The effect on annoyance estimation of noise modeling procedures

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INTRODUCTION

Worldwide the impact of noise exposure on a community is estimated by the percentage highly annoyed. The proper determination of the percentage highly annoyed depends among other factors related to the quality of the survey (sample size, selection, questionnaire) also on the quality of the noise assignments related to the type and quality of the modeling procedure. Meta-analyses have demonstrated large variations in the exposure-annoyance curves and described personal, environmental and social factors which may be responsible for these differences (Job 1988; Fields 1993; Miedema & Vos 1999, 2003; Miedema & Fields 2005). Even when these individual differences are accounted for, Fields et al. (2000) have observed that on average the community response still differs the equivalent of about 7 decibel in noise exposure. At the last ICBEN conference Fields (2003) stated "There is almost no research" into these differences. It would, however, be important to investigate the determinants of these differences, "because it identifies communities that might be treated differently in noise regulations". In practice, several modeling standards and minor or larger variations of these coexist. Hitherto, a systematic cross-validation of the effect of the various modeling procedures on the estimation of the percentage highly annoyed in community studies is missing. Realizing this fact, the European community has spent a lot of research money (Harmonoise & Imagine projects) to establish a new modeling standard. This new standard should account better for topographical and meteorological conditions which vary a lot across (not only) Europe (low and high land, coastal regions). It should guarantee that the costly noise mapping exercise – enforced by the Environmental Noise directive (END) – actually leads to what is intended: to get reliable cross-national estimates of the percentage of people exceeding certain thresholds of noise exposure (e.g. 55 dBA or 65 dBA) by 2012. Furthermore, utilizing the exposure-effect curves from the END appendixes (Miedema & Oudshoorn 2001) reliable percentages of highly or moderately annoyed for various noise indicators (Lden, Lnight) should be calculated.

The Alps can be considered as a specific case in terms of orography, climate and meteorology and hence a real challenge for noise modeling. The ALPNAP project ("Monitoring and Minimisation of Traffic-Induced Noise and Air Pollution Along Major Alpine Transport Routes") was funded to describe the Alpine-specific processes that determine the propagation of air and noise in Alpine valleys and their impact on health. One collaboration across disciplines aimed at assessing the effects on the estimation of the percentage highly annoyed in an alpine valley for rail and main road traffic due to the use of different modeling techniques (ISO9613 (Bass3 by INTEC), NMPB-96 (Mithra-Sig by CSTB). Additionally, for motorways the Harmonoise/Imagine method (implemented by INTEC and CSTB) was evaluated. It should be stressed that the same source power for road vehicles and trains is used as well as the same traffic densities and thus the differences between these models only originate from differences in approximation of the propagation term.

METHODS

Area, sample selection and recruitment

The area of investigation, the Unterinntal, is the most important access route for heavy goods traffic over the Brenner. The goods traffic over the Brenner has tripled within the last 25 years and the fraction of goods moved on the road has substantially increased (up to 2/3). The area consist of small towns and villages with a mix of industrial, small business and agricultural activities. The primary noise sources are highway and rail traffic. In addition a main road is of importance. This road links the villages and access roads to the highway.

People were contacted by phone based on a stratified, random sampling strategy. The address base was stratified by use of the GIS (Geographic information system), based on fixed distances to the major traffic sources (rail, highway, main road), leaving a common „background area“ outside major traffic activities and an area with exposure to more than one traffic source “mixed traffic”. From these five areas households were randomly selected and replaced in case of non-participation. Selection criteria for people were age between 25 and 75 years, sufficient hearing and language proficiency. An exclusion criterion was duration of living less than one year at this address. 45 % did not want to participate. The rest of the addresses were not valid (commercial etc), did not have telephone or could not be reached by 3 attempts at different times of the day. Eventually, 1,643 persons (35 % of the original sample on an individual basis), participated in this study. On household level the participation was much higher. Women were more willing to participate (61 %).

Noise exposure assessment

Three groups of traffic noise sources are covered: Motorway traffic, traffic on main roads, and railway traffic. For motorway traffic the yearly average load (light and heavy vehicles) is combined with an average diurnal traffic pattern. Traffic frequency data on main roads were supplemented with additional counting data. Road traffic noise emission is calculated on the basis of the Harmonoise source model (Jonasson 2007). Railway noise emission is extracted from a typical day of noise immission measurements at close distance to the source. Bass3 is an extended version of ISO9613. The model includes up to four reflections and two sideway diffractions (de Greve et al. 2005, 2007).

