CEDR Call 2012: Noise

CEDR Transnational Road Research Programme
Call 2012: Noise

Funded by Norway, Sweden, Germany, Belgium/Flanders, United Kingdom and Ireland

ON-AIR
Assessment of traffic noise in complex situations

Deliverable D.3.1. 8-Dec-15

Danish Road Directorate – DRD

Institute of Transport Economics – TOI

LÄRMKONTOR – LK

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ON-AIR
Optimised Noise Assessment and Management Guidance for National Roads

Assessment of traffic noise in complex situations

Due date of deliverable: 31-Oct-2015
Actual submission date: 8-Dec-2015

Start date of project: 1-Nov-2013

End date of project: 31-Oct-2015

Front page photo:
Highway fly-under on M4
West of Copenhagen, Denmark

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--ON-AIR--

Version: Final, 8-Dec-15

Preface

The ON-AIR project “Optimised Noise Assessment and Management Guidance for National Roads” was launched in November 2013. The aim has been to develop tools and guidelines to facilitate the integration of noise abatement into three common planning and management situations encountered by national road administrations (hereafter NRAs):

1. Planning new roads and motorways
2. Planning reconstruction and enlargement of existing roads and motorways
3. Maintenance and management of existing roads and motorways

Guidelines are presented in a European guidance book together with examples of noise mitigation measures, the final Deliverable D.4.1 of the ON-AIR project; see the home page: www.on-air.no.

As a part of the ON-AIR project an analysis was made on how to handle noise in complicated situations like highway intersections. The results are documented in the present report.

The ON-AIR project was carried out for the Conference of European Directors of Roads (hereafter CEDR). The project was selected by the CEDR on the basis of the CEDR Call 2012: Noise, entitled “Noise integration into the planning of new national road schemes and upgrade of existing roads”. ON-AIR addresses the first project of this call: “Optimisation of noise assessment and management strategies”. To follow the work of the ON-AIR project CEDR established a Project Executive Board having the following members:

- Barbara Vanhooreweder, Road Administration, Belgium/Flanders,
- Helena Axelsson, Norwegian Public Roads Administration
- Ian Holmes, Highways England
- Lars Dahlbom, Swedish Transport Administration
- Vincent O'Malley, Transport Infrastructure Ireland
- Wolfram Bartolomaeus, Federal Highway Research Institute, Germany

Wolfram Bartolomaeus, Federal Highway Research Institute (BASt), Germany was the CEDR Project Manager of the ON-AIR project.

ON-AIR was carried out by three partners:

- Danish Road Directorate (hereafter DRD)
- Institute of Transport Economics (hereafter TOI)
- LÄRMKONTOR (hereafter LK)

Hans Bendtsen, DRD, Denmark has been the coordinator of ON-AIR.

Executive summary

In its technical specification for project proposals the Project Executive Board (PEB) in the 3rd bullet asked for (quote): “Research into novel, cost effective methods for undertaking noise measurements in complex noise situations, which can be used to validate strategic noise maps as well as to assist in the prediction of noise levels in complex situations and assessing the effectiveness of noise mitigation measures implemented as part of an action planning programme”.

The ON-AIR consortium’s project proposal focused on situations representing complex noise source conditions and complex sound propagation. Based on typical cases selected in cooperation with the PEB, for which noise maps had already been made in connection with strategic or other noise mapping, the consortium should, if possible, suggest strategies for performing noise measurements to assist in validating a noise map, defining appropriate input data for noise prediction or documenting the effect of a measure taken to mitigate traffic noise. During the execution of the project, discussions between the PEB and the consortium resulted in changing the originally proposed focus and to stick to the task described in the consortium proposal and at the same time to reduce the number of person-hours originally allocated to WP 3 significantly, in order to allocate more resources to other WPs.

After having looked at literature and performing a number of interviews the consortium reached the conclusions that

1) Planning and mitigation should predominantly be based on calculations made by means of high quality software based on high quality prediction models and operated by skilled personnel, based on an accurate 3-D model of the roads and their surroundings
2) The process denoted reverse engineering was found less versatile for noise mapping than anticipated when drafting the project proposal, but might in some cases provide a practical way of improving noise source models and thereby increase the accuracy of noise maps. Measurements should then be made in positions near to important noise sources
3) Only in exceptional cases, however, should measurements be applied, and it should be realised that measurement uncertainty is substantial. Such an exceptional case could by that there is reason to suspect that a noise limit is clearly exceeded at a complainant’s home, but even then a review of a noise calculation would be preferred instead of carrying out a noise measurement
4) If a measure like traffic speed regulation or laying a noise reducing pavement is taken, then its effect may be reliably estimated based on noise measurements made at the same position close to the road before and after taking the measure, utilising the same methodology
5) In cases where it is indicated that calculation results do not yield true and fair assessment of traffic noise exposure, resources should be allocated in improving models and their implementation rather than in measuring noise exposure of individual dwellings

Contents

Abbreviations used in the report

Abbreviation	Meaning
AADT	Annual average daily traffic
BASt	Federal Highway Research Institute, Germany
CRTN	Calculation of Traffic Noise, British Ministry of transport standard1988
DRD	Danish Road Directorate, Denmark
END	Environmental Noise Directive (2002/49/EC)
$L_{Aeq,T}$	Energy-equivalent A-weighted sound pressure level for the time period T
Nord2000	Nordic prediction method for road traffic noise
NorStøy	Traffic noise prediction software applied by the Norwegian road administration
SMA	Stone mastic asphalt
PEB	Project Executive Board
Predictor-LimA	Commercial software package provided by the Brüel & Kjær company

1 Background, aim and applied method

Task 3.1 of ON-AIR has dealt with case studies. The aim was to identify, in cooperation with the PEB, a number of traffic noise situations representing complex source conditions and complex sound propagation conditions. The basis should be available noise maps made in connection with strategic or other noise mapping. Such an example of complex source conditions could be a situation with stop-and-go traffic with different traffic speed during parts of the day. Knowing the pattern of speed variation could add to the chance of obtaining a valid prediction of noise levels such as L_{day}, L_{night} or L_{den}. A case of complex propagation conditions could be a situation with flyovers and/or fly-unders at different levels. A combination of complex source and complex propagation conditions could be the opening of a tunnel into a road cutting. Three complex cases should be identified as a basis for describing possible strategies for performing noise measurements to assist in 1) validating a noise map; 2) defining appropriate input data for noise prediction; or 3) documenting the effect of a taken noise mitigation measure.

