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Moderation of people's subjective reactions to road noise

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Abstract

When the road administrations have used all technically feasible and economically possible measures to reduce the noise, there can still be a need for further reduction of the annoyance. Analyses reveal that only about 1/3 of the variance in the annoyance response is caused by the noise level itself, the other 2/3 are determined by so-called non-acoustic factors. The annoyance response therefore can be altered without changes to the actual noise level. The FAMOS project quantify how different factors modify people's subjective reactions to traffic noise. A literature survey has been carried out and experimental tests using sound walks, questionnaires and listening tests have been performed. The result was a European guidebook with practical applications for the National Road Administrations on how to handle noise annoyance by non-acoustic moderators in planning of roads etc.

Keywords: Road noise; annoyance; reduction; guidebook.

1. Introduction

Even when the road administrations have used all the technically feasible and economically possible measures to reduce the noise, there might still be a need for a further reduction of the annoyance perceived by people exposed to road noise to achieve acceptable conditions. Former analyses of the results from noise surveys reveal that only about 1/3 of the variance in the annoyance response is caused by the noise level itself. The other 2/3 are determined by other factors, among these are those often referred to as “non-acoustic factors” (Guski, 2017). According to the World Health Organization (WHO), road traffic noise is one of the most important environmental risks to health” and a major contributor to 1.6 million healthy life-years are lost annually in Europe due to road traffic noise, (WHO, 2018). About half of these can be related to the subjective element “annoyance.

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The surveys display a wide range for the annoyance response. Differences in noise levels of up to L_{den} 20-25 dB to evoke a certain percentage of annoyance are not uncommon, (FAMOS, 2022-B). This means that the annoyance response can be altered within wide limits without doing any changes to the actual noise level. So, when all practical noise reduction measures have been applied, the noise impact can still be reduced by making changes in the non-acoustic factors known to moderate the annoyance response. The FAMOS project is about analysing and testing if non-acoustic moderators for noise annoyance can be a promising tool for obtaining an additional supplement to other noise and annoyance mitigation measures to reduce the annoyance without reducing the noise level further. Non-acoustic moderators in FAMOS covers a large range of "activities" from performing a very good public participation process integrating the neighbours of a road in the decision process, over having access to silent side, to using greenery to improve the visual environment. FAMOS has been initiated by the Conference of European Road Directors (CEDR) and funded by the CEDR members of Belgium – Wallonia, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom. FAMOS is the acronym for "FActors MOderating people's Subjective reactions to road noise". The project consortium consists of the partners FORCE Technology (Project leader), LÄRMKONTOR and SINTEF.

2. The "Annoyance equivalent noise level shift"

Reports from previous surveys of annoyance caused by road traffic noise have been systematically analysed in order to describe the different annoyance moderators, (FAMOS 2022-B). Scientific methods have been used to find, extract, and analyse data and turn the results into models formulated for practical use. It has been quantified how different factors modify people's subjective reactions to road traffic noise.

The "Annoyance Equivalent noise level Shift", Leas, is the (hypothetical) shift in noise level that will give the same change in annoyance as the presence or absence of a moderator. This is a practical way to express the effect of a moderator. It should not be confused with any actual changes in noise levels. At the same noise level, persons who are not affected by one moderator (blue curve in Figure 1, e.g. "traffic visible") could be more annoyed than people that are affected by a moderator (orange curve in Figure 1, e.g. "traffic not visible"). The difference of percentage of Highly Annoyed may e.g., be 30 % points. The same annoyance reduction may be observed by lowering the noise level L_{den} by 13 dB (see the black arrows in Figure 1). The "Annoyance equivalent noise level shift", L_{eas} in this case is about 13 dB. In this example the moderator will change the annoyance response in the same way as a reduction of about 13 dB in the noise level.