Mithra-Sig is the NMPB-96 implementation by CSTB, the current standard engineering method recommended by the END for road traffic modeling.

The Harmonoise/Imagine point-to-point propagation model is a candidate European standard engineering model that builds upon the Nord2000 project (van Maercke & Defrance 2007; Defrance et al. 2007). It promises better performance in complex terrain – but is computationally quite intensive and some simplifications had to be made to be applicable in such a large area. Only one reflection and two vertical diffraction edges were accounted for in this implementation.

An extensive noise monitoring campaign was conducted to check the validity of these simulations. At 38 locations sound levels were recorded for over one week during winter (October to January) and during summer (June to August). In addition, the predicted sound pressure levels resulting from PE-modeling have been evaluated against these long-term measurements (van Renterghem et al. 2007).

Indicators of day, evening, night exposure and Lden were calculated for each source and total exposure at several points on the facade of the building of the survey participants. In the present analyses Lden of the respective sources was utilized.

Questionnaire information

The questionnaire covered socio-demographic data, housing, satisfaction with the environment, general noise annoyance, attitudes toward transportation, interference of activities, coping with noise, occupational exposures, lifestyle, reported sensitivities, health status, selected illnesses and medications. The phone interview took about 15-20 minutes to complete Noise annoyance was measured with a 5-point verbal scale according to ICBEN and ISO standards (Fields et al. 2001; ISO TC 43/SC 1, 2002). In the present analyses, highly annoyed was defined by responses to the two upper points (4+5) on the 5-point verbal scale.

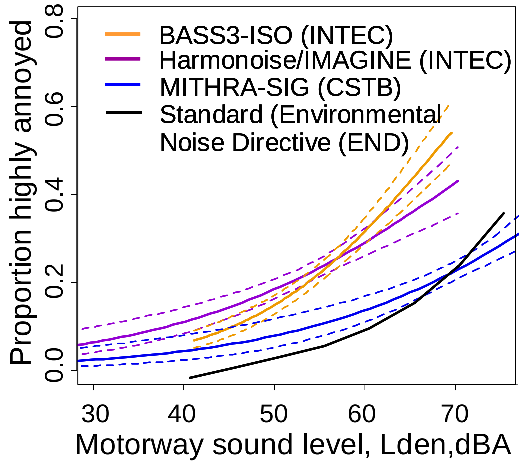
Statistical analysis

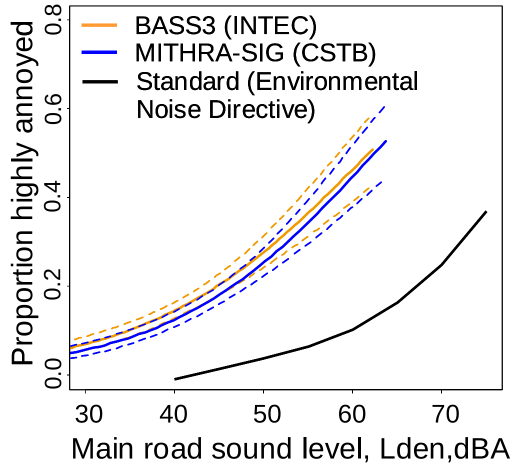
Exposure-effect curves were calculated with extended logistic regression methods using restricted cubic spine functions to accommodate for non-linear components in the fit if appropriate (Harrell 2001). The non-parametric regression estimate and its 95 % confidence intervals are based on smoothing the binary responses and taking the logit transformation of the smoothed estimates. The analysis was carried out with R version 2.4.1 (R Development Core Team 2006) using the contributed packages “Design” and “Hmisc” from F Harrell.

RESULTS

Figures 1, 2 and 3 show a side-by-side comparison of the noise-annoyance relationships for motorway, main road and railway sound levels for BASS3-ISO, MITHRA-SIG and HARMONOISE/IMAGINE (only motorway) noise modeling. For comparison, the standard exposure-annoyance curve (from END) is inserted (black line) in addition. For motorway noise, the sound modelling with MITHRA-SIG shows reasonable agreement with the standard curve, except for an underestimation at higher sound levels. Both, the BASS3-ISO and the HARMONOISE/IMAGINE modeling depart substantially and indicate higher annoyance at any noise level.

