average response from one group of people, one community, may be very different from the response from another group. The difference in the annoyance response is caused by factors other than the noise level itself. These are commonly referred to as *non-acoustic* factors, but a more precise definition would be *non-noise dose* factors, as the annoyance response is commonly presented in relation to the noise dose, *i.e.* the average noise level, for instance L_{den}. Differences in acoustic parameters such as maximum levels, frequency content, exposure pattern, etc. may not alter the cumulative noise dose, but may still influence the annoyance response.

The preferred way of reporting the relationship between the annoyance and the noise exposure is by so-called exposure-response functions. These functions express the percentage of the respondents that are annoyed to a certain degree as a function of the noise exposure levels. Dose-response curves or dosage-response curves are other names for the same functions.

3 CTL – The Community Tolerance Level

According to the international standard ISO 1996-1 (2016) the relationship between the prevalence of highly annoyed residents and the noise exposure can be described by a fixed function similar to the duration-adjusted loudness function. However, the position of this function relative to the noise axis (the x-axis) varies depending on the effect of non-acoustic factors. The relative position can be described by a single quantity, the Community Tolerance Level – CTL, expressed in decibels.

Differences between the results from different surveys, or between different sub-groups within the same survey can be expressed as differences in CTL values. This difference shows how much more (or less) noise one community will tolerate to express a certain degree of annoyance compared with another community. A high CTL value indicates that the community is very tolerant to noise, whereas a low CTL value indicates the opposite, a low tolerance to noise.

The CTL method thus provides a convenient way of describing the influence of various non-acoustic factors. A more detailed description of the CTL method is given in appendix A1.

4 Non-acoustic factors

The non-acoustic factors that will modify the annoyance response can be categorized in different ways. Some factors pertain to the road itself and its immediate surroundings such as type of road, traffic volume, speed limit, road pavement, barriers, visual appearance, etc. These are factors that to a large extent can be controlled or influenced by the road owner.

Then there are factors pertaining to the neighborhood such as type and location/orientation of residences, prevalence of community conveniences like shops, schools, parks, playgrounds, etc.

neighborhood traffic conditions and so on. These factors can only to a small extent be influenced by the road owner. Chances for control are better at completely new developments than for projects in existing communities.

Some factors deal with the relationship between the local residents and the road owner. Do they feel a personal ownership to the road and benefit from its existence? Have the residents had a chance to be involved in the planning and construction process? Do they have a feeling of being treated fairly by the road owner? These factors deal with public relations and can to a large extent be controlled and managed by the road owner.

Finally, there are a number of factors completely out of control by the road owner. However, it is important to recognize that such factors exist and to know how they affect the annoyance response. These are typically personal and demographic factors like age, gender, income, noise sensitivity, etc.

4.1 Controllable factors pertaining to the road

4.1.1 Traffic volume

The traffic volume, *i.e.* the number of vehicles, affects the annoyance response. As the number of passing vehicles increases, the noise exposure level will increase and consequently the prevalence of noise annoyed residents will increase. However, the annoyance increases more rapidly than would be expected from the noise level itself. At equal noise levels, a high number of vehicles appear to be more annoying than a small number. The effect has been reported equivalent to about 1.5 dB per doubling of the number of vehicles (increase in CTL value). A more detailed analysis with proof of evidence is shown in appendix A2.

4.1.2 Noise barriers

Noise barriers are often used as a means to reduce the noise from a major road. Different constructions and different materials are being used; dirt berms, solid walls made of concrete or wood, transparent walls made of glass, etc. The walls may be reflective or fitted with absorption on the side facing the road. The screening effect of a noise barrier is primarily defined by the effective height. A barrier introduces an insertion loss of 5-6 dB when the direct line of sight from the source to the receiver is just barely broken. An effective height of 3-4 meters will provide an insertion loss of up to about 15 dB. A typical noise barrier will provide an insertion loss of about 10-12 dB, but the subjective effect, *i.e.* the corresponding reduction in the annoyance response is dependent on a number of other factors. Did the effect of the barrier meet the expectations of the residents? Were they involved in the visual design or were they left alien to the design process? The physical effect, *i.e.* the reduction in noise level, may often be offset by an opposite shift in the annoyance response. A more detailed discussion with illustrative examples is presented in appendix A3.

4.1.3 Visual appearance

The visual appearance of the road and its immediate surroundings have a significant impact on the annoyance response. Visual greenery in the form of single trees or bushes, strips of grass, etc. have no effect as a noise-reducing element, but never-the-less such elements may reduce the subjective annoyance equivalent to a shift in the CTL value of as much as 10 dB. Examples and references are presented in appendix A4.

4.2 Factors pertaining to the neighborhood

4.2.1 Locations and orientation of residences

The noise response is per definition presented as a function of the most noise-exposed façade of the residence. The house itself can act as an effective noise barrier and it has been observed that it may be advantageous to locate noise-sensitive rooms of the residence away from the noise source. Living room and bedroom windows should not be facing the roadside. Likewise, balconies, terraces and similar outdoor areas should preferably be located on the quiet side of the house. Various studies report having access to a quiet side of the residence will shift the CTL value by 6 dB or more. Examples and references are presented in appendix A5.

4.2.2 Neighborhood soundscape

It has been shown that the annoyance reported by a resident is not only dependent on the noise level at the (most exposed) façade of the residence, but also depends on the soundscape qualities of the neighborhood. Neighborhoods characterized by general high levels of road traffic noise are assessed as being more annoying than a quieter neighborhood even if the residence is not directly exposed to this noise. It may therefore be worthwhile to re-direct the neighborhood traffic and divide the traffic in local streets and through-streets according to origin and destination. This may even increase the noise in some areas, but the net effect may be a reduction in the overall community annoyance. Appendix A6 has further information.

4.3 Factors pertaining to attitudes and public relations

4.3.1 Attitudes towards authorities and road owners

Many annoyance surveys indicate that the relationship between the authorities (source owners) and the neighborhood is an important non-acoustical factor. People that have a high trust in the authorities and believe that a road is being constructed to impose a minimum impact on the neighborhood and society are less annoyed than people with a low trust and people that feel alien to the road work and having a feeling of not being treated fairly. Examples have been presented in appendix A7,

4.3.2 Public relations

In the aviation industry a "high rate change airport" (HRC) is characterized by large and abrupt changes in the operation pattern (but not necessary changes in the noise exposure level). If plans for future changes are launched, and especially if these plans are controversial and not rooted properly in the community, the airport may also be characterized as an HRC airport. Likewise, negative media attention may lead to an HRC characteristic. It is quite likely that a similar situation may be found for road traffic. In the aviation industry the average difference between a typical airport and an HRC airport is equivalent to a shift in the CTL value of about 9 dB. This is about the same shift that can be expected from the erection of a typical noise barrier or the «clean-up» of the traffic situation in an existing community. An unfortunate presentation of such plans that will trigger adverse actions in the community can completely reverse the expected positive effects. References are given in appendix A8.

4.4 Non-controllable personal and demographic variables

One of the objectives of the FAMOS project is to identify and quantify non-acoustical factors that have an influence on peoples' annoyance reactions to road traffic noise. In this chapter a number of such factors that to a greater or lesser extent can be controlled by the road owner, have been discussed. Control is a matter of necessity if the objective is to use a certain factor actively in road planning and traffic control.

However, there are also many personal and demographical factors that may or may not be important for annoyance assessment. Such factors are for instance age, gender, dependency of road transportation, house ownership, social status, income, education, etc.

Information about these may be important when assessing the results from annoyance surveys. Some of these factors have been discussed in appendix A9.

4.5 Results from recent surveys

Most of the work in FAMOS WP1 has been based on literature and reviews of reported survey results. In addition, direct contact with researchers that are active in this field have given us access to unpublished results from recent surveys. These results have confirmed earlier findings and have helped quantify the effect of many non-acoustic factors. Information on recent studies have been reported in appendix 10.

5 Modifiers suitable for further study in the FAMOS project

The results from other surveys on annoyance from road traffic noise indicate that the annoyance response is affected by a set of non-acoustic factors. The influence of these factors, *i.e.* the magnitude of the effect, varies, and the feasibility and practicality of manipulating these factors depends on local circumstances. It is recommended that the FAMOS project should focus on factors that have a large potential for annoyance reduction, and that are easily implemented.