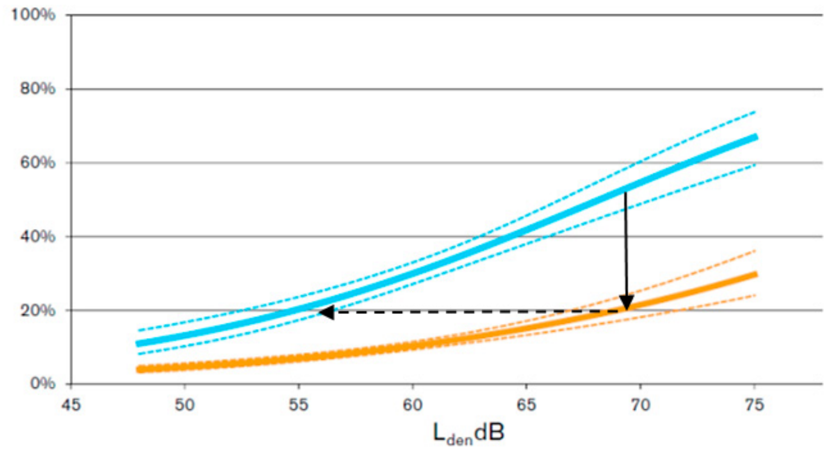

Fig. 1. The blue curve shows an example for the percentage of people being highly annoyed in a situation without moderators. The orange curve shows the percentage of highly annoyed in a situation where a moderator has been implemented.

3. Moderator search and qualification

As a main fundamental of the FAMOS project, the identification of possible moderators was carried out through an international literature study of previous noise annoyance surveys, (FAMOS, 2022-B). It revealed that several factors can change the perceived annoyance by people exposed to road traffic noise, (FAMOS, 2022-B). Reducing the noise is an obvious factor, but many other factors have an influence on the annoyance. Moderators are factors that can change the relation between the noise exposure and the perceived annoyance response.

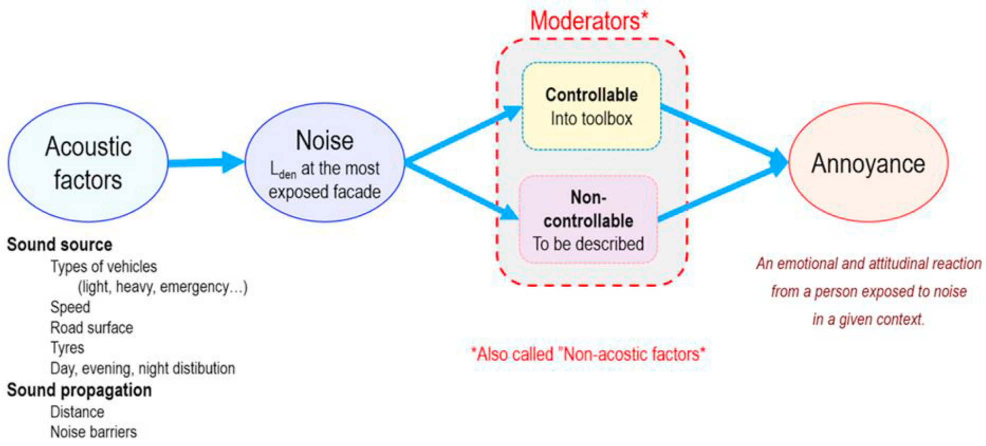

Fig. 2. Connection from acoustic factors leading to noise and moderators influencing the perceived annoyance, (FAMOS, 2022-B).

The non-acoustic factors that will modify the annoyance response can be categorized in different ways:

- 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 – the road administration.
- Factors pertaining to the neighbourhood such as type and location/orientation of residences, prevalence of community conveniences like shops, schools, parks, playgrounds, etc. neighbourhood traffic conditions and so on. These factors can only to a small extent be influenced by the road owner. Options for control are better at completely new developments than for projects in existing communities.
- Relationship between the local residents and the road owner. Do the residents 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 the residents/neighbours trust the decision makers and road administration? These factors deal with public relations and can to a large extent be controlled and managed by the road owner.
- 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.

The results from surveys on annoyance from road traffic noise indicate that the annoyance response is affected by a set of non-acoustic factors in this project defined as moderators. The influence of these moderators, i.e., the magnitude of the effect, varies, and the feasibility and practicality of manipulating these factors depends on local circumstances. The objective of the FAMOS project was to focus on moderators that have a large potential for annoyance reduction, and that are easily implemented by road administrations.