In Task 3.2, measurement strategies should then be outlined for applying noise measurements to reach targets 1) - 3) mentioned in Task 3.1, based on the identified typical complex situations A literature survey should be carried out and interviews should be made with providers of measuring and analysis equipment and with experienced consultants. As mentioned in the executive summary, the scope of WP3 was reduced during the project and no measurement strategy has been worked.

2 General observations

The trend in many European countries, at least during the last two or three decades, has been to develop reliable prediction methods and apply them for assessing population exposure to traffic noise rather than making noise measurements in individual assessment situations. A major reason for preferring prediction to measurement is the high cost of measuring traffic noise levels. Therefore many administrations have found it advantageous to invest in developing and validating reliable prediction methods and then solely depend on calculated noise levels when making decisions in matters concerning environmental noise protection.

It must be admitted, though, than on many occasions road neighbours tend to show more confidence in “real” noise levels measured at their dwelling or on their property than in noise levels originating from a computer program to appear in colourful noise maps on a web-site or in a report. However, noise metrics used today, such as a yearly average L_{den} or L_{night}, are difficult and hence expensive to measure with good accuracy, and such noise levels often deviate significantly from readings taken on-site with a sound level meter. This requires lengthy explanatory statements, and such statements might as well be that computation results are in fact reliable, and often more reliable than results of measurements carried out during a limited time interval, because the prediction methods have been based on and validated by means of a large number of such measurements.

A measured noise level at the dwelling of an individual citizen could perhaps be considered by some to be more representative of the noise exposure of that individual. It is known that persons exposed to the same noise exposure may perceive this differently, corresponding to 10 dB or more in noise level difference: So even if one would measure the individual noise exposure of a person’s dwelling, there is no guarantee that the measurement result represents the annoyance experienced by that individual. This is part of the background why guidelines and environment regulation are, in general, based on a statistical approach.

When planning new road infrastructure, noise prediction is the only available option, because noise measurements cannot be made before the planned new road infrastructure has been constructed. Similarly, in some regulations citizens may obtain compensation if they become exposed to noise levels from new infrastructure which exceeds the noise levels they had before. When such situations arise, it may be too late to measure the noise level before the new infrastructure was built.

3 Noise measurements applied for noise mapping

In some cases attempts have been made to base noise maps of a city area on noise levels measured by means of long-term noise monitoring terminals placed at fixed positions combined with mobile monitors installed over shorter periods at strategic places to determine source strengths which, in turn, are fed into a prediction method to create noise maps (Manvell, 2004). Equipment manufacturer Brüel & Kjær, for example, has introduced a concept denoted ‘Integrated Environment Noise Management’, promising new possibilities for managing environmental noise through an interaction between noise measurement and noise calculation. An aspect of this has been called ‘dynamic noise mapping’, in which measured noise levels are used in a process of updating already calculated noise maps in order to improve them. This procedure has been used in Madrid, Spain and in Bucharest, Rumania, and outside of Europe it has been applied in in Beijing, China (Manvell, 2015).

Noise monitoring station in Aarhus, Denmark

Among the national road administrations interviewed in ON-AIR, only Ireland uses noise measurements in this way (Bendtsen 2015). An example of the application of measurements is described in (King 2007). Typical noise variation patterns occurring during an average year were used to determine relations between the yearly average L_{den} required for END noise mapping and short-term noise levels measured at a number of points in an area in the city of Dublin. The objective was to support impartial public validation of, and improving public confidence in, END noise maps. An attempt was made to find out how independent noise measurements would probably be made by members of the general public: The purpose was to investigate the parameters influencing measurement results. Based on this, guidelines should be provided to the general public for validating noise maps, which are expressed in terms of the yearly average L_{den}, by means of measured short-term noise levels. How this could be obtained was not easy to comprehend for the present author, but at a closer look the results seem to boil down to finding that when measuring for 15 min during daytime one may estimate the average daytime noise level to an accuracy ± 3 dB. Furthermore it was found that the average daytime noise level can be expected to correlate with the yearly average L_{den}, and hence a relation can be established between L_{den} and L_{Aeq} measured during 15 minutes.

The present ON-AIR work package is intended to deal with the application of measured noise levels as a tool to improve noise maps made from predicted noise levels in situations believed not to be well represented by the noise prediction method applied for the mapping, be it due to complex source operation conditions or complex sound propagation conditions. Such application of traffic noise measurements was recorded in the ON-AIR interviews to be applied in Norway and Sweden.

Noise measurements are also applied to document effects of mitigation measures, be they noise barriers, stricter speed limits or whatever measure taken to mitigate traffic noise. In some cases, for example in Belgium/Flanders, noise measurements are carried out as a basis for dealing with complaints from residents about the traffic noise.

4 Measurement methods

4.1 Yearly average L_{den} or L_{night}

A method for measuring yearly average noise levels L_{den} or L_{night} was proposed in the IMAGINE project (Jonasson, 2007). This method has been introduced in draft international standard ISO/DIS 1996-2, the latest version of which was voted on terminating on 2015-09-02. The method is intended to be applicable to all kinds of environmental noise; it is rather complicated and it includes an elaborate procedure for estimation measurement uncertainty.

The method principle is to measure traffic noise under well-defined conditions, both concerning the noise source operation and the sound propagation between source and receiver, and then normalise the measurement results to “reference” conditions, which in this case are the yearly average conditions. Measurements may be long-term or short-term measurements.