In a brand-new situation where a whole new community is being developed the most effective annoyance-reducing measure is probably to make sure that houses and residences are located in a favorable position/orientation relative to the road. Noise-sensitive rooms should not be facing the noise source, and all dwellings should have access to a quiet side.

In a new situation it is also possible to pay more attention to the visual appearance of the road and make room for green elements that are known to have an annoyance-reducing effect.

So, the two factors:

- Visual appearance of the road and its immediate surroundings
- Orientation of dwelling, access to a quiet side of the dwelling

should be studied further.

In a situation where a road is being refurbished the location of houses and the community infrastructure is already fixed. In these cases, it may be advantageous to focus on the planning and construction process, involving the residents in the planning whenever feasible and developing good relations between the community and the road owner. These are factors that may have a large impact on the annoyance response.

In a major refurbishing process, the whole traffic pattern in the entire community is often under consideration. Concentration of traffic in chosen preferred streets leaving others with minimum traffic will often lower the general traffic noise level in the neighborhood, or at least create some areas in the neighborhood with low (and more agreeable) noise levels. An improvement of the neighborhood soundscape will lower the annoyance even if the noise exposure from the major through-roads remains the same.

So, the factors:

- Attitudes and relations between the community and the road authorities
- Neighborhood soundscape

should be studied further.

5.1 Conclusion – Prioritized list of modifiers for further studies

So far, the results from other surveys and research projects have shown that the annoyance response will vary significantly depending on the presence or absence of other non-acoustic factors. It may therefore be feasible to alter the annoyance response without changing the actual noise levels. This requires detailed knowledge about the different non-acoustic factors and possible interaction between them.

In order to prioritize different modifiers, the following criteria have been considered:

- To which degree is this modifier controllable by the road authority
- What is the potential for shift in the annoyance response
- What is the quality of existing data that support the conclusions

The following preliminary list of modifying factors for further studies has been developed based on these criteria; the magnitude of the modifying effect and possibilities for implementation. Situational variables will determine which one of these that are most suitable in any one situation and thus also the priority.

- Visual appearance of the road and its immediate surroundings, e.g. visibility of traffic, greenery and the type and visual appearance of mitigation measures
- Orientation of dwelling, access to a quiet side of the dwelling
- Attitudes and relations between the community and the road authorities
- Neighborhood soundscape

6 Appendices

The appendices give a more detailed description of the different non-acoustic factors and references to studies that provide such information.

6.1 Appendix A1 – The CTL method

Assessment of annoyance using the CTL method

The CTL method

The CTL (Community Tolerance Level) method is described in the international standard ISO 1996-1 (2016) [1]. The theoretical background for the method was presented by Fidell *et al.* (2011) [2] and Schomer *et al.* (2012) [3].

The CTL method is based on the observation that the annoyance response seems to be closely related to the loudness function. This observation can be traced back to Schultz (1978) [4]. For modelling purposes, it was hypothesized that the prevalence of annoyance with transportation noise should increase at the same rate as the duration-adjusted loudness of exposure. This implies that the dose-response function (annoyance vs. noise exposure) can be described by a single, fixed function, but the position of the curve relative to the noise axis will vary according to the influence of other non-dose factors. So, instead of finding a regression function based on a set of observation data where both slope and intercept must be calculated/predicted, as is done in regular univariate regression analysis, the CTL method fits the pre-determined annoyance function to the field data simply by "sliding" the function back and forth along the noise exposure axis to achieve the «best fit» according to some statistical criterion. Fidell *et al.* used a «least squared error» criterion in their first analysis. Subsequently Taraldsen *et al.* (2016) [5] showed that a «maximum likelihood estimate» would be preferable. However, in most cases both methods give very similar results.

The dose-response function for any study of prevalence of annoyance with transportation noise can thus be characterized by a single number that anchor the annoyance function to the noise axis (DNL or DENL). Any arbitrary point on the effective loudness function could be used to anchor the function to the DNL axis. For example, DNL values corresponding to the 10% or 90% highly annoyed points could serve to describe the position of the effective loudness function along the DNL axis. Since the choice is arbitrary, the midpoint of the effective loudness function—the point corresponding to a 50% annoyance prevalence rate—was selected as a convenient anchor point for present purposes. This value of DNL is termed the Community Tolerance Level (CTL) (L_{ct}). CTL so defined represents a DNL value at which half of the people in a community describe themselves as "highly annoyed" by the specific noise (and half do not).

The results from different surveys can be conveniently compared by simply comparing their respective CTL values. A high value indicates that the community has a high tolerance for noise and low values indicate that the community have a low tolerance for noise. The difference between two CTL values shows how much more or less noise one community will tolerate compared to another one in order to express the same degree of annoyance.

The complete dose-response function for a survey can thus be described by the following equation:

%HA = 100*exp(-1/((10^((Ldn-Lct+5.3)/10))^0.3)))

where L_{ct} is the only variable.

The results from different surveys can be combined by calculating the arithmetic average of their respective CTL values.

Comparison of different analyses

The average CTL value for a compilation of surveys on road traffic noise conducted over the past 50 years is about L_{ct} = 78 ± 5 dB. Figure 1 shows the dose-response curve corresponding to L_{ct} = 78 dB compared with the regression function derived by Miedema & Vos (1998) [6] for annoyance caused by road traffic noise. The *Miedema-curve* is currently being used as a *de facto* EU standard. Considering the rather large spread in the background data, and the wide confidence intervals, these curves may be considered equal for regulatory purposes.

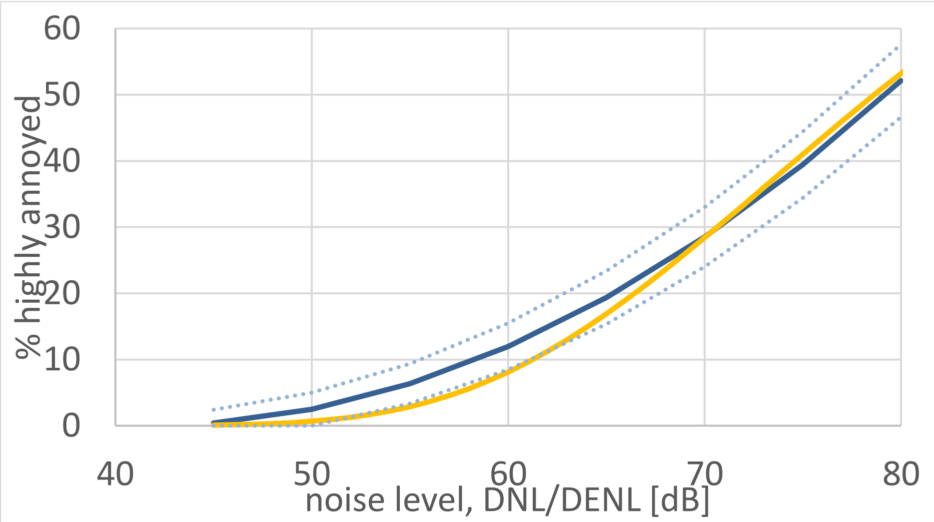


Figure 1. Dose-response curves for road traffic noise. Regression function derived by Miedema & Vos (blue line) with corresponding 95% confidence intervals (dotted lines) and curve corresponding to L_{ct} = 78 dB (yellow line)

The Danish Road Directorate has published results from a survey on annoyance from noise from different types of roads: urban roads and motorways [7]. In their report they use a logistic regression function and conclude that the dose-response curves for the two traffic situations have different slopes and different intercepts. Figure 2 shows these two regression functions compared with a CTL analysis of the same data. The two CTL curves are described by <u>identical mathematical functions</u> but spaced 12 dB apart on the x-axis. The CTL values are L_{ct} = 79.6 dB (urban roads) and L_{ct} = 67.6 dB (motorways) respectively. The traffic volume for the roads that are included in this study varies, but the traffic on the motorways (ADT) is typically five times higher than on the urban roads.

The Danish Road Directorate has also conducted a similar study of motorways and urban roads in or near Copenhagen [8]. The CTL values for this study are L_{ct} = 76.2 dB (urban roads) and L_{ct} = 66.9 dB (motorways). This is a difference of 9.3 dB. The traffic volume for motorway M3 is about twice as high as the motorways in the study above.

Lercher *et al.* have reported a study on annoyance from motorways and main roads in the Alpine region. They report CTL values of L_{ct} = 75.3 dB (main roads) and L_{ct} = 72.3 dB (motorways). This is a difference of only 3 dB.