The strongest deviation from the standard curve is observed in the main road graph while both modeling techniques agree quite well. Railway annoyance (Figure 3) is increasingly underestimated at higher levels by MITHRA-SIG modeling - but much less when compared with motorway sound modeling.





Figures 1 and 2: Exposure effect relationships: highly annoyed by motorway (left) and main road sound exposure (right) by different noise modelling procedures compared with the standard curve (Environmental Noise Directive). Dashed lines indicate 95 % confidence intervals.

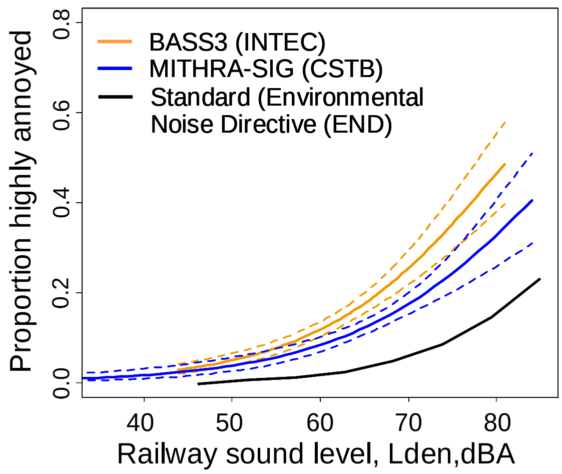


Figure 3: Exposure effect relationship: highly annoyed by railway sound exposure by two modeling strategies and compared with the Standard annoyance relationship

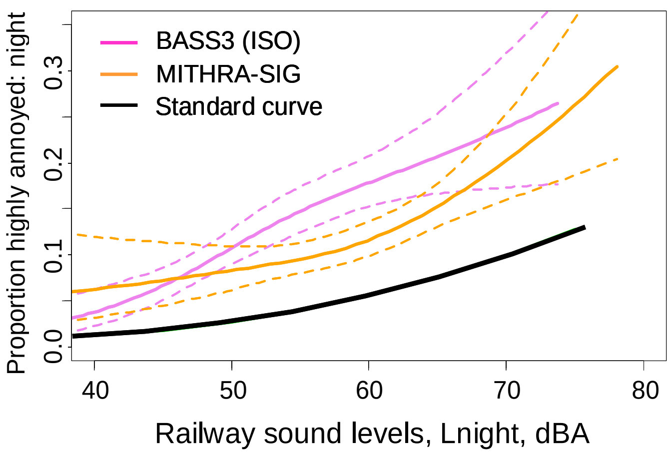


Figure 4: Exposure effect relationship: highly annoyed by railway exposure **during night** by two modeling strategies and compared with the Standard annoyance relationship

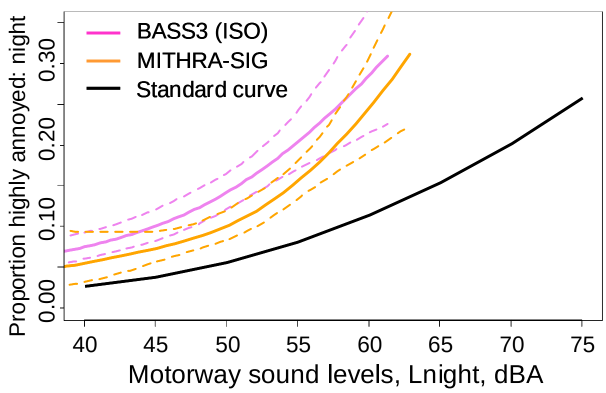


Figure 5: Exposure effect relationship: highly annoyed by motorway exposure **during night** by two modeling strategies and compared with the Standard annoyance relationship

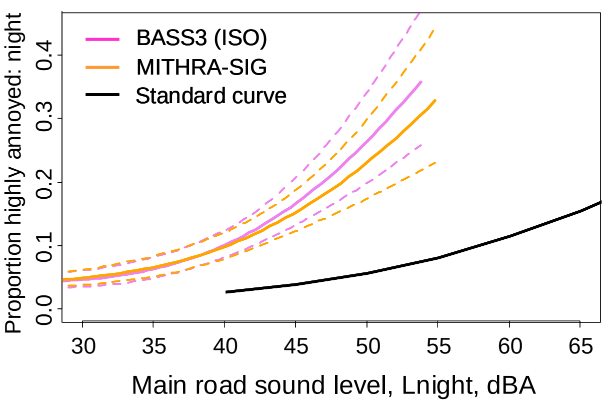


Figure 6: Exposure effect relationship: highly annoyed by main road exposure **during night** by two modeling strategies and compared with the Standard annoyance relationship