The normalisation of a measurement result to correct for reference source operating or sound propagation conditions different from those during the actual measurement in general will have to be made based calculations made by means of advanced software. Two calculations shall be made:

1) the noise level for the reference conditions, $L_{\mathrm{Aeq,ref}}(\mathrm{calc})$
2) the noise level for the conditions prevailing during the measurement, $L'_{\mathrm{Aeq}}(\mathrm{calc})$

The measured noise level L'_{Aeq} is then corrected to reference conditions by means of Eq. (1)

$$L_{\mathrm{Aeq,ref}} = L'_{\mathrm{Aeq}} + L_{\mathrm{Aeq,ref}}(\mathrm{calc}) - L'_{\mathrm{Aeq}}(\mathrm{calc}) \qquad (1)$$

Selected parts of the measurement procedures are included in Appendix D.

4.2 Short term L_{Aeq}

A Nordtest method (Nordtest, 2002) describes how to measure road traffic noise levels. The Nordtest document is slightly more explicit than ISO/DIS 1996-2 in defining appropriate measuring conditions, such as weather, sound reflection effects etc. but the Nordtest method does not give specifications for determining yearly average noise levels. Similar methods may be available in a variety of countries. A survey of this has not been performed in ON-AIR WP 3.

In its chapter “Field of application”, the Nordtest method states (quote): “Road traffic noise levels are often calculated in accordance with “Road Traffic Noise, Nordic Prediction

Method"[1]. When calculation is considered insufficient, the traffic noise level can be measured in accordance with this Nordtest method[2]. This could for example be the case in particularly complicated topographical situations, with sound reflecting obstacles or several noise barriers or buildings screening the traffic noise[3]. The method is useful, within its constraints due to measurement uncertainty etc., to test compliance with noise limits, for example when residents complain about their exposure to traffic noise. The method is also applicable for assessing the effect of noise mitigation measures."

4.3 Measurement uncertainty

The uncertainty of sound pressure levels determined as described in ISO/DIS 1996-2 depends on the traffic conditions and the measurement time interval, the weather conditions, the distance from the source and the measurement method and instrumentation. ISO/DIS 1996-2 describes procedures for determining the measurement uncertainty which comply with the ISO/IEC Guide 98-3, often referred to as GUM.

The measurement uncertainty is associated with a chosen coverage probability, which often by convention is chosen as 95 % corresponding to a coverage factor of 2. This means that the final result becomes $L \pm 2\,u$, where L is the measured noise level and u is the standard uncertainty. The standard uncertainty u depends on the measurement conditions and will only in exceptional cases only be smaller than 1 dB.

5 Principles of reverse engineering in traffic noise mapping

The principles of so-called reverse engineering have been described, by identical texts, among other places in (Manvell, 2007) and (Stapelfeldt, 2011). The basic idea seems to be to assign, as a first step, an emission value (i.e. a source sound power level) to every road in a mapping area. This is most efficiently done using a good prediction method and good traffic data. Then the noise level is calculated at each of a number of receiver positions. To do this takes a good prediction method and/or the receiver positions shall be selected so that the sound attenuation during the propagation from source to receiver is easy to determine accurately. Then traffic noise levels are measured at the selected receiver positions and source sound power levels are adjusted by the difference found between in the measured and calculated noise levels. A grid noise map is then made using these adjusted source noise emissions.

With multiple source-receiver combinations, reverse engineering in some cases involve iterative processes to minimise deviations between measurement and calculation results. Such iterative algorithms are probably more useful in dealing with noise from industrial plants having more stationary point noise sources than in dealing with the moving sources of traffic noise. In any circumstance, in order to be successful in adding accuracy to a noise map by combining measurement and prediction it must be assured that the measurement conditions agree with the conditions presumed in the noise map. In the case of mapping yearly average levels, the source operation conditions and the sound propagation conditions must be representative of the reference conditions of the noise mapping, for example yearly average

[1] TemaNord 1996:525, the Nordic prediction method preceding Nord2000
[2] which has been incorporated in among others Norwegian standard NS 8174-1:2007+A1:2008
[3] Note by the present author: Therefore, Norwegian Road Public Roads Administration prescribes measurement used in such cases

conditions. If this is not the case, measurement results must be normalised to reference conditions prior to feeding them into the reverse engineering process.

Several papers, e.g. (Wessels, 2014), (Zambon, 2015) have been published on how to generate so-called “dynamic noise maps” based on on-line systems of monitors operating continuously and feeding information to a central computer system for frequent updates of a noise map. The idea is that municipal officials could apply such systems in order to be proactive in reducing the number of noise complaints they receive. So far this has probably only been done on an experimental basis, and such application is of little relevance for and traffic noise management and planning which is based on yearly average noise levels.

6 Examples in literature

6.1 Comparison of noise maps from prediction and measurement

An interesting paper (Borelli, 2014) was found on the mapping of traffic noise levels from a flyover highway. The position of the flyover is shown in Figure 1. Comparisons were made between noise maps based on measurements and noise maps based on predictions applying various methods. The paper concludes among other things, that the difference in approach to noise mapping has an effect on the results obtained. Also the graphic design of the map influences the outcome of a comparison. But even so, the paper claims to have identified key elements, see the following.

Figure 1: Satellite view of flyover (red line) in Genoa

Predicted noise maps in the paper look like the one in Figure 2 while noise maps based on measurements look like the map in Figure 3. The former shows noise contours calculated