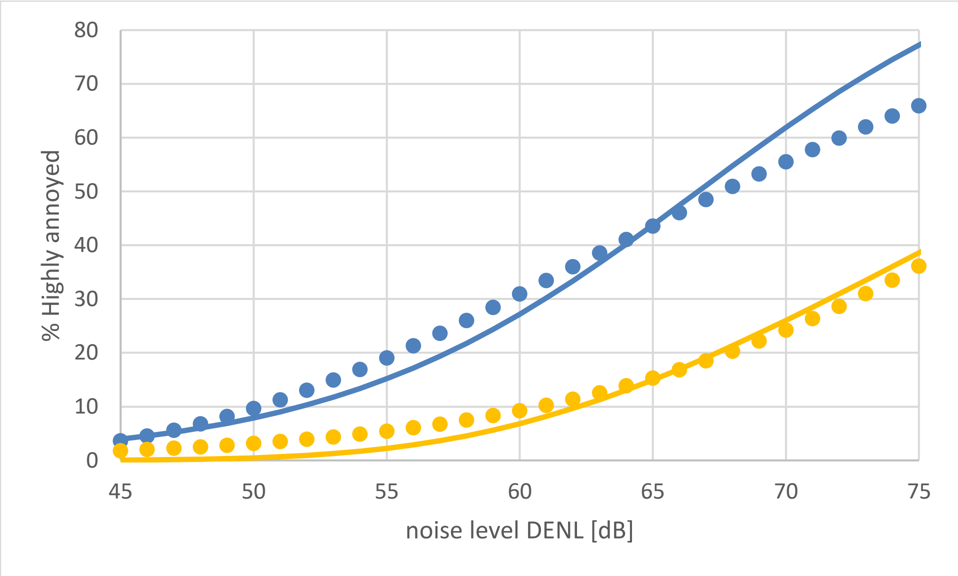


Figure 2. Dose-response curves derived from a Danish survey [7]. Solid lines show conventional logistic regression functions (motorways – blue, urban roads – yellow). The dotted lines are based on CTL analysis.

CTL for comparative studies

The results from the two Danish studies are similar with a difference in CTL between motorways and urban roads of 9 – 12 dB. A likely conclusion could be that noise from a motorway is more annoying than noise from an urban road equivalent to a difference in exposure of about 10 dB. However, a similar comparison between the Alpine studies show that the difference is only about 3 dB.

Gjestland *et al.* have studied the connection between aircraft noise annoyance and number of aircraft movements [9]. They have shown that a doubling of movements is equivalent to about 2 dB in noise exposure. In the Danish studies the traffic volume on the motorways is about 5 times higher than for the urban roads. If the results from the aircraft noise studies can be applied to road traffic as well, one may hypothesize that about half of the difference in annoyance between the Danish motorways and urban roads is caused by differences in traffic volume (see Appendix A2-Traffic volume). In other words, the difference in the annoyance response is caused by two major non-acoustic factors: traffic volume and road type (driving behavior, speed, etc.).

For the Alpine studies the difference in traffic volume between motorways and main roads is smaller, and thus the "volume factor" plays a smaller role.

Conclusions

Analyses according to the CTL method give results that are well suited for comparison of inter-survey differences. The CTL value gives a direct quantification of the effect of non-acoustic factors influencing the annoyance response.

The challenge with respect to the FAMOS project is to find surveys on road traffic noise annoyance that are reported in a sufficiently detailed manner so that different non-acoustic factors can be identified.

Bibliography

[1] ISO, "ISO 1996-1 Acoustics- Description, Assessment and Measurement of Environmental Noise - Part 1," International Standardization Organization, Geneva, Switzerland, 2016.

[2] S. Fidell, V. Mestre, P. Schomer, B. Berry, T. Gjestland, M. Vallet and T. Reid, "A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure," *J Acoust Soc Am,* pp. 791-806, 2011.

[3] P. Schomer, V. Mestre, S. Fidell, B. Berry, T. Gjestland, M. Vallet and T. Reid, "Role of community tolerance level (CTL) in predicting the prevalence of the annoyance of road and rail noise," *J Acoust Soc Am,* pp. 2772-2786, 2012.

[4] T. J. Schultz, "Synthesis of social surveys on noise annoyance," *J Acoust Soc Am,* pp. 377-405, 1978.

[5] G. Taraldsen, F. B. Gelderblom and T. Gjestland, "How to measure community tolerance levels for noise," *J Acoust Soc Am,* vol. 140, pp. 692-701, 2016.

[6] H. Miedema and H. Vos, "Exposure-response relationships for transportation noise," *J Acoust Soc Am,* pp. 3432-3445, 1998.

[7] Vejdirektoratet, "Støjgener fra byveje og motorveje, report 551," Vejdirektoratet, Copenhagen, 2016.

[8] Vejdirektoratet, "Støygener fra byveje og motorvej M3. Report 447," Vejdirektoratet, Copenhagen, Denmark, 2013.

[9] T. Gjestland and F. B. Gelderblom, "Prevalence of Noise Induced Annoyance and Its Dependency on Number of Aircraft Movements," *Acta Acustica united with Acustica,* vol. 103, pp. 28-33, 2017.

6.2 Appendix A2 – Traffic volume

Annoyance dependency on traffic volume

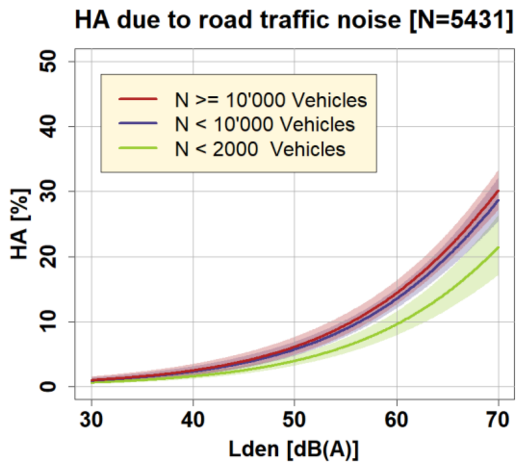
The prevalence of highly annoyed residents in a community that is exposed to noise is assumed to be proportional to the noise exposure level, characterized by the equivalent level or a derivative such as DNL or DENL. However, analysis of surveys of annoyance from road traffic noise indicate that there is also a traffic volume effect.

If the number of passing vehicles increases, the noise level will increase and consequently the annoyance will increase, but even for situations with the same DNL level the prevalence of highly annoyed residents seems to correlate with the traffic volume. People that are exposed to a high number of passing vehicles are in general more annoyed than those exposed to a small number of vehicles even if the noise levels are equal.

This "number effect" has been studied on the basis of two Danish surveys of annoyance from different types of roads (1) (2). In the original reports it was concluded that different dose-response functions characterized the annoyance from motorways and urban roads. A CTL analysis reveals that the same dose-response function can be used for both types of roads, but the CTL value differs depending on the traffic volume.

A recent Swedish report on annoyance from road traffic noise has data from a number of sub-sections together with traffic information. This information can be used to compare similar communities with similar type of housing but with different traffic volume (3).

Unpublished data from the SIRENE project indicates a volume effect of about 2 dB per doubling.



Data from the SIRENE project

Using the CTL method, the analysis gives relative differences in CTL values which can be translated into a "traffic volume effect" under the assumption that other non-acoustic factors are similar and/or not dominating. The average CTL value for all surveys included in the FAMOS project is L_{ct} 78.4 dB. Similarly, the average CTL value for the surveys included in the analysis by Miedema and Vos (Miedema & Vos, Exposure-response relationship for transportation noise, 1998) for establishing the EU reference curve (*Miedema curve*) for road traffic noise is L_{ct} 78.7 dB. The traffic volume has not been specified in detail for all of these surveys. However, since we are interested in relative differences between surveys, this quantity is not critical.