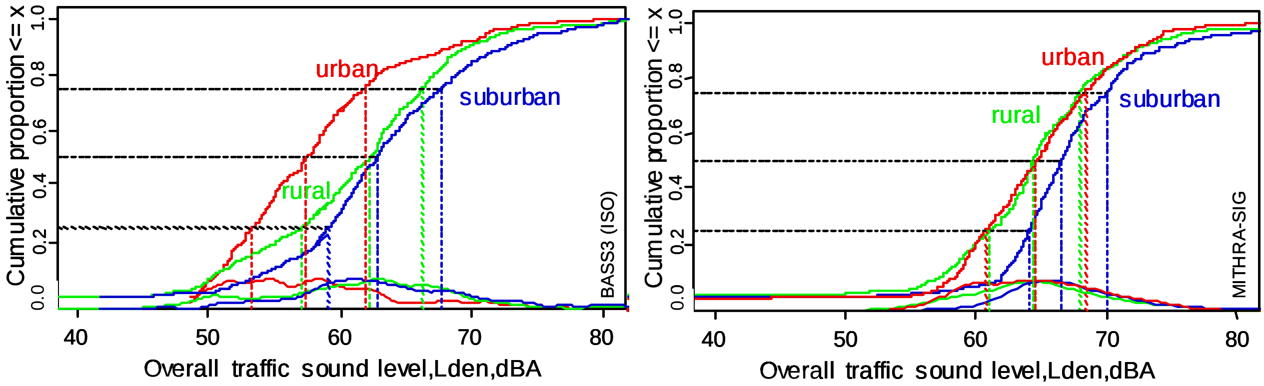


Figure 7: Cumulative distribution of sound levels by subregion displaying three percentiles (25th, 50th, 75th) for a comparison with two sound modeling procedures (ISO left, Mithra right)

Viewing the modeling differences between Mithra and Bass3 for the Lnight-indicator (Figures 4, 5, 6) it is evident that they are not completely mimicking the differences seen with the Lden-indicator. Especially, the motorway curve shows a smaller systematic difference and the difference for the railway is shaped in another way. However, the distance of the annoyance curves to the standard curves remains about the same.

The cumulative distribution plots by region (Figure 7) reveal different values in urban and rural areas for the models. MITHRA tends to give higher values here.

Figure 8 gives an estimate of the mapping effect size in two situations. The prevalence at higher sound levels (>70 dBA) is over- and at lower levels under-estimated by Mithra mapping. The difference in the estimation is much larger for the fraction below 55 dBA which is not surprising since overall accuracy is lower.

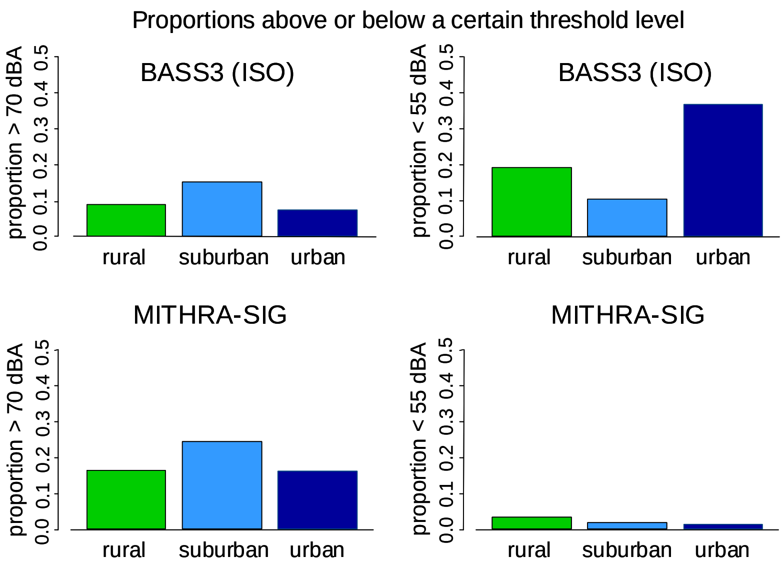


Figure 8: Proportions of sound levels above 70 dBA (left side) and below 55 dBA (right side) by region and type of sound level calculation (BASS3-ISO upper graphs, MITHRA-SIG lower graphs)

DISCUSSION

By independent comparison of standard techniques in noise modeling we could demonstrate significant differences in the estimation of the highly annoyed.