4. Data collection, hypothesis testing and modelling

Three different methods for data collection on perceived noise annoyance were investigated in FAMOS within a limited experimental setup to investigate the suitability of methods for measuring the effect of moderators in future road projects, for hypothesis testing of the order of magnitude for already identified moderators and for gap filling for knowledge missing for important moderators retrieved, (FAMOS, 2022-B). The methods used were:

- Soundscape measurements (sound walks)
- Mini survey using questionnaires
- Listening tests performed in the laboratory

The soundscape measurements (sound walks) (FAMOS, 2022-B) are performed by a group of persons who on a tablet evaluate the soundscape at different locations. The soundscape measurements were successful in the sense that they gave a good representation of the sound sources in a sound source hierarchy. The results gave detailed characteristics of the six measuring positions used. A "systems factor map" could be constructed, which gave a clear picture of the relations between the six measuring positions, and why they differed. By combining the assessments of annoyance from the sound walks with the measured noise levels it was possible to make a model (dose-response curve) for the annoyance as function of the noise level (L_{Aeq}) with a good fit (R2 = 0.9). The results for the moderators greenery and the visibility of the traffic are summarized as part of the hypothesis testing.

The mini survey, (FAMOS, 2022-B) based on questionnaires was designed with limited extent and the non-personal address of respondents. A general correlation and a confirmation of earlier project results was assessed. As for noise annoyance in general, the responses mostly showed an expected outcome although several respondents reported a higher annoyance although the noise levels were supposed to be reduced. Results for as well visibility and greenery as expectations and expectations met were analysed as part of the hypothesis testing. Overall, the results showed that moderators previously identified in the FAMOS project had a contribution to the perceived noise annoyance. A quantification on the effect, i.e., changes in noise level, could not be derived due to the low number of participants.

The listening tests, (FAMOS, 2022-B) are performed in the laboratory where a group of assessors (listeners) are presented for road traffic noise at various locations and at the same time a video of the location. Several locations were selected so that there were variations in moderators of interest (visibility of the traffic, amount of greenery, type, and appearance of noise screens). For all positions, a significant increase of the annoyance with the noise level increasing was found. From the results on the annoyance assessments, logistic dose-response curves could be constructed with a good fit (R2 > 0.95 on the mean values). The dose-response curves show that the visual perception has a clear and significant influence on the perception of annoyance from the noise. Differences in the annoyance corresponded to level differences, the annoyance equivalent change in noise levels, up to 4 dB for the same sound stimuli. Some of the results deviated from findings elsewhere and it was concluded that it is important that the assessors (the persons participating in the test) have a full understanding of the context, e.g., by a short introductory video tour showing the road and its surroundings or by using virtual reality to enhance the assessors envelopment in the scenario.

Supplementing the findings of the first work packages additional modelling ways concentrated on the most relevant moderators already retrieved. Based on input from the two large Danish questionnaire surveys on perceived noise annoyance, (Bendtsen et al., 2014) and (Danish Road Directorate, 2016) the models developed could demonstrate the effect of various moderators, (FAMOS, 2022-B). The models provide strong evidence for the effect of the moderators that are found significant in this study, (FAMOS, 2022-B). The data from the Danish studies had a very high quality and covered a broad range of questions, many of which were identified in the literature as relevant. This confirms the findings in the literature study to a large extent. The contribution of the modelling was also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of "questions of importance" to be used in future studies.

5. Summary on moderators of noise annoyance

Evidence was found that a wide range of moderators affects the noise annoyance, (FAMOS, 2022-B). The "direction" of the effect size, it depends on the situation itself: when implementing a "favourable moderator", like improving greenery, the effect size works towards "lower annoyance".
Whenever a moderator is removed (like greenery) or changed towards a less favourable situation (like increase in neighbourhood noise), the same effect might occur towards "higher annoyance". The selected moderators and their order of magnitude can be seen in Figure 3. Except "trust/acceptance", only the "positive effect" is plotted. This depicts the possible gain that is achievable by road administrations for each moderator, based on a situation "without positive influence of a moderator". For "trust/acceptance", the possible effect size of ± 10 dB shows that this moderator might in most cases have an "average" from which a change is possible in both directions. So even without further influence or consideration, the annoyance might increase.

