Conclusions from 13 years of repeated traffic noise exposure measurements in Flanders-Belgium

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ABSTRACT

To assess the overall noise exposure of the population in Flanders and in particular the exposure to street traffic noise, a measurement campaign was set up involving 250 randomly selected households in Flanders. Measurements were conducted first in 1996 and were repeated twice afterwards. This unique longitudinal noise monitoring exercise revealed that although the traffic intensity has grown over this period, noise exposure on average hardly changed. Small trends in exposure distribution and in statistical noise levels do nevertheless occur but they are marginally significant. Contrasting these measurements with status reporting based on noise maps, prediction of population exposure, and noise annoyance surveys shows that although all of these methodologies have their merits, they cannot be readily compared. In particular the difference between estimated trends in percentage of highly annoyed inhabitants based on noise level measurements and observed trends in reported noise annoyance, is striking.
Keywords: traffic noise, population exposure, annoyance

1. INTRODUCTION

Today, exposure of the population to (traffic) noise is mostly assessed by modeling [1]. Although the noise mapping technology underlying this assessment has matured, the quality of results still largely depends on the quality of input data. In addition, for capturing evolution and trends one has to make hypothesis on the expected change in noise emissions. This leads to uncertainties in the model results and demands an occasional validation by measurements.

In this article a concise monitoring methodology based on population guided sampling is proposed (Section 2). The measurement method has been applied to Flanders, the northern part of Belgium. Flanders has about 6 million inhabitants living on 13,500 square kilometers. About one quarter of this area is a built-up area. The largest city in the region is Antwerp, with about 470,000 inhabitants. Thus mega-city problems are not expected in the study area. Transport is attracted to several sea harbors: Antwerp, Gent, Zeebrugge, Oostende, together handling about 250 million tons of goods/year. In addition Flanders is very close to the Dutch harbors of Rotterdam and Duinkerken. Flanders is also surrounded by several big cities: Brussels, the capital of Belgium, Paris, Amsterdam, … influencing strongly the amount of traffic on the major arteries. The results of three measurement campaigns conducted in 1996, 2001, and 2009 in this area are given in Section 3. Section 4 discusses results in a broader context and draws conclusions.

2. MEASUREMENT PROCEDURE

The measurement procedure is based on the technology of 1996 when the measurement was first conducted.

2.1 Measurement locations

The main goal of the measurement campaign was to determine the percentage of the population

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with façade exposure higher than 65 dB(A). Since this number was expected to be around 20%, a statistical sampling error of 1 percent point would require 1600 observation point. After balancing costs with accuracy, 250 measurement locations were considered to be appropriate, resulting in an expected statistical error of 2.5 percentage points. These 250 dwellings were selected using a population based sampling. No stratification was used which resulted in a higher sampling density in cities. Since high noise levels are expected there, this sampling strategy automatically focuses on highly exposed people. By using the same measurement locations during subsequent campaigns, the uncertainty on the change in exposure is lower than the uncertainty introduced by taking a statistical sample.

Since accurate portable GPS systems were not common in 1996, the measurement locations were identified by address with the additional requirement that the measurement should be performed one meter in front of the main entrance to the building. If for some practical reasons this place was not accessible, measurements are still taken but the deviant location is noted in the measurement report. During the later campaigns GPS coordinates were stored and used for returning to the measurement location afterwards. The uncertainty on measurement location is about one meter at that stage.

2.2 Measurement time and duration

To avoid seasonal effects, every measurement campaign was conducted during the same time of the year. Based on school holidays and local weather conditions, it was decided to conduct measurements in October-November-December. Route planning learned that it is possible for a single researcher to reach each of the 250 locations once in this three month period. Involving multiple researchers increases the equipment, transport, and training cost, thus the decision was taken to work on the basis of a single, manned observation.