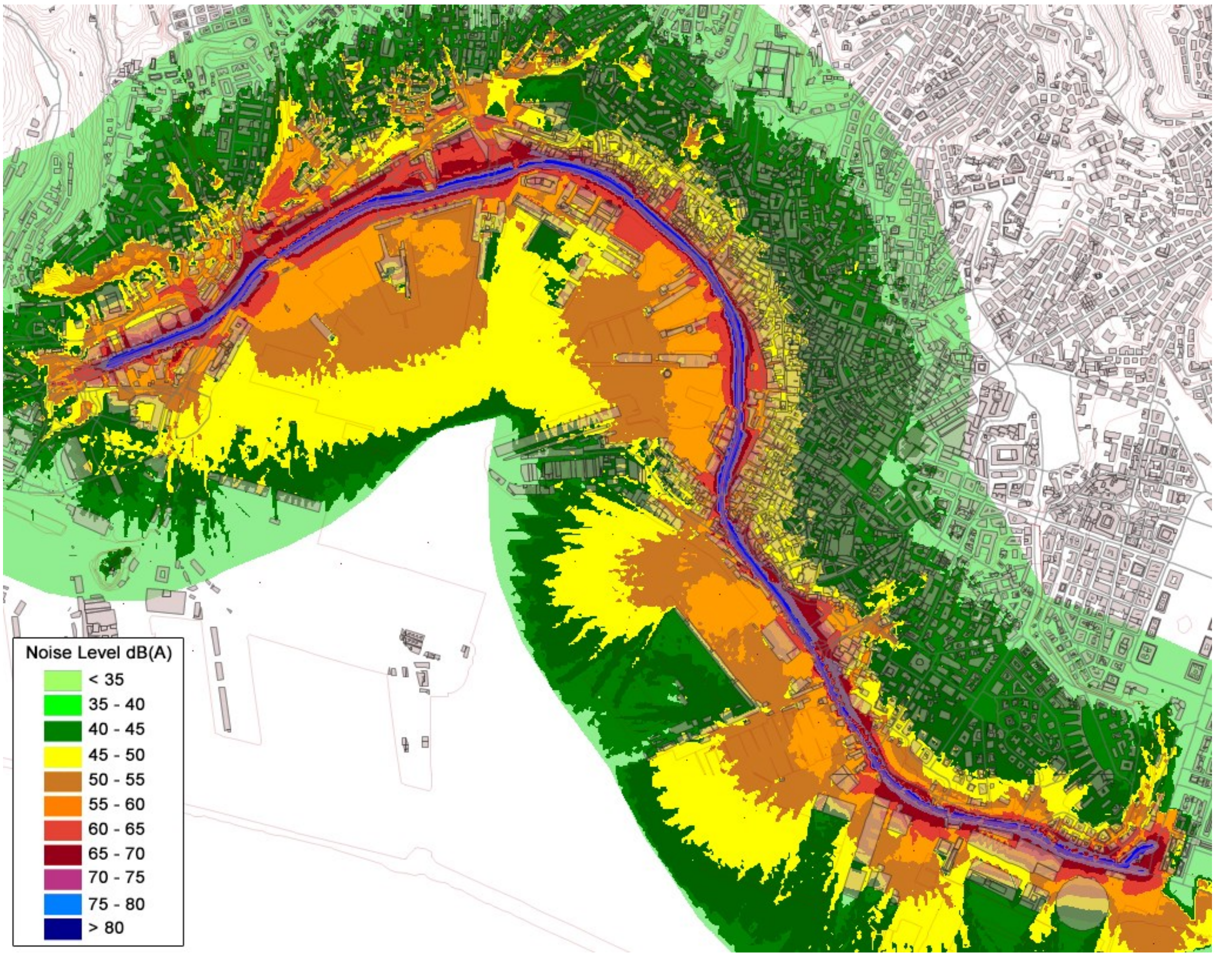

Figure 2: Noise level contours around a highway flyover based on L_{den} noise levels 4 m above the ground calculated in octave bands by means of (NMBP-Routes, 2008), (Borelli, 2014)

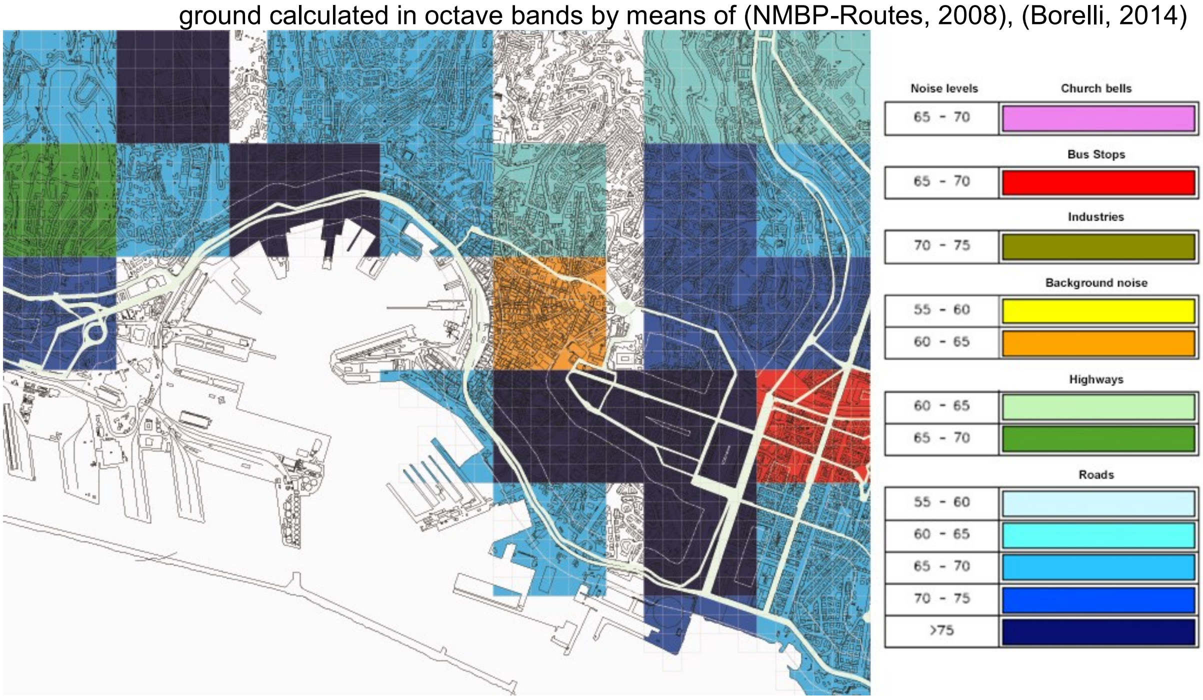

Figure 3: Average noise levels L_{den} and dominant sources in 100·100 m^2 squares in the vicinity of the highway flyover shown in Figure 2, (Borelli, 2014)

from predicted noise levels from highway traffic in points 4 m above the ground in a 10·10 m grid while the second map shows a kind of average noise levels from a variety of noise sources in 100·100 m^2 squares of which only a few are dominated by highway noise. These are based on what is denoted “a multilevel approach, in which long-term, mid-term and

short-term measurements have been combined to get a full description of the sound climate in the investigated area.” The “key elements” mentioned in the above conclusion seem to be that both types of maps are necessary to comprehend the noise pattern in order to decide on actions needed to mitigate noise impacts on the population.