As a rough estimate the average CTL value for a situation with a traffic volume of about 2000 ADT can be set at L_{ct} 78 dB. Then the relative differences found from references (1), (2) and (3) can be used to introduce a traffic volume effect that corresponds to an adjustment of -1.5 dB per doubling of the traffic. The following values can be used as a first approximation:

Traffic volume	CTL value
1 000 ADT	L_{ct} 79.5 dB
2 000 ADT	L_{ct} 78 dB
5 000 ADT	L_{ct} 76 dB
10 000 ADT	L_{ct} 74.5 dB
20 000 ADT	L_{ct} 73 dB
50 000 ADT	L_{ct} 71 dB
100 000 ADT	L_{ct}69.5 dB

References

1. Vejdirektoratet. *Støjgener fra byveje og motorveje, report 551.* Copenhagen, Denmark, 2016.

2. Vejdirektoratet. *Støygener fra byveje og motorvej M3. Report 447.* Copenhagen, Denmark, 2013

3. Länsstyrelsen i Stockholms län**.** *Trafikbuller och planering IV.* Stockholm : https://www.lansstyrelsen.se/download/18.4e0415ee166afb59324513/1540559797208/Rapport%20Trafikbuller%20och%20planering%204.pdf, 2012.

4. Miedema, H.; Vos, H. *Exposure-response relationship for transportation noise.* J Acoust Soc Am, . pp 3432-45, 1998.

6.3 Appendix A3 - Barriers

Effects of barriers

A noise barrier alongside a busy road will typically reduce the noise level by 5 – 15 dB depending on the height of the barrier and the distance to the observation point. A small pilot study in Denmark has been conducted to find out the effect of barriers and people's attitude and expectations regarding noise barriers [1].

In one study area, area A (see below), without barriers the noise levels were about 75 dB in front of the houses facing the street. The traffic was 60 000 ADT. The study sample was 113 residents. This is sufficient to give a fairly good indication of the annoyance situation. According to the rough estimate presented in Project memo 2, one could expect a CTL level of about 70 dB with this traffic volume. The survey questionnaire did not comprise a question on "annoyance in general" but a CTL calculation based on the response to a question on annoyance outside gives the same result: L_{ct} 70 dB. In other words, the response to the noise in this community is quite normal. Their expectations regarding the effect of a noise barrier is quite high, and about 2/3 of the residents expect that they will not be annoyed by road traffic noise outside when a barrier is erected.

There was also another study area without a noise barrier, area B, but the number of responses, only 20, was considered too small for a meaningful analysis.

In two other study areas noise barriers had been installed [2] [3]. The traffic volume was about 60 000 ADT and 52 000 ADT respectively. A rough estimate would be about L_{ct} 70 dB and L_{ct} 71 dB for these two communities.

In the first area, area C, the calculated CTL value is about L_{ct} 66 – 69 dB which is slightly less than the first estimate L_{ct} 70 dB. This seems to indicate that the barrier has not had any "extra value", and the effect is proportional to the reduction in the noise levels.

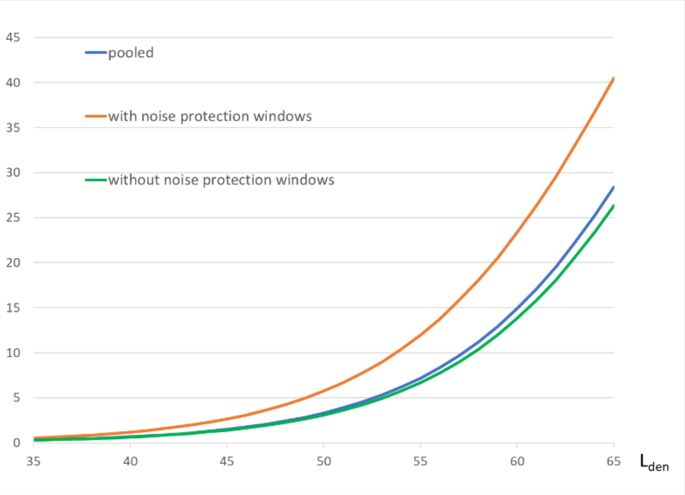
In the second area, area D, the two sides of the road have been analyzed separately. The calculated CTL value for the two communities, north and south, is L_{ct} 55 dB and L_{ct} 66 dB respectively. This indicates that especially the residents on the north side of the road are relatively more annoyed by the noise after erection of the noise barrier.

When asked about the noise reduction only 15 % of the residents on the north side think the noise is lower than before. They are also negative to the building process. Only 6 % felt they have been properly informed about the whole process.

These results indicate that when people's expectations about the effect of a planned noise barrier are not properly fulfilled and when they feel alien to the building process, the community becomes less tolerant to noise. In this case the dose-response function has been shifted equivalent to a 15 dB change in exposure. So instead of having about 25 % highly annoyed at a level of 60 dB, the percentage has increased to about 60 % HA.

In this particular case the measured noise reduction was 5 – 16 dB for the houses closest to the road. However, the effect of this reduction was almost completely offset by a similar shift in the annoyance response as shown by the CTL calculations. So subjectively, measured as persons highly annoyed by road traffic noise, this noise barrier had almost no effect.

A similar situation regarding expected effect of a noise abatement project has been observed in Austria (unpublished data). People that were highly annoyed by road traffic noise could apply for improved façade insulation (special windows). However, as their expectations were not met regarding reduced annoyance, the effect of lowered indoor noise levels had no effect on the exposure-response curve.



Unpublished data from an Austrian study

Conclusion

It seems to be important to involve the residents of a community in a proper way when planning and building noise barriers. If people's expectations are not properly fulfilled and if people are left alien to the process, the physical effect of the barrier (reduced noise levels) can be offset by a similar shift in the local dose-response function, so the prevalence of highly annoyed people in the community remains the same.

Study areas

Area A: Søbredden, Gentofte kommune, Denmark. Three-floor houses along main through-road (Lyngbyvej). 60 200 ADT, speed limit 90 km/h.

Area B: Vildkildevej, Ny Fløng, Denmark. Small single-family houses. Main noise source: near-by motor way at 100 m distance. 51 800 ADT, speed limit 110 km/h.

Area C: Lyngparken, Buddinge, Denmark. Mixed apartment houses (40 % of respondents) and small detached homes (60 % of respondents). 60 600 ADT, speed limit 110 km/h. Noise barriers have reduced the noise level by 8 – 15 dB (first row of houses).

Area D: Fløng, Denmark. Residences on both sides of the motor way. Mostly detached homes. 51 800 ADT, speed limit 110 km/h. Noise barriers have reduced the noise levels by 5 – 16 dB on the north side and by 4 -13 dB on the south side (first row of houses).

Bibliography

[1] H. Bendtsen and L. E. Larsen, "Oppfattelse af støjskærme," Vejdirektoratet, København, 2001.

[2] Vejdirektoratet, "Støjgener fra byveje og motorveje, report 551," Vejdirektoratet, Copenhagen, 2016.

[3] Vejdirektoratet, "Støygener fra byveje og motorvej M3. Report 447," Vejdirektoratet, Copenhagen, Denmark, 2013.

6.4 Appendix A4 - Greenery

The effect of trees and bushes as noise barriers

Many studies have been conducted to assess the effect of vegetation along the road. Trees and bushes cannot act as a noise barrier and will only give a marginal noise reduction, except for very wide areas of trees (> 100 meters). The psychological effect, however, *i.e.* the reduction in annoyance has often been observed to be much greater than what could be expected from the actual reduction in the noise level.

Langdon (1976) conducted a survey among more than 1000 residents in the Greater London area. The respondents were asked to assess different situation with trees/bushes as noise barrier. Langdon concluded that visual greenery could add as much as 15 dB excess attenuation compared to no greenery at all. In other words, greenery will reduce the annoyance considerably.

Langdon reported a multiple correlation analysis for items evaluating environmental amenity. He showed that 70 % of the group variance was accounted for by two items: appearance and parks, and these two continue to play the predominant part accounting for the 25 % of individual variance accounted for by all items. It is therefore reasonable to say that environmental quality as rated by respondents is indeed their perception of the visual appearance of the neighborhood – the state of buildings and streets and the presence of parks, trees and green spaces.

Fricke (1983) conducted experiments with trees as noise barriers and concluded that the psychological effect of having trees (as opposed to barriers without vegetation) would add as much as 10 dB extra attenuation.

Huddard (1990) summarized a number of reports on the attenuation of traffic noise by means of trees and shrubs. He also referred to studies reporting a change in the annoyance even if the change in the noise level is minimal*: Many researchers have suggested that a major benefit of a vegetation noise barrier might be psychological. Kurze* (1974) *remarked on the possibility of this form of benefit, even when the actual transmission loss is minimal.* Kurze had observed that *a row of trees* ranked among the most frequently desired protective measures for outdoor noise control.