At locations with traffic densities that would result in noise levels of the order of 65 dB(A), a measurement duration of about 15 minutes was considered to be sufficient. Increasing the measurement time is not expected to improve the estimate of daytime noise levels unless a few short measurements at different times of the day are conducted as has recently been confirmed [5]. Including nighttime noise levels is not an option using this procedure since the lower traffic intensities and the higher importance of distant sources (that are influenced more by meteorological conditions) would introduce too much uncertainty. More permanent monitoring would improve accuracy, but this was not feasible on this geographic scale at the start of the measurements in 1996. A possible approach is the use of low-cost microphones (from consumer electronics) which were shown to sufficiently accurate for typical environmental noise monitoring applications [6].

To check the impact of the short measurement period, a 20 minute measurement split in two 10 minute periods was used. The standard deviation between these two 10 minute measurements indeed indicates that the uncertainty decreases as overall traffic noise levels increase (Figure 1).

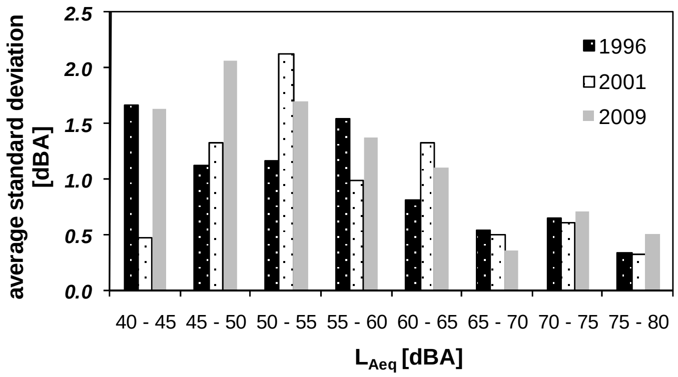

Figure 1 – Standard deviation based on two successive 10-minute measurement intervals as a function of noise level.

2.3 Measurement methodology

A ½" electret microphone (type Bruel & Kjaer 4189 or equivalent) connected to a logging device (SIP95 in 1996, B&K 2236 in 2001, and Svantek 959 in 2009) was placed at 1.5m above the ground pointing away from the building façade. L_{Aeq}, L_{95}, L_{50}, and L_5 were recorded and in 2009 one second recording was added. In addition to the noise level other relevant observations were also made: number of vehicles passing on the nearest road (cars, trucks, mopeds), distance to the closest road, speed limit, road surface including whether the road is wet during measurements, and weather conditions. In addition the presence of sounds other than sound resulting from road traffic was assessed subjectively to be able to exclude those measurements when analyzing afterwards This selection procedure reduces the amount of valuable measurements as shown in Table 1.

Table 1 – Number of observations retained after selection criteria.

	1996		2001		2009
all locations	250		250		250
corresponding locations		247		234	
locations with dominant road traffic noise	164		203		157
corresponding locations		140		134	

2.4 Correcting for the time of the day

All measurements are conducted between 7:00 and 19:00 on working days. The aim of the travelling researcher was set to get an equal distribution over the time of the day and over the days of the week. The distribution over the days of the week was flat within 20% and no significant correlation was found between day of the week and noise level. The distribution over the hours of the day was centered in the afternoon and rolled off towards 7:00 and 19:00. In addition, it turned out to be impossible to visit the same place at the same time of the day during the three successive measurement campaigns. During the first measurement campaign it was observed that measured noise levels showed a clear variation over the day. Although this might have been partly due to correlation between location and measurement time, it was decided to correct for the time of measurement based on external data. Based on data from 20 fixed traffic intensity measurement stations, a theoretical diurnal noise pattern was estimated which showed an average fluctuation of one dB(A) over the course of the day. Measured noise levels were corrected based on this pattern.