Besides this general observation, the paper (Borelli, 2014) gives differences in computation results[4)] found when using various prediction methods. It is the opinion of the present author that such differences are in general of limited interest in cases when “true” calculation results are unknown, although it may be of interest to show, if this is in fact the case, that using more complex and time consuming methods will not lead to results differing significantly from results of calculations made by means of faster methods.

6.2 Examples of reverse engineering in noise mapping

A particularly simple example of reverse engineering was described in (Novak, 2009). It has been included here to illustrate the procedure of reverse engineering. An urban area of 1·5 km^2 in Canada was modelled, using the British CRTN–method for road traffic noise calculation. Roadway traffic noise emission levels were calculated by means of the Predictor-LimA software package, based on annual average daily traffic data (AADT) provided by the municipality, and on assumptions made concerning the traffic distribution on the day and night periods. A number[5)] of 24 hour long measurements of $L_{Aeq,20min}$ were performed at “representative” locations, selected based on their proximity to the more significant noise sources. The measurement results were fed into the software and its reverse engineering algorithms were applied in several iterations to improve the agreement between CRTN results and actual measurement data. In the end, according to (Novak, 2009), (quote): “… very little of the original noise model was altered in the final noise map…”. This latter result is not surprising to the present author, because variations in day/night traffic distribution are normally very limited, while at the same time it would take a doubling of traffic to change the noise level by 3 dB.

A more elaborate project was described in (Comeaga, 2007). The City of Bucharest acquired a monitoring system with 12 stationary and 3 mobile stations for noise measurement and applied them in an attempt to calibrate its city noise map. According to the paper, it would at the time of writing take a computer 150 days of computation to calculate traffic noise levels in all of 9 million points in a 10·10 m grid covering the city. The paper outlines a strategy for selecting a more limited set of points, the actual number of which is not specified, and a set of algorithms allowing a reverse engineering process to adjust the original noise map. Using this strategy it should be possible to update the Bucharest city noise map in a matter of a few days of computation time. At the time the paper was published the system was under test at the Bucharest City Hall, the outcome of which is unknown to the present author.

Figure 4 - Figure 6 illustrate a situation with a complex traffic noise source, where it should be determined how high a noise barrier needed to be in order to keep traffic noise levels in a

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4) and differences in computation times depending on prediction method and computer configuration
5) 50 – 60 positions judged by Figure 1 in (Novak, 2009)

residential area within the traffic noise limit. The complexity is caused by stop-and-go-traffic and by traffic congestion occurring during certain time periods of the day. Figure 4 is an extract of a map showing the planned residential area next to the intersection between two roads controlled by traffic lights (Søndergård, 2002). The road in direction northwest-southeast is heavily trafficked and there are long tailbacks on this road during parts of the day. Figure 5 illustrates, as an example, the average vehicle speed as a function of the time of day, for vehicles heading southeast towards the city centre measured when they pass a line 50 m from the intersection. Figure 6 is an attempt to illustrate how the traffic intensity and the vehicle speed distribution vary during a 24-hour day. During daytime with dense traffic, in particular around the morning rush hour (07-08 hours), the speed is lower than during the evening and night, when the traffic is less dense. Also, the degree of vehicle acceleration varies during the day. In such a situation it is not straightforward which ("noise equivalent") traffic speed should be introduced in noise calculations.

Figure 4: Map of intersection

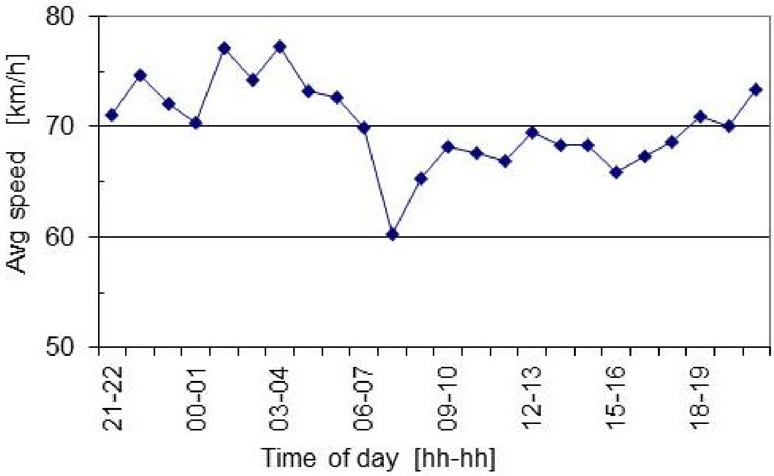

Figure 5: Average speed as a function of the time of day

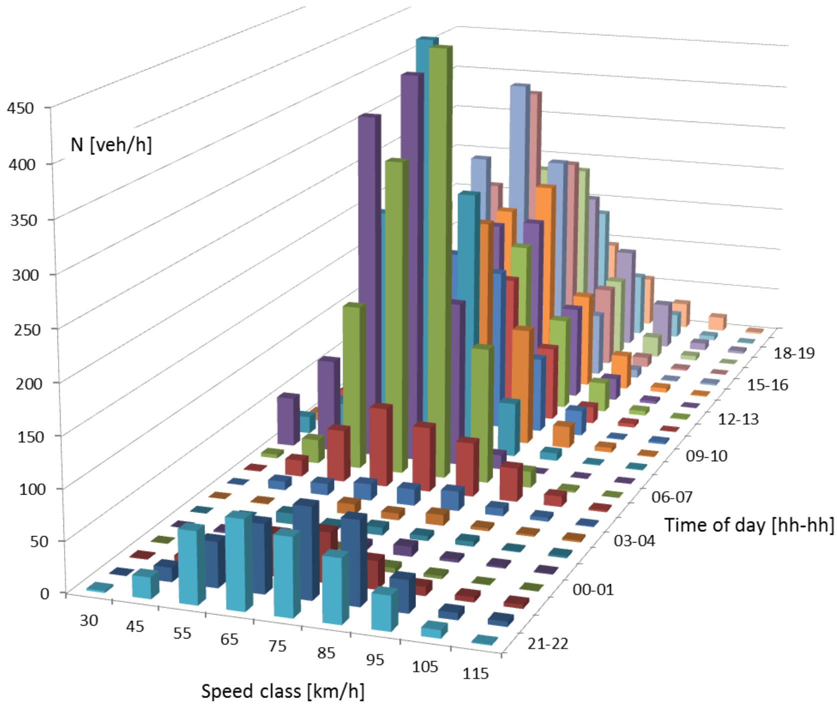

Figure 6: Example of varying hourly speed distribution and traffic intensity during a 24-hour period