Moderator	Effect size
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	5 to 8 dB
Low/no visibility of the road	2 to 10 dB
Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB
Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

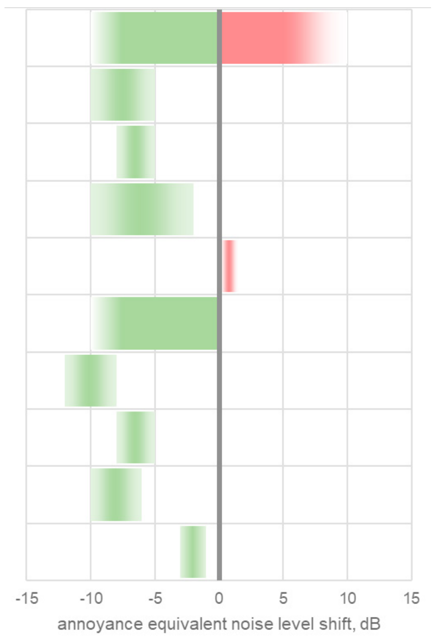

Fig. 3: Overview on effect sizes of moderators, (FAMOS, 2022-B).

Regarding uncertainties, the literature analysis shows a high variance in the annoyance equivalent noise level shifts for some moderators between different surveys. Results of listening tests, mini surveys and sound walks also showed a high uncertainty, mostly due to a low number of respondents. For some moderators, dependencies and interactions can be found. The effect size suggests that the effects are not simple to combine for different moderators, as they would result in a total change higher than actual noise levels (e.g., ± 10 dB for trust, up to 10 dB for expectations, 10 dB for vegetation and greenery and so on).

6. The moderators

6.1. Attitudes towards authorities and road owners

Many annoyance surveys indicate that the relationship between the authorities (noise source owners) and the neighbourhood is an important non-acoustical moderator, (FAMOS, 2022-B). People that have a high trust in the authorities and believe that a road is being constructed to impose a minimum impact on the neighbourhood 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. Overall, trust and acceptance can yield in an annoyance equivalent noise level shift of about 20 dB from highest trust to lowest trust. This effect can be taken into account "two ways" based on an "average trust", i.e. resulting in a possible shift of 10 dB towards "less annoyance" for good trust and a shift of 10 dB towards "higher annoyance" for mistrust. The FAMOS project did not investigate how this moderator changes/evolves. Trust and acceptance are likely no steady constant that will remain at a certain value over a longer period of time. It may change due to changes in residents (residents leaving the area, new residents moving in) or by external influence (e.g., from other projects in other areas). However, events influencing trust and acceptance (both positive and negative) may just fade after a longer time, making the influence on annoyance smaller.

6.2. Expectations / 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), (FAMOS, 2022-B). 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 an annoyance equivalent noise level shift of about 9 dB. Attention is needed if plans for future changes are launched, especially if these plans are controversial and not rooted properly in the community. This is especially the case when large and abrupt changes occur. An unfortunate presentation of plans of noise mitigation can trigger adverse actions in the community and thus can completely reverse the expected positive effects. The effect of expectations and expectations met can result in a shift of about 5-10 dB. This is about the same shift that can be expected from the erection of a typical noise barrier or extensive noise mitigation measures of the local traffic situation in an existing community.

6.3. 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, (FAMOS, 2022-B). At equal noise levels, a high number of vehicles appear to be more annoying than a small number. The annoyance equivalent noise level shift has been reported to about 1.5 dB per doubling of the number of vehicles.

6.4. Safety expectation

People may feel unsafe about both local and national roads in their neighbourhood. For local roads, typically belonging to the municipalities, improvements could be affected e.g., by reduced speed, speed control, humps, chicanes, bike lanes, pedestrian crossings, traffic light regulation, removing heavy traffic to other routes etc. NRA could help the municipality with technical advice and also money to do the improvements. For national roads, the perceived safety can also be influenced by the proximity of traffic to residential usage and the presence or absence of guardrails speed limits and speed control. The effect corresponds to an annoyance equivalent noise level shift of about 5 dB, (FAMOS, 2022-B).