3. RESULTS

3.1 Overall façade noise levels

As a first result the overall façade noise exposure during the day is presented. Figure 2 shows the distribution of the population in Flanders over L_{Aeq}, L_{A95}, and L_{A5}. Although the distributions have quite different shapes for these indicators, they are surprisingly constant over time and fall within the error estimates on the measurements. By focusing on changes on the locations where valid noise measurements are obtained in both campaigns the sampling error can be eliminated. Based on a paired comparison focusing on the average of the change over the 250 selected locations one obtains a change in L_{Aeq} at the observation point of -0.10 dB(A) between 1996 and 2001 and a further change of -0.12 dB(A) between 2001 and 2009. The 95% confidence interval based on the standard deviation of the observed changes remains 0.6 dB(A) however. Peak levels, estimated by L_{A5}, change on average -0.12 dB(A) between 1996 and 2001 and a further -0.02 dB(A) between 2001 and 2009. Background levels measured by L_{A95} change by +0.20 dB(A) between 1996 and 2001 and by +0.21 dB(A) between 2001 and 2009.

3.2 Road traffic noise

Façade traffic noise exposure distributions of the Flemish population during the day extracted from the three measurement campaigns can be found in Figure 3. The error bars in this figure refer to the accuracy of the percentage for each of the campaigns and include sampling error and the uncertainty introduced by the short measurement duration. Estimating changes on the basis of observations that were valid during both measurement campaigns reduces again the uncertainty on the estimation of the change. Between 1996 and 2001 the average L_{Aeq} changed by -0.03 dB(A) but this change was reversed to +0.12 dB(A) between 2001 and 2009. Between 1996 and 2009 an average change of +0.07 dB(A) was observed. The 95% uncertainty interval on these conclusions is still 0.6 dB(A) thus they could be due to statistical error. However, the difference in trend between overall level and the trend on the selection of locations that was subjectively not disturbed by other sound could also be different because the subjective evaluation of disturbance by other sounds has changed over time because a different researcher assessed them.

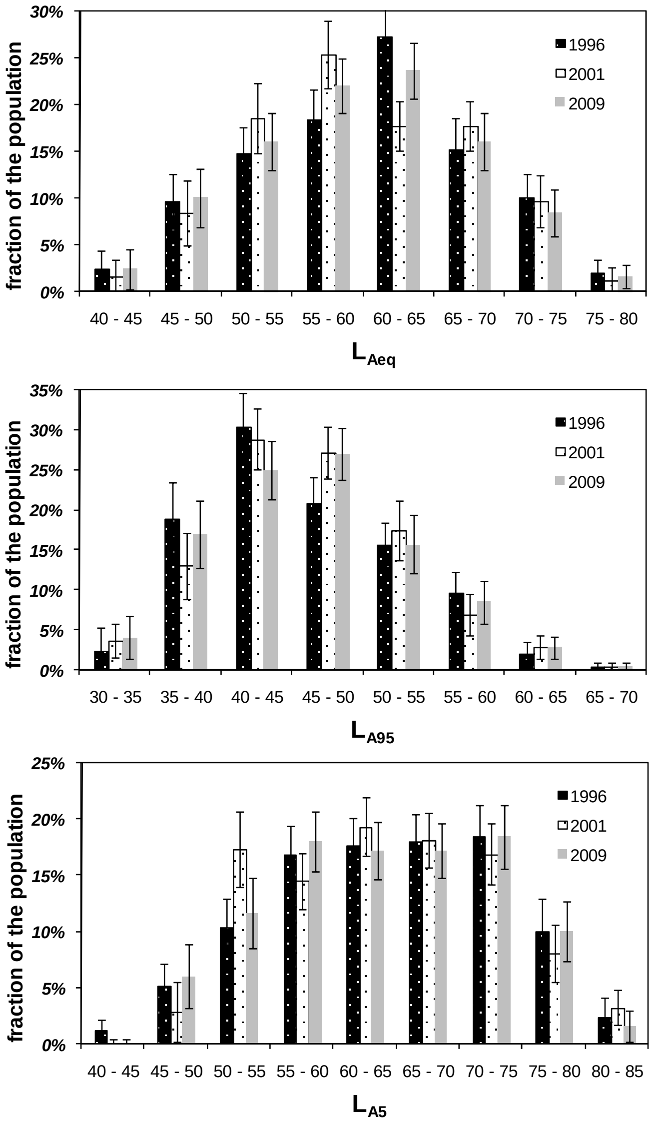

Figure 2 – Percentage of the population exposed to different levels of noise during the day; top: 20 minute L_{Aeq}, middle: average of two 10 minute L_{A95}, bottom: average of two 10 minute L_{A5}.