One way of dealing with this could be to measure hourly traffic noise levels for 24 hours at a representative position near the intersection and then “back-calculate” the speeds that would yield the correct value of L_{day}, L_{eve} and L_{night}, respectively, when introduced in the mapping calculations. Another solution could be to count the vehicles and measure their speed, calculate the hourly noise levels, average them over day, evening and night, respectively, and finally “back-calculate” traffic speeds which would yield the correct noise levels.

7 Typical cases of complex noise calculation

The complex cases selected by the PEB for analysis as mentioned in the following were
- Tunnel openings (material was supplied by Helena Axelsson, NO)
- Fly-under (material was supplied by Jakob Fryd, DK)
- Fly over (material was supplied by Helena Axelsson, NO)

7.1 Tunnel openings

Noise from vehicles, when they are driving in a tunnel, is reflected repeatedly from the tunnel walls. This reverberant sound adds to the sound transmitted directly from a vehicle to a receiver, while the vehicle drives outside the tunnel. With reference to the uncertainties inherent in measurements such as those mentioned in connection with the below examples, it cannot be recommended to undertake noise measurements for assisting in mapping traffic noise exposures in the vicinity of tunnel openings.

7.1.1 Prediction methods

In a comprehensive prediction model such as Nord2000, a method for calculating the noise from a tunnel opening is given. On top of sound level contributions arriving directly from vehicles driving outside the tunnel, extra contributions from the tunnel opening (or “mouth”) are added, which depend among other things on the sound propagation conditions inside the tunnel. Equations are given in Nord2000 (Jonasson, 2001) by means of which an apparent sound power level can be calculated for each of four point sources positioned in the tunnel opening as shown in Figure 7. A similar description is given for rectangular tunnel openings. Parameters are: vehicle sound power level and speed, tunnel width and length and the sound absorption coefficient of the tunnel walls and ceiling. The report includes (frequency dependent) guideline values of the absorption coefficients and source directivity corrections. The propagation of noise from point sub-sources is dealt with using the Nord2000 propagation model.

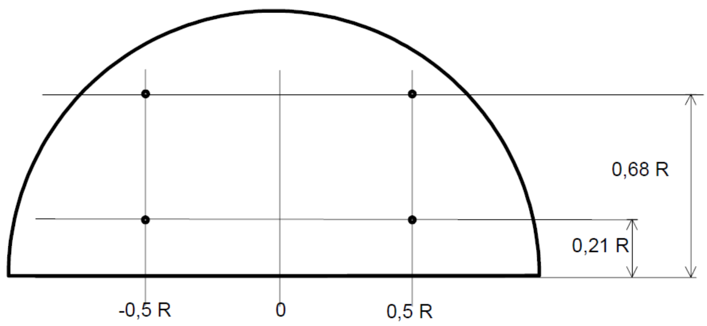

Figure 7: Positions of sub-sources representing the sound emission from a semi-circular tunnel opening in Nord2000. R is the tunnel roof circle radius

Figure 8 shows an example of the changes in noise levels obtained after introducing tunnel sub-sources as prescribed in Nord2000 on a road. In an area in the order of 100 m or so from the tunnel opening, a significant increase in noise level is seen in directions around 45 ° from the road. In positions further from the tunnel and near the road contributions are negligible, because direct sound from passing vehicles dominates.

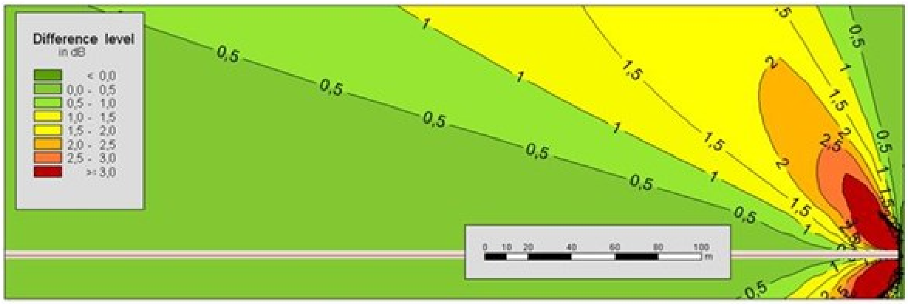

Figure 8: Example of differences in traffic noise levels occurring when tunnel sub-sources are introduced according to Nord2000. Source: SoundPLAN Nord

The Nord2000 method was applied for calculations made for two tunnels as part of a master thesis (Tørnquist, 2012); see Appendix A. Comparisons between calculation results and field measurements results indicated that predictions tended to underestimate the traffic noise levels by a couple of decibels or so. However, the uncertainty involved both in modelling and in field measurements in the case study is substantial, and in reality prevents firm conclusions to be drawn concerning model validity.

Contrary to Nord2000, the CNOSSOS-EU method (Kephalopoulos, 2012) does not deal with sound contributions from tunnel openings.