Lercher (1996) has studied the effect of visual greenery along busy roads, and concluded that an excess attenuation of at least 5 dB may be expected due to the visual appearance of the road.

Van Renterghem *et al.* (2016) have studied how view of outdoor vegetation can reduce the perceived annoyance induced by road traffic noise. They refer to own survey results and cite other authors (Leung & al., 2017) and conclude that vegetation along the road may add about 10 dB excess attenuation.

Reduced annoyance due to visual greenery may be explained by a research paper by Vienneau et al. (2017). They conclude that residential areas with a green appearance are associated with lower mortality.

Conclusions

The use of greenery as noise barriers gives an additional reduction of the perceived annoyance equivalent to about 10 dB reduction in the noise level.

Bibliography

Fricke, F. (1983). Vegetation - attenuation for the birds? *Conference of Australian Acoustical Society.* Sydney, N S W.

Huddart, L. (1990). *The use of vegetation for traffic noise screening.* Crowthorne, UK: Transport and road research laboratory.

Kurze, U. (1974). Noise reduction by barriers. *J Acoust Soc Am*, 504-518.

Langdon, F. (1976). Noise nuisance caused by road traffic in residential areas. *J Sound Vib*, Vol 47, p 243-63.

Lercher, P. (1996). Environmental noise and health. *Env. Int.*, Vol 22, p 117-29.

Leung, T. M., & al., e. (2017). The effects of neighborhood views on containing multiple environmental features on road traffic noise perception at dwellings. *J Acoust Soc Am*, vol 141, p 2399-2407.

van Renterghem, T., & Botteldooren, D. (2016). View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. *J Landscape and Urban Planning*, vol 148, p 203-15.

Vienneau et al. (2017)): "More than clean air and tranquility: Residential green is independently associated with decreasing mortality.", Environment International, vol 108, p 176

6.5 Appendix A5 – Quiet side

The effect of access to a quiet facade

Many studies both in the laboratory and under actual field conditions have been conducted to assess the effect of having access to at least one quiet side of the dwelling. A *quiet side* is defined as having a noise level at the façade at least 10 dB below the most exposed façade.

It is well documented that residents that have access to a quiet side of their dwelling are less annoyed by road traffic noise than people without such access.

Lercher (1996) observed that having bedroom windows facing a quiet side of the residence, reduced the perceived annoyance. The reduction was equivalent to 8-15 dB reduction in noise exposure. The effect was level dependent, increasing with increasing noise level.

Gjestland *et al.* (2001) conducted a laboratory study comparing a situation (1) with equal traffic noise on all four sides of a residence, with a situation (2) with a high level on one side and low on the other sides. The test persons were asked to adjust the high or the low noise level in situation (2), so that the situation was assessed "equally annoying" as situation (1). The difference between the high and low noise level for equal annoyance was 6 – 10 dB depending on the absolute noise level.

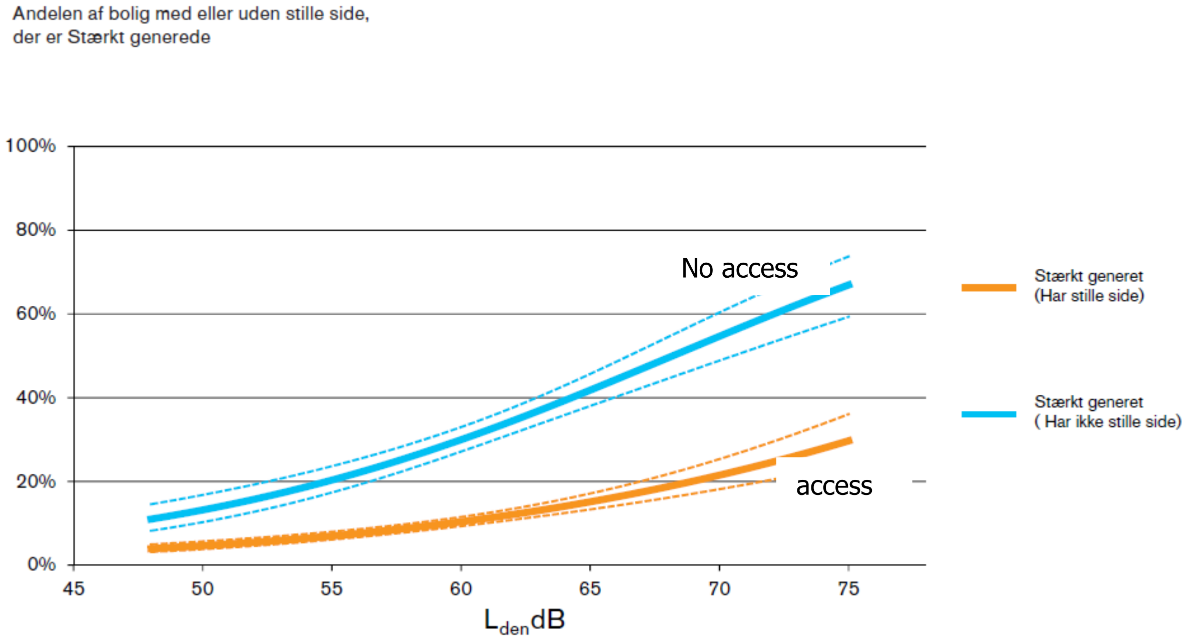
Öhrström *et al.* (2004) conducted field interviews of about 1000 residents in Stockholm and Gothenburg. About half of the participants in the study had dwellings with access to a quiet side away from city traffic, and the other half did not. The noise level, DENL, at the most exposed façade varied between 48 dB and 71 dB. The difference in CTL value for the two situations were 6.3 dB. To protect most people from adverse health effects the sound levels from road traffic noise should not exceed 60 dB (LA,24h) on the most exposed façade (Öhrström, Skånberg, Svensson, & Gidlöf-Gunnarsson, 2006)

Bluhm *et al.* (2004) analyzed the responses from about 650 residents in Stockholm. They did not quantify the reduced annoyance of having access to a quiet side, but confirmed previous findings by Öhrström *et al.*

de Kluizenaar *et al.* (2011) analyzed the responses to a mail survey from about 17 000 residents. They concluded that people with access to a quiet side of the residence would accept about 5 dB higher noise levels (on the noisy side) to express a certain degree of annoyance than people without such access.

Amundsen *et al.* (2011) conducted a before/after study to assess the efficacy of improved façade insulation. About 600 responses were collected in the before study and about 400 in the after study. They concluded that residents having bedroom windows facing a quiet side of the dwelling would tolerate about 6 dB higher noise levels than those that did not have a quiet side of the residence.

A Danish report (Vejdirektoratet, 2016) confirms that access to a quiet side of the dwelling reduces the annoyance. The prevalence of highly annoyed drops to about one half compared to no such access. The effect is level dependent (cfr. Gjestland et al. 2001, and Lercher, 1996).



Results reported from a Danish study ((Vejdirektoratet, 2016). Prevalence of highly annoyed vs. exposure level. The difference in annoyance reaction may amount to more than 10 dB in exposure level.

A Swedish research program on soundscape and health (Ljudlandskap för bättre hälsa, 2008) concluded that access to a quiet side of the dwelling could be equivalent to a 5 dB reduction in the exposure level.

Another Swedish study (Länsstyrelsen, 2012) provides annoyance and exposure data for 56 sites around Stockholm. The average CTL for road traffic noise surveys is L_{ct} 78 dB. The average value for these 56 sites is L_{ct} 80.3 dB indicating that these residents are somewhat less annoyed than average. A majority of the dwellings have access to a quiet side of the building.

Conclusion

Access to a quiet side of the residence away from city traffic will increase the CTL value for that situation equivalent to 6 dB.

Bibliography

Amundsen, A., Klæboe, R., & Aasvang, G. (2011). The Norwegian facade insulation study. *J Acoust Soc Am*, 1381-89.

Bluhm, G., Nordling, E., & Berglind, N. (2004). Road traffic noise and annoyance. *Noise & Health*, 43 - 49.

de Kluizenaar, Y., & al., e. (2011). Urban road traffic noise and annoyance. The effect of a quiet facade. *J Acoust Soc Am*, 1936 - 42.

Gjestland, T., & Støfringsdal, B. (2001). The influence of a quiet facade on road traffic annoyance. *J Acoust Soc Am*, 2732.

Lercher, P. (1996). Environmental noise and health. *Env. Int.*, Vol 22, p 117-29.