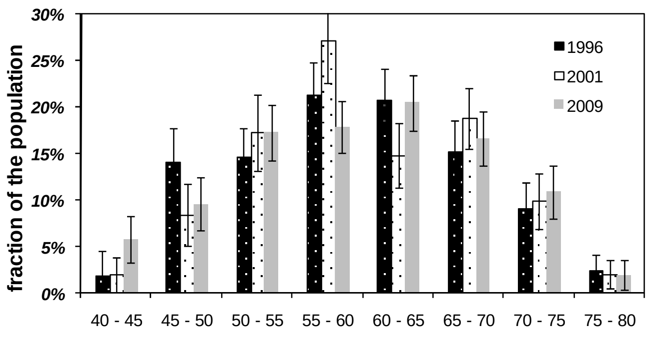

Figure 3 – Percentage of the population exposed to different levels of road traffic noise during the day for the measurement years 1996, 2001 and 2009.

3.3 Policy indicators

Several indicators are used to monitor the state of the environment and to evaluate policy. Two of them relate to the measurement campaigns presented in this paper: the percentage of the population exposed to traffic noise levels above 65 dB(A) during the day and the percentage of the population highly annoyed by road traffic noise. Figure 4 shows the trends in these indicators as obtained from the measurement campaigns. The exposure is also calculated regularly on the basis of annual traffic data for all roads and a simplified propagation model ignoring the effect of screening by buildings and terrain (noise barriers are however included). It can be observed that measurements show a similar stagnating trend as the model. The difference in absolute value is expected to be due to the sampling error. In 2008, detailed noise maps for the most important roads were calculated in response to the European Noise Directive. These maps show that 5% of the population in Flanders is exposed to L_{den} at the façade of over 65 dB(A), 0.6% is exposed to levels over 75 dB(A) [2]. Although one cannot directly compare L_{den} to L_{Aeq} during the day, it is clear that these low numbers fail to account for a majority of the traffic noise exposure measured.

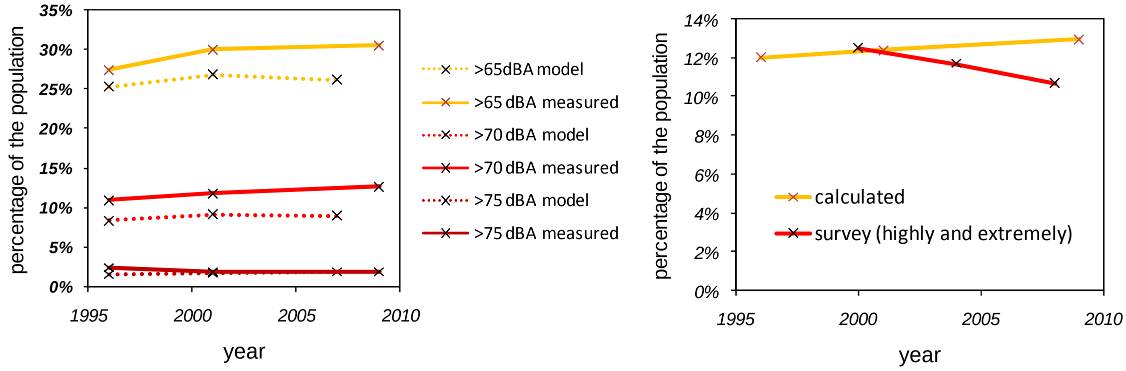

Figure 4 – Percentage of the population exposed to levels of road traffic noise during the day above three thresholds (left) and percentage of the population highly annoyed by traffic noise as obtained by survey and calculated using exposure annoyance relationships and measured exposure (right).