A different approach was used in (Bekkos, 2015); see also Annex A. In this study the Nordic prediction method (TemaNord 1996) preceding Nord2000 was applied to calculate traffic noise from vehicles while outside a tunnel. The contribution from the tunnel was calculated using a method proposed in (Probst, 2010) to determine the sound power level of a sub-source in the tunnel opening while the propagation was dealt with using the Nordic prediction method for environmental noise from industrial plants (Kragh, 1982) which in this connection is the same as (ISO 9613-2:1996). The outcome of such calculations of tunnel contributions is illustrated in Figure 9. The figure shows a plan view with noise level contours giving the increase in road traffic noise level due to contributions from a tunnel opening. In the case with a straight road an increase is seen up to 50 m from the tunnel opening, while in the in case with a curved road an increase of 1 – 2 dB is seen even at larger distances on one side of the road.

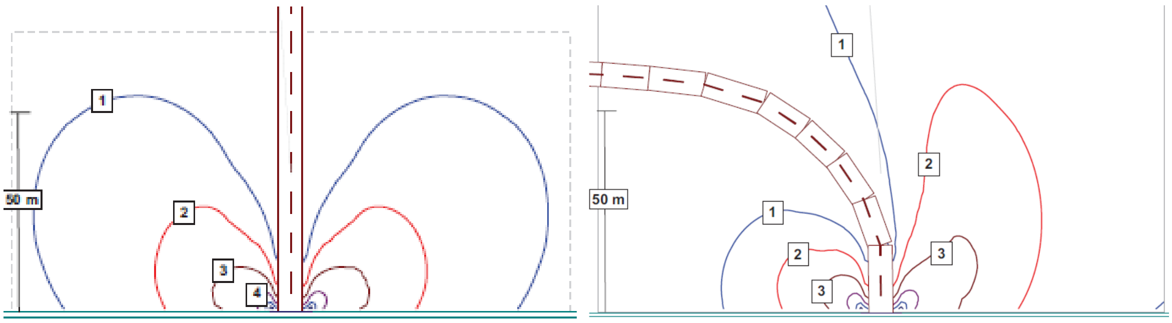

Figure 9: Example of increase [dB] in calculated noise levels due to contributions a from tunnel opening, (Probst, 2010)

As mentioned above, the uncertainties associated with results of the kind of measurements mentioned here are substantial, and it cannot be recommended in practice to perform noise measurements as a basis for adjusting calculated traffic noise levels in points adjacent to tunnel openings.

7.2 Flyovers or fly-unders

Roads on flyovers differ from other roads in that they are situated at various heights above the adjacent terrain. The situation is as in Figure 10, which shows noise level contours in a cross-section of the bridge calculated for traffic on the bridge. The figure is an attempt to illustrate how traffic noise propagates from a fly-over, without having the complex influences of noise from other sources which are present in some figures in Annex C. There is no legend explaining the noise levels in this qualitative illustration, but red colour shows high noise levels and green colour shows low noise levels. There is no traffic on the road passing under the bridge. Noise barriers are mounted at the edges of the bridge deck, and the figure illustrates that noise level contours above the bridge are similar to those seen for a road on the terrain surface. The contours also illustrate that bridge deck and noise barriers screen points below the bridge from noise from vehicles driving on the bridge. These contours, as well as those in Figure 11, have been calculated using the Nord2000 method as implemented in the SoundPLAN software package. The figure indicates, that when a good prediction model is well implemented and the software is operated by a skilled user, good prediction results should be expected, although it must be admitted that the system has probably not been validated by measurements in a situation exactly matching the one in the figure.

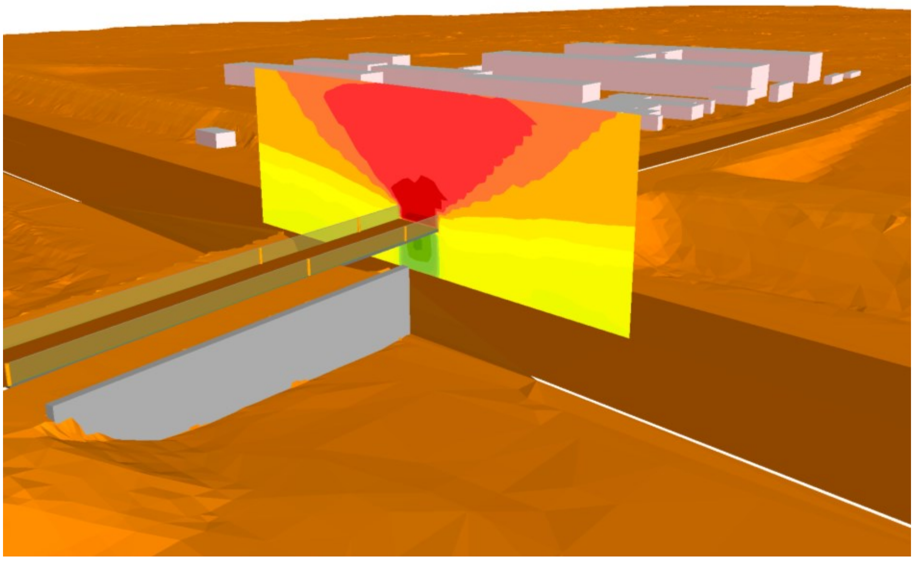

Figure 10: Traffic on a bridge. Predicted noise level contours in a vertical plane. Source: SoundPLAN Nord

Sound reflected from the underside of flyovers is not included in any available noise prediction software, as far as the present author is informed. These reflections, from a sound propagation model point of view, are just as other sound reflections such as those from facing walls of buildings or from reflecting noise barriers. If taken into consideration they would add to the directly transmitted traffic noise in the same way as the contributions from tunnel openings. But a universally valid implementation in automated computation software would be extremely tricky.

A fly-under situation is illustrated in Figure 11, where there is traffic on the fly-under but not on the flyover as was the case in Figure 10. Also in Figure 11, influences from other noise sources are absent. Blue colour shows high noise levels while green colour shows low noise levels. The noise level contours demonstrate that the implementation used does not include contributions from sound reflected from the underside of the bridge deck. This, in principle, leads to an underestimation of the sound exposure at road neighbours. But if road neighbours are exposed to noise from other parts of the road which are significantly closer than the image sources representing the reflected sound, then the effect is negligible; see also Annex B. Also in this case, a well-implemented and well-operated good model and prediction software should be expected to deliver good prediction results.