Ljudlandskap för bättre hälsa. (2008). *Ljudlandskap för bättre hälsa, Resultat och slutsatser från et multidisciplinärt forskningsprogram.* Gøteborgs Universitet, Chalmers, Stockholms Universitet.

Länsstyrelsen. (2012). *Trafikbuller och planering IV.* Stockholm.

Vejdirektoratet. (2016). *Støjgener fra byveje og motorveje, Rapport 551.* København: Vejdirektoratet, Danmark.

Öhrström, E., & Skånberg, A. (2004). Annoyance and activity dirsurbances caused by road traffic noise - field studies on the influence of access to quietness. *Internoise 2004.* Prague, Czech Republic.

Öhrström, E., Skånberg, A., Svensson, H., & Gidlöf-Gunnarsson, A. (2006). Effects of road traffic noise and the benefit of access to quietness. *Journal of Sound and Vibration*, 40-59.

6.6 Appendix A6 – Neighborhood soundscape

Neighborhood soundscape

It has been shown that the annoyance reported by a resident is not only dependent on the noise level at the (most exposed) façade of the residence, but also depends on the soundscape qualities of the neighborhood.

Klæboe *et al.* have introduced a soundscape index which is the difference between the "maximum DNL in the neighborhood" and the DNL for the most exposed facade. The *neighborhood* in this context is the area within a certain distance from the dwelling. In their calculations, Klæboe *et al.* have used a circle with r=75 meters to define the neighborhood. (Note that the index is based on the maximum DNL and not he regular maximum exposure level) [1].

If this difference is large, people living in the area may be exposed not only to the noise levels in their homes but also to high levels when they go for a walk in their immediate neighborhood. A small difference on the other hand, means that the noise exposure in the neighborhood is not very different from what they have outside their own house [2].

Consider a situation with a secondary road running parallel to a main street. The houses along the secondary road may be the second or third row of houses as seen from the main street. Special noise reduction measures for the main street may have little effect regarding the actual (physical) noise levels for the houses along the secondary road, but since the "neighborhood noise" will be reduced, so will the reported annoyance be reduced.

So far Klæboe *et al.* have not been able to quantify the influence of the neighborhood soundscape.

References

[1] R. Klæboe, M. Kolbenstvedt, A. Fyhri and s. Solberg, "The impact of an adverse neighborhood soundscape on road traffic noise annoyance," *Acta Acustica united with Acustics,* vol. 91, pp. 1039-1050, 2005.

[2] R. Klæboe, E. Engelien and M. Steinnes, "Context sensitive noise impact mapping," *Applied Acoustics,* vol. 67, pp. 620-642, 2006.

6.7 Appendix A7 - Attitudes

Attitudes towards authorities and road owners

Many studies indicate that the relationship between the authorities (source owners) and the neighborhood is an important non-acoustical factor. This has been studied systematically in the NORAH study. This study deals with airports and aircraft noise, but it is reasonable to assume that similar relationships exist for road traffic as well. However, the exact magnitude of the effect may be different.

In the NORAH study [1] considerable differences in exposure-response functions for aircraft noise annoyance were found depending on *trust in authorities, perceived procedural fairness,* and *expectations regarding the air traffic's impacts.* The influence of these three factors was studied using longitudinal survey data.

The "degree of impact" was scored using the modifiers from the ICBEN verbal scale, for instance:
1 – no trust
2 – a little trust
3 – moderate trust
4 – rather some trust
5 – very much trust

The regular annoyance responses were sorted according to the respondents' *trust in the authorities* and new exposure-response curves were established; one for each "degree of trust". An example is shown in Figure 1. These curves have been calculated for road traffic noise based on the results from the NORAH study.

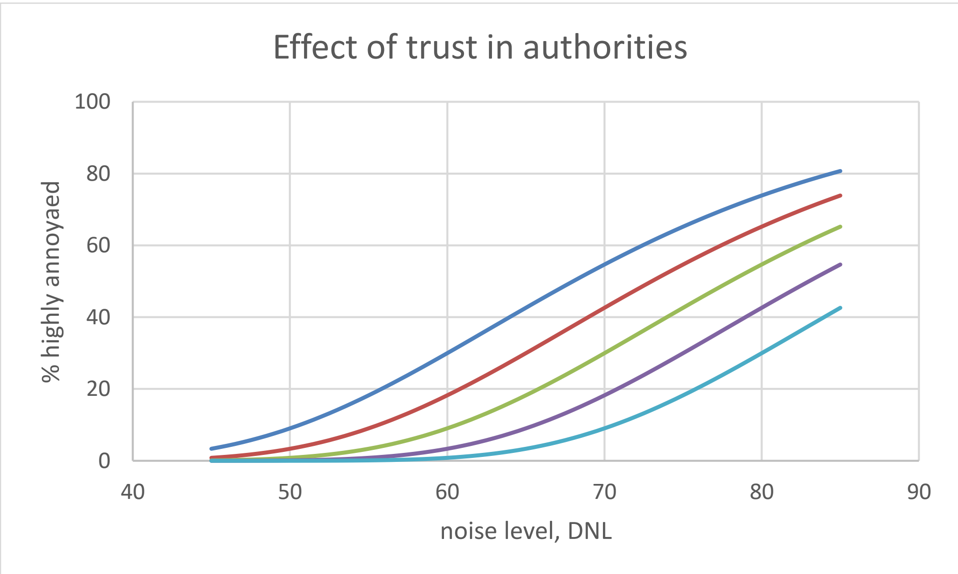


Figure 1. Exposure-response functions for transportation noise annoyance depending on the respondent's trust in the authorities

The difference between the various ERFs is equivalent to about 20 dB in noise exposure from the highest to the lowest *trust in authorities.* A more limited dynamic range for the effect, will compress the curves around the middle.

A similar analysis was also done for *perceived procedural fairness.* In other words how the respondents viewed the whole process from planning to implementation: did they have any influence in the planning process, did they have a chance to appeal decisions that they considered wrong, were the decisions explained and justified in detail, etc.

The difference between the various resulting ERFs appeared to be equivalent to about 15 dB in noise exposure from the highest to the lowest *perceived procedural fairness.*

The last item that was analyzed by Schreckenberg *et al.* was an assessment of the impact of air traffic on the regional development and the residents' quality of life. This is a more *fuzzy* characteristic with many subjective aspects. The biggest difference in the ERFs was therefore equivalent to more than 30 dB in noise exposure.

The example above is from a study on aircraft noise, but it is a fair assumption that similar effects can be found for other transportation noise sources. However, the magnitude of the effect may be different. There is a clear tendency that good relations between the source owner (for instance the road authority) and the neighborhood residents will reduce the annoyance. The effect is rather strong and the difference in reported annoyance for a situation characterized by good relations versus a situation with bad relations is by far larger than the effect of for instance a noise barrier. The benefit of investments in good public relations should therefore not be overlooked.

Bibliography

[1] D. Schreckenberg et al., "Attitudes towards authorities and aircraft noise annoyance," in *12th ICBEN congress on noise as a public health problem*, Zurich, 2017.

6.8 Appendix A8 – Controversial plans

Assessment of annoyance due to controversial plans

Annoyance in aviation

In the aviation industry it has become customary to classify airports in two categories: "high rate change airports" (HRC) and "low rate change airport" (LRC). The annoyance responses at these two types of airports are distinctly different.

Almost all airports experience an increase in traffic. For most airports this change is gradual, and the rate of change is low. However, some airports experience abrupt changes in operations such as the opening of a new runway, or a major carrier moves its hub to a new location. This can trigger a different response mechanism in the airport population. The same change in the response can be observed if controversial plans for future changes are being launched. Such airports are categorized high rate change airports. Unfavorable media attention can also trigger this type of HRC response. The average difference in the annoyance response has been found to be equivalent to as much as a 9 dB change in noise exposure. So, people at an HRC airport "tolerate" on average 9 dB less noise than people living near an LRC airport [1] [2].

Janssen and Guski have presented a definition of the two categories [2] and have shown that the effect of a change will linger for quite some time in the airport community. Janssen and Guski define an airport HRC if an abrupt change has occurred within 3 years before a survey and if controversial plans for a change less than 3 years in the future has been launched. Gelderblom *et al.* [1] indicate that the effect of a category change can be even longer.