The risk for high noise annoyance at every of the measurement locations can be estimated based on the measured noise level during the day and broadly accepted exposure-annoyance relationships [3] if some hypothesis is made on the difference between L_{den} and $L_{Aeq,day}$. Based on long measurement experience in this area, we estimate this difference at 4 dB(A) but this value is far from critical. During the same period as the noise measurements, a social survey was conducted on a regular basis involving 3000 persons in the year 2000 and 5000 persons in the years 2004 and 2008. A standard question on street traffic noise annoyance using a five point answering scale was included. The percentage of the people answering highly or extremely annoyed is also plotted in Figure 4. There is a striking difference in trend between the calculated annoyance and the survey results. Because of the small sample of dwellings used for the measurements one can expect a significant uncertainty in the absolute value of the calculated percentage of highly annoyed, but since the same measurement locations are used repeatedly, the estimated confidence level on the trend is less than plus or minus one percentage point.

4. Discussion and conclusions

Changes in overall noise exposure of the population in Flanders over the period 1996-2009 are so small that they are not statistically significant taking into account the sample size used in the study. Based on paired comparison of noise levels at sites where valid measurements were collected during two consecutive campaings, a slightly decreasing trend in average level and L_{A5} and a slightly increasing trend in L_{A95} could be identified. When focusing more specifically on measurements where no other sounds were clearly noticed, the decrease in average level almost completely vanished, but this could be due to observation errors that are introduced by the procedure used to evaluate disturbance. In a comparable study conducted in the UK [4] using over 600 dwellings a small decay in L_{Aeq} (-0.53 dB(A)) and L_{A10} (-0.59 dB(A)) during working days was observed between 1990 and 2000. L_{A90} remained more or less constant during the day, but increased slightly during the night.

These observed trends, confirmed by the UK study, are consistent with a model where the noise of individual cars decreases while an increase in traffic still raises background levels [7].

The percentage of the population in Flanders living in a dwelling with façade exposed to road traffic noise levels (L_{Aeq}) over 65 dB(A) during the day is rather high (around 30%). Although there was an initial small increase between 1996 and 2001, this increase stagnated in 2009. The aforementioned UK study found that in 2000 10% of the UK population was exposed to noise levels during the day higher than 65 dB(A), a number that had decreased from 12% in 1990.

It is worth noting that the exposure as estimated in compliance with the EU environmental noise directive does not find this high exposure number since it only accounts for the more intensively used roads while high exposure is also encountered close to roads with a lower traffic load. The model used for monitoring the environment in Flanders that takes into account all roads carrying a minimal amount of traffic (but ignores screening by buildings and terrain) produces a quite good estimate of the highly exposed population. Thus if only high exposure is of interest, it seems more important to take into account sources accurately than to estimate longer distance urban propagation correctly.

The most striking discrepancy is observed when comparing the percentage of the population highly annoyed by traffic noise calculated on the basis of measured exposure and "standard" exposure annoyance relationships to survey results. Although one can argue that the absolute value of the prediction is expected to be off for various reasons, the predicted trend should be quite accurate. Several possible reasons for the opposite trend observed in Figure 4 can be given:

- The relationship between L_{Aeq} during the day and L_{den} may have changed over time. This would explain the decrease in reported annoyance only if the nighttime noise levels dropped considerably while the noise level during the day did not, which is not very likely.
- There could have been a trend to move to quieter living areas. This would not be seen in the noise exposure measurement since the same measurement locations have been used over the years. About 2% of the population should have found a quieter dwelling over the period of 10 years. Taking into account that the moving rate in Flanders is about 4% per year, this could be a factor.
- Acoustic insulation of buildings could have improved over the measurement period, which is plausible taking into account the strong efforts of government to stimulate thermal insulation of older houses and the new standard for noise insulation of new buildings. However, this would immediately imply that façade exposure is not a suitable indicator.
- L_{den} versus noise annoyance relationships may have changed over time. This could be due to a change in frame of reference [8] caused by for example the political discourse. It could equally likely be due to the poor ability of the exposure indicator, L_{den}, for capturing the relevant change in exposure. An evolution in exposure-annoyance relationship has been observed in the HYENA study for aircraft noise but not for road traffic noise [9].

Further investigation is needed to uncover which of the above hypothesis explains the observed noise annoyance anomaly.

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