The best agreement among the modeling procedures was found for main road noise followed by railway noise exposure. The largest discrepancy observed was with motorway noise. The HARMONOISE/IMAGINE mapping implementation was closer to the ISO-variant Bass3 than to Mithra.

Because no gold standard is available for comparison it cannot be decided on the ground of this study what is the truth.

The comparisons between the regional annoyance curves and the standard curve from the END have revealed that all curves show higher annoyance at the same sound exposure. The strongest departure in annoyance is observed with main road noise exposure which shows a steeper slope than motorway noise. Around 60 dBA, the underestimation of the percentage of highly annoyed by the standard exposure response would be more than 25 %. This substantial departure from the standard curve is likely to reflect a recent increase in the exposure to traffic which bypasses the motorway due to the introduction of restrictions for trucks, a new toll on the motorway and increasing traffic jams.

On the other hand – although both motorway and railway annoyance are higher than in the standard curve at the same sound level – annoyance due to railway noise is lower than due to motorway noise. A comparison with an identical survey ten years ago (Heimann et al. 2007) has shown a decreasing annoyance prevalence and a "normalization" of the exposure response curve – probably due to an extended noise abatement program over the years and less reported annoyance from rail induced vibrations. However, the separately asked question about annoyance during night still shows larger percentages of highly annoyed by rail than by motorway (Heimann et al. 2007).

The annoyance due to noise from the motorway is still at a high level. Mithra noise mapping would underestimate the percentage highly annoyed at 70 dBA against HARMONOISE/IMAGINE mapping by 20 % and even 30 % against the Bass3-ISO mapping implementation.

Furthermore, the different estimation of the population exposure above or below a certain threshold or guideline by Mithra and Bass3 is another worrying finding of relevance for planning, risk assessment and noise control.

The findings about the different performance of Bass3 and Mithra in urban versus rural areas may be an important reason for the different population exposure assessment of these two mapping methods.

The evaluations carried out in this comprehensive study differ in some relevant aspects from previous validation work (van Leeuwen 2000; Lui et al. 2006; van Renterghem et al. 2007).

- Earlier evaluation studies were conducted predominantly in "easier" open area propagation conditions. This study performed in complex terrain and under the difficult meteorological conditions of alpine valleys.
- The sound propagation had to be calculated for much larger distances (> 1000m) from the main sources and for rather different pattern of residential living (urban, suburban, rural settings).
- Previous evaluations of sound propagation models focused on the comparison between predicted sound levels and levels from long-term measurements.
- This study related the results of the various modeling procedures to the actually reported annoyance and hence was able to evaluate the effect different

noise propagation models have on the human perception of sound from different sources (road, motorway, railway).

- For the first time the candidate European standard engineering model (HARMONOISE/IMAGINE) was evaluated against standard models under real life conditions.

While the evaluations conducted in this study definitely are not able to decide which of the modeling results are the "real truth" – the observed differences should be seriously considered.

The observation that the European candidate model is not performing superior in the mapping of motorway sound than the older ISO-implementation in Bass3 is another important result which needs further confirmation in annoyance based evaluation studies in other areas. The much larger computational effort forced the introduction of approximations that could have counteracted the potential benefits in this study.

Eventually, some of the differences in the comparison of the exposure effect curves may also be due to the restricted assumption which underly the standard curve: namely, that the curve crosses zero somewhere between 40 and 45 dBA. This assumption was not considered reasonable in this study due to relevant exposure occurance below these values in alpine areas.

CONCLUSION

The substantial effects different noise mapping procedures may exert on annoyance estimation and on the prevalence of population exposure above or below certain noise levels can introduce significant bias in environmental health impact assessment in different areas and for different sound sources. The different performance in urban versus rural areas deserve further attention. Eventually, evaluations of noise mapping software should be always performed in conjunction with annoyance surveys.

The annoyance response along major transalpine transit routes continues to remain at higher levels than the standard exposure response curve from the END.

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