Road traffic noise

There are no reasons to believe that a community exposed to road traffic noise will react very differently from and airport community but the magnitude of the effects may be different. If the community experiences large abrupt changes (major traffic changes, opening of a new road, etc.) it is likely that this will trigger an annoyance response similar to what can be observed at an HRC airport. Also plans for future changes that can be considered controversial («you know what you have, but not what you will get«) are likely to trigger an HRC response. Actions of community interests' groups and noise activists may also trigger this response.

In order to avoid this augmented annoyance response, it is therefore vital that plans for future changes are developed in close contact with the community, and the road authorities should strive to develop a mutual trust between themselves and the community.

Conclusion

The launch of controversial plans for a future change in a traffic situation that is not well anchored in the neighborhood community may change the annoyance response equivalent to a change in the CTL value of 5 – 10 dB.

Bibliography

[1] F. Gelderblom, T. Gjestland, S. Fidell and B. Berry, "On the stability of community tolerance for aircraft noise," *Acta Acustica united with Acustica,* vol. 103, pp. 17-27, 2017.

[2] S. Janssen and R. Guski, "Aircraft noise annoyance: In Evidence review on aircraft noise and health, Stansfeld et al, eds.," Directorate General Joint Research Center and Directorate General for Environment, European Union, Bonn, Germany, 2015.

6.9 Appendix A9 – non-controllable factors

Non-acoustical factors outside regular control

One of the objectives of the FAMOS project is to identify and quantify non-acoustical factors that have an influence on peoples' annoyance reactions to road traffic noise. A number of such factors have been discussed in a series of WP1 memos. However, this list of factors has been limited to factors that can be managed or controlled to a certain extent. Control is a matter of necessity if the objective is to use this factor actively in road planning and traffic control.

To complete the picture, we will briefly discuss a set of personal and demographical factors that may or may not be important for annoyance assessment. This information may be important when assessing the results from annoyance surveys.

Demographic factors

Age
Several authors report an age dependency [1] [2]. People aged 40-50 years seem to have the lowest tolerance to noise, whereas relatively young and relatively old people have a higher tolerance. The difference can be expressed in an equivalent shift in the noise exposure. This shift can be as much as 3-5 dB. In a recent survey on aircraft noise in England, the SoNA study, the response data was analyzed for two different age groups: 18-85 years old and 45-70 years old. The first group is the normal age range for these types of surveys. The other limited age range was used for half of the surveys included in a recent WHO recommendation on transportation noise annoyance [3] . For the SoNA study the difference between the two groups was equivalent to 4 dB in the noise exposure [4].

Use and dependency on noise source
People who depend or profit from a noise source are somewhat more tolerant than others. This has been shown for aircraft noise. People who depend on the existence of an airport, either for work or as a customer for goods and services, tolerate about 2.5 dB more noise than others. People who are frequent users of the noise source (frequent flyers or drivers) may tolerate 1-2 dB more noise [2].

Home ownership
It is often hypothesized that homeowners are more likely to have a negative attitude towards a noise source since the noise is likely to affect the value of their home negatively. This effect has been found to be equivalent to 1-2 dB shift in the noise level [2].

Other demographic factors
Other factors such as gender, social status, income, education and length of residency seem to have little influence on the annoyance assessment.

Personal factors
Several personal factors that affects the annoyance response have been identified. For aircraft noise, fear of accidents is by far the most important factors. People that are afraid a plane crash or other aviation-related disaster may hit them, tolerate up to 20 dB less noise in order to express a certain degree of annoyance [5] [2].

Likewise, personal noise sensitivity is an important factor. People who consider themselves highly sensitive to noise tolerate 10-12 dB less noise than others [2].

Other personal factors that have been found to affect the annoyance response, but only to a limited degree, are beliefs that the noise exposure could have been prevented, attitudes about the importance of the noise source, and annoyance with other non-noise related impacts. In the latter case noise is being used as a proxy for expressing discontent.

Conclusions

If the participants in a noise survey has been selected according to a proper random procedure, so that all «types of people» have the same probability to give their response, these personal and demographic factors will even out. Calculations have shown that about 300 respondents is enough to keep the confidence interval for the response function within acceptable limits [6]. Personal factors are assumed to be evenly distributed across a community, and it is unlikely that for instance only very noise sensitive persons are located in a specific area.

Some annoyance studies have been primarily designed to study other health effects which requires a special age range for the respondents. They HYENA project, for instance, was designed to study hypertension among residents near airports, and therefore the target was people likely to have noise-induced hypertension. The age range was therefore limited to 45 – 70 years. Due to age dependency the results from this study cannot therefore be readily compared with results from a general survey using a wider age range, 18-85 years old.

References

[1] P. van Gerven, H. Vos, S. Janssen and H. Miedema, "Annoyance from environmental noise across the lifespan," *J Acoust Soc Am,* vol. 126, pp. 187-194, 2009.

[2] H. Miedema and H. Vos, "Demographic and attitudinal factors that modify annoyance from transportation noise," *J Acoust Soc Am,* p. 3336, 1999.

[3] W. Babisch, D. Houthuijs, E. Cadum, K. Katsouyanni, M. Velonakis, M. Dudley, W. Swart and e. al., "Annoyance due to aircraft noise has increased over the years - Results of the HYENA study," *Environ. Int,* vol. 35, pp. 1169-1176, 2009.

[4] D. Rhodes, "UK Survey of Noise Attitudes," Civil Aviation Authority, London, UK, 2018.

[5] J. Fields, "Effect of personal and situational variables on noise annoyance in residential areas," *J Acoust Soc Am,* pp. 2753-2763, 1993.

[6] T. Gjestland and F. Gelderblom, "Sample size implications for calculations of community tolerance level values from social surveys of noise-induced annoyance," *J Acoust Soc Am,* vol. 146, pp. 1212-2018, 2019.

6.10 Appendix A10 – Information from external specialists

Contacts with external researchers

Under Task 1.3 it was planned to contact specially selected external researcher to find out if they could provide additional data and information to the FAMOS project, and to have their assessment of the preliminary conclusions that had been drawn.

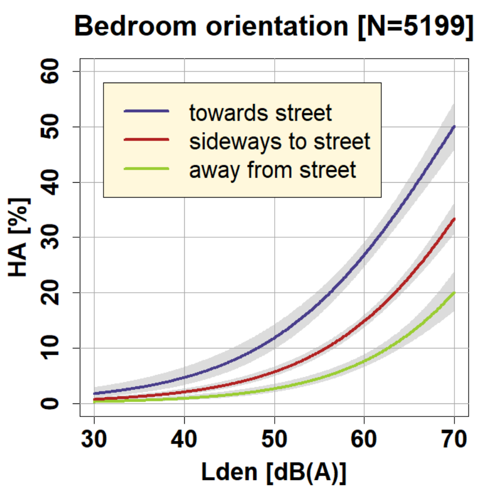
The format of these consultations was planned to be either a common workshop or one-on-one contacts. It was soon realized that the organization of a workshop would be complicated timewise, and rather expensive as the intention was to contact a large number of experts on road traffic noise annoyance. The Covid-19 situation also made a workshop impossible.

Fifteen researchers who had published papers on road traffic noise annoyance were contacted. We subsequently had several exchanges of e-mails with ten of these. The experts were mainly from Europe but also Australia and the US.

We soon realized that most of these experts had a psychological approach to the topic, and they were quick to point out that we had omitted personal and demographic factors in our analyses. Personal noise sensitivity was mentioned as one of the main factors for explaining the large variations in the annoyance response. Also factors like age, gender, length of residency, etc. were among those that contributed to the large spread in the survey data.