6.5. Vegetation and greenery influencing the visual appearance of the surroundings

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 little or no effect as a noise-reducing element, but never-the-less such elements may cause a reduction in the annoyance equivalent noise level of as much as 10 dB, (FAMOS, 2022-B). However, it is a well-known fact that the physical design of the top of a noise barrier is important for the performance. Trees or bushes on or near the top can act as diffraction elements and thus reduce the effective height of the barrier. This must be taken into consideration when using greenery as an annoyance-reducing element. Regarding the effect of vegetation, a decrease in vegetation and greenery can often occur after trimming of bushes and cutting of trees as part of maintenance that is carried out every couple of years. This should be considered as it may have a major influence on noise annoyance (increase due to reduced vegetation/greenery), maybe even leading to loss of trust/acceptance.

6.6. Noise barriers (expectations and visual appearance)

Noise barriers are often used as a means to reduce the noise from a major road. Different constructions and different materials are being used; earth berms, solid walls made of concrete, steel or wood, transparent walls made of glass, etc. The walls may be acoustic 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, dependent on as well the distance to the road as to the receiver. 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 metres will provide an insertion loss of up to about 10 dB. A typical noise barrier will provide an insertion loss of about 6-12 dB, but the subjective effect, i.e., the corresponding reduction in the annoyance equivalent noise level is dependent on a number of other factors.

The physical effect, i.e., the reduction in noise level, may often be offset by an opposite shift in the annoyance response. This is partially due to expectations (see “Expectations / public participation” on the previous pages) which can result in a shift of 5-10 dB, (FAMOS, 2022-B). Regarding the visual appearance, the influence of the design itself is mostly unclear, but most likely lower with about 2 dB, (FAMOS, 2022-B). Greenery and vegetation may result in a higher shift (see section on “vegetation and greenery” above).

6.7. Locations and orientation of residences / access to a quiet side

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 especially 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 reduce the annoyance equivalent noise level by about 10 dB, (FAMOS, 2022-B).

6.8. Neighbourhood soundscape

It has been shown, (FAMOS, 2022-B) 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 neighbourhood, i.e., the outdoor area around the dwelling. Neighbourhoods characterized by general high levels of road traffic noise are assessed as being more annoying than a quieter neighbourhood even if the residence is not directly exposed to this noise, (FAMOS, 2022-B). It may therefore be worthwhile to re-direct the neighbourhood 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. Based on observations from Oslo FAMOS estimate that the annoyance equivalent noise level shift may be up to 10 dB, (FAMOS, 2022-B).

The knowledge found on these moderators has been used as the foundation for developing the FAMOS guidebook (Guidebook how to reduce noise annoyance, (FAMOS, 2022-A)) that road administrations can use in planning of new roads, enlargements of existing roads, road maintenance as well as in noise abatement projects.

The Guidebook also contains examples for different situations on possible effects of those moderators and gives indications on how to implement measures to address those moderators.

7. Outlook

In the FAMOS project, a series of moderators was researched that can change the noise annoyance by people living in neighbourhoods exposed to road traffic noise e.g., from motorways. The effect of these moderators is present even though no measures are taken to reduce the actual noise levels. Primary research subject were acoustic moderators that could be controlled by (national) road administrations. Non-controllable factors and non-acoustical factors (such as personal factors) are not investigated. To facilitate future data collection, the FAMOS project has also tested three rather simple methods to investigate the perceived annoyance of road traffic noise. Insights on conducting those methods can help road administrations in order to investigate the effect of new road or noise abatement projects (best practice / worst practice). Valuable information includes information on number of respondents, suggestions for common questions, situations/locations for surveys etc.

Results of similar surveys can be used to derive new and improved information about moderators and their effect on perceived annoyance. Elaboration of a common basis for questions to be used in surveys would be helpful for getting more and more reliable data on the effect of the moderators. An advanced data foundation from surveys will make it possible to improve the models for noise annoyance including the influence of the moderators. Questions relating to the moderators should be included in the survey questions in future surveys (for inspiration find the questions used in the Motorway and Copenhagen study, (Bendtsen et al., 2014) and (Danish Road Directorate, 2016) which is the basis for the modelling in this project and the mini survey for the Hamburg region, (FAMOS, 2022-B).

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