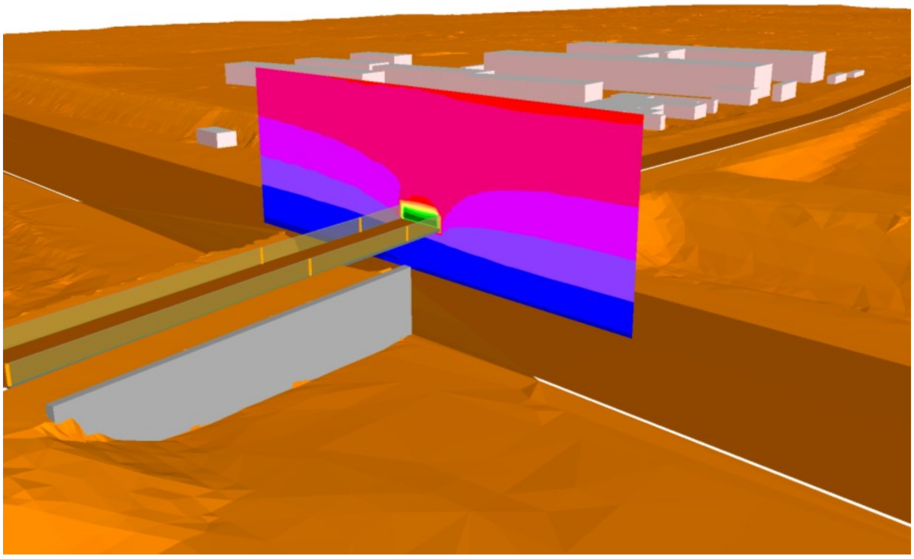

Figure 11: Traffic under a bridge. Predicted noise level contours in a vertical plane. Source: SoundPLAN Nord

In all circumstance, in analogy with the arguments given in Section 7.1 on tunnel openings, it would not be possible to define a measurement strategy to improve prediction accuracy other than proposed in Section 6.2 for improving the noise source models, i.e. to measure noise levels near the road to improve the accuracy of the noise source input data. However, noise measurements could indeed be used to validate a noise map or document the effect of a taken noise mitigation measure as indicated in Section 4.

8 Discussion and conclusions

Very often the question arises, whether traffic noise levels shall be measured or calculated. The general answer is that, for several reasons, traffic noise levels should be predicted rather than measured. First of all, it is not possible to carry out measurements at a planned but not yet built road project. In this case noise level prediction is the only tool available for generating the basis for decision making concerning the tracing of the road on the map or for designing mitigation measures such as noise barriers.

In cases when citizens complain about traffic noise from new infrastructure, they may be entitled to receiving financial compensation depending on how much the new infrastructure has caused traffic noise levels to increase. If such cases are raised after the new infrastructure has already been opened for traffic, the traffic noise levels prevailing earlier cannot be measured, and the assessment will have to be based on computation.

Fluctuations in traffic load (summer/winter, weekday/weekend/holidays, etc.) and weather conditions, which influence both sound generation and sound propagation, would have to be taken duly into account when carrying out noise measurements as discussed in Section 4. This requires comprehensive measurements together with thorough documentation of prevailing measurement conditions and the processing of these data, all of which is associated with significant cost. Even carefully performed measurements made by skilled personnel may easily be associated with measurement uncertainties in the order of 3 dB, so in general noise measurements cannot be expected to be more accurate than good quality predictions made by skilled staff applying a validated prediction model, high quality verified software and accurate 3-D models of the roads and their surroundings.

Due to their higher efficiency, the use of computational methods is prescribed in a majority of regulations in Europe. According to the present author's experience, computation models are often designed to be a bit "conservative", i.e. with calculated noise levels in most cases being slightly higher than what would have been measured. For example, when deciding on the height of a building to be inserted in the computation of its screening effect, its top edge is often represented by a straight line through the lower points of the building top. In other words, method designers often tend to be careful not to overestimate screening. Concerning input data on vehicle noise emission, though, energy-average values are used rather than conservative estimates.

The examples mentioned in Appendix A and other experience show that measurements in complex situation such as at tunnel openings, made only once and over short measurement time intervals, are associated with substantial uncertainty. To be able to decide whether a prediction model or software implementation needs adjustments one would have to repeat measurements and base the comparison between measurement and prediction on average measurement results associated with narrow confidence intervals.

Exceptions from this general finding could be to measure in positions near to major sources of traffic noise, in positions representative for the traffic noise emission from the source and unaffected by noise from other sources or by uncontrolled sound propagation conditions. Such measurements, if carried out carefully by experienced personnel applying high quality, calibrated measuring instruments and following high quality measurement procedures, could potentially lead to improved prediction results. Also, if measures like traffic speed regulation or noise reducing pavement are taken, their effect may be reliably estimated based on noise measurements, made in the same position and applying the same procedure, before and after taking the mitigation measure. Then a procedure like the methods mentioned in Section 4 should be applied.

The reflection of sound from the underside of flyovers does not seem to be included in available traffic noise prediction software, and unlike contributions from tunnel openings, sound waves reflected from the underside of flyovers are not included in the calculations. However this effect is normally of no significance as described in Annex B. Contributions from tunnel openings are included in some prediction methods and indications have been found that such contributions may be slightly underestimated. To remedy this will take a comprehensive research project which cannot be replaced by a limited measurement effort made at a specific site.

To obtain reliable results of traffic noise prediction requires accurate modelling of the road and its surroundings, a good prediction method, high quality software which has been verified to produce correct results, and skilled software users.

9 Acknowledgements

The research presented in this report was carried out as part of the CEDR Transnational Road Research Programme Call 2012 on noise. Funding was provided by the national road administrations of Norway, Sweden, Germany, Belgium/Flanders, the United Kingdom and Ireland. The ON-AIR project team would like to thank the mentioned national road administrations making it possible to carry out the ON-AIR project. The project team would also like to thank the members of the Project Executive Board and the international experts who participated in interviews and in the Future Workshop in Hamburg in April 2014 for their positive and enthusiastic contributions.

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