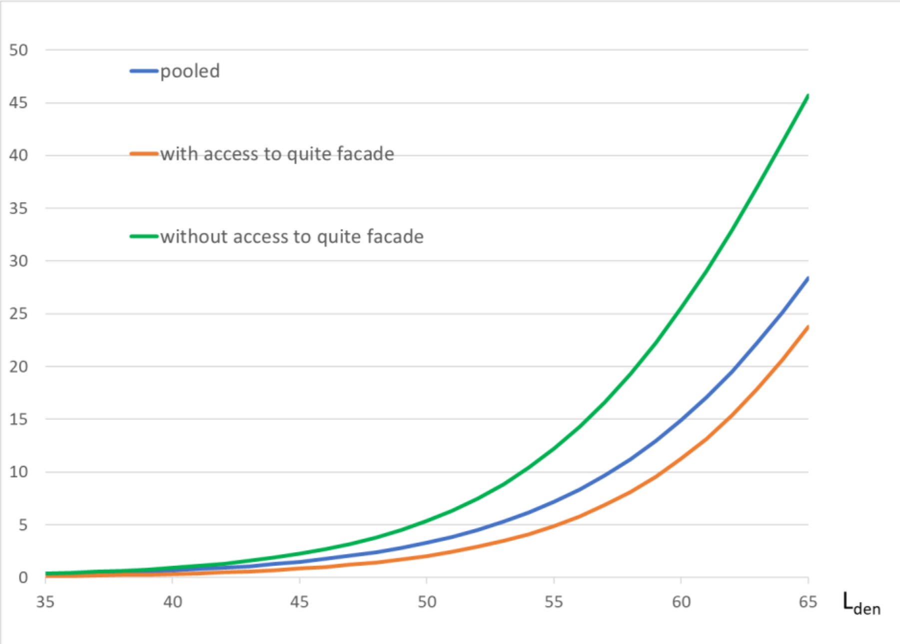
In our following exchange of information, we pointed out that in the FAMOS project we concentrated on factors that at least to some extent could be altered or manipulated by the road owner. One cannot presuppose that only people with certain personal characteristics will reside along a specific road.

In our preliminary conclusions we had estimated the effect of having access to a quiet side of the residence equivalent to a shift of 6 dB in the noise exposure. Many contacts pointed out that this was very conservative. A shift closer to 10 dB would be more appropriate, especially at higher exposure levels. I was pointed out that the importance of this annoyance-reducing factor increased with increasing noise levels.

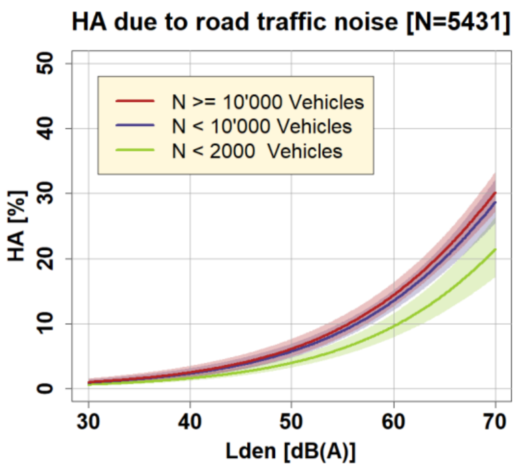


Unpublished data from the SIRENE project shows bedroom orientation could amount to a shift in noise exposure equal to about 15 dB

Unpublished results from another survey on noise annoyance confirms the effect of having access to a quiet façade, but the effect is smaller, about 5-6 db.

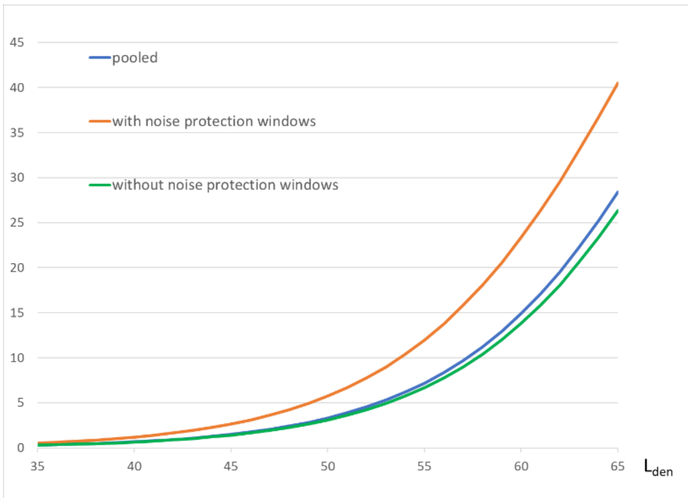


The findings regarding a *number effect* was also confirmed. At equal noise levels a high number of vehicles is more annoying than a small number of vehicles. We had estimated the effect to about 5*log (N/n). Unpublished data from the SIRENE project show that the effect may be even larger.



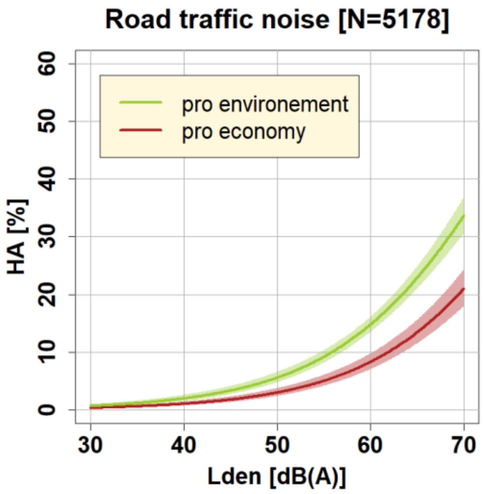
In a research paper submitted for publication the effect of visual greenery had been estimated to equivalent to 5 dB shift in the noise exposure. This is somewhat less than we concluded in Memo 5. However, an interesting observation was published by Vienneau et al. (Env.Int. 2017, vol 108, p 176): «More than clean air and tranquility: Residential green is independently associated with decreasing mortality.» This latter research paper stresses the importance of visual greenery to promote general well-being and thus confirms the annoyance-reducing effect of visual greenery.

A clear indication that the annoyance response is controlled by other factors than the noise itself was confirmed by another yet unpublished survey on road traffic noise. Under a special noise abatement program people that were very annoyed by road traffic noise could apply for funding to have the facades of their residences improved (change to special sound insulated windows). One would assume that this would lower their annoyance corresponding to a lower indoor noise level. However, their annoyance response was still high after the windows had been installed, and significantly higher than those residents that had not applied for façade improvement.



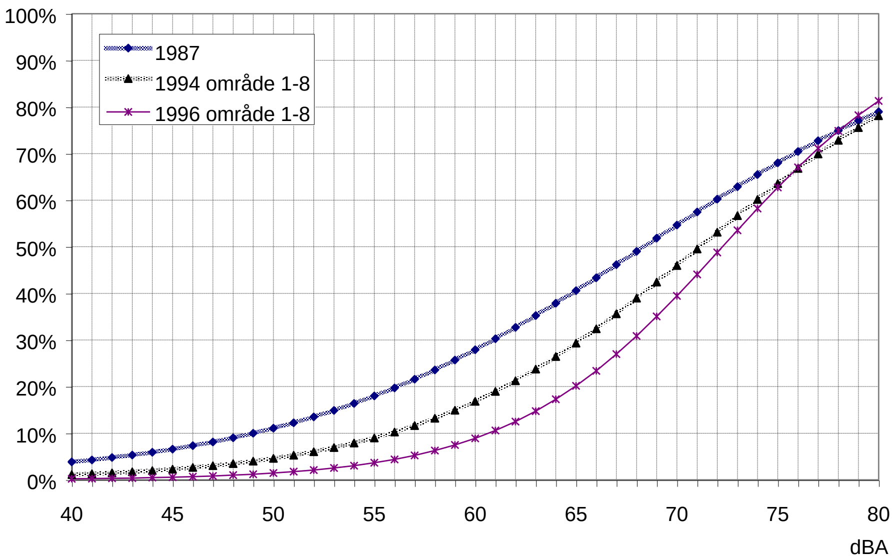
The researcher behind this study offers two alternative explanations. Either the annoyance response is very stable and drastic changes are necessary in order to modify it, or the residents' expectations regarding the improved situation were not met, and this fact eliminated the effect of the lowered indoor noise level.

Attitude in general is an important modifying factor. Not only attitude towards the road owner but also attitude towards the environment and the community in general. Unpublished data from a recent study show that people that have a «pro-environmental attitude» are more annoyed by road traffic noise than those who favor economic growth.



The results from a comprehensive study in Oslo revealed that not only the noise level at the most exposed façade, but also the general noise level in the immediate neighborhood is important for the annoyance response.

The traffic situation in a part of Oslo was constantly improved over a period of about ten years. The traffic was concentrated to designated main roads thus reducing the traffic in many small roads throughout the community. Annoyance surveys were conducted at regular intervals to monitor changes in the response. The change in the annoyance response due to a lowering of the neighborhood noise was quite substantially. After the traffic improvement project was completed the average exposure-response curve for the community was lower than the Miedema curve.



Exposure-response curves for various levels of neighborhood noise. From 1987 to 1996 the traffic situation in the community was vastly improved and the general neighborhood noise was reduced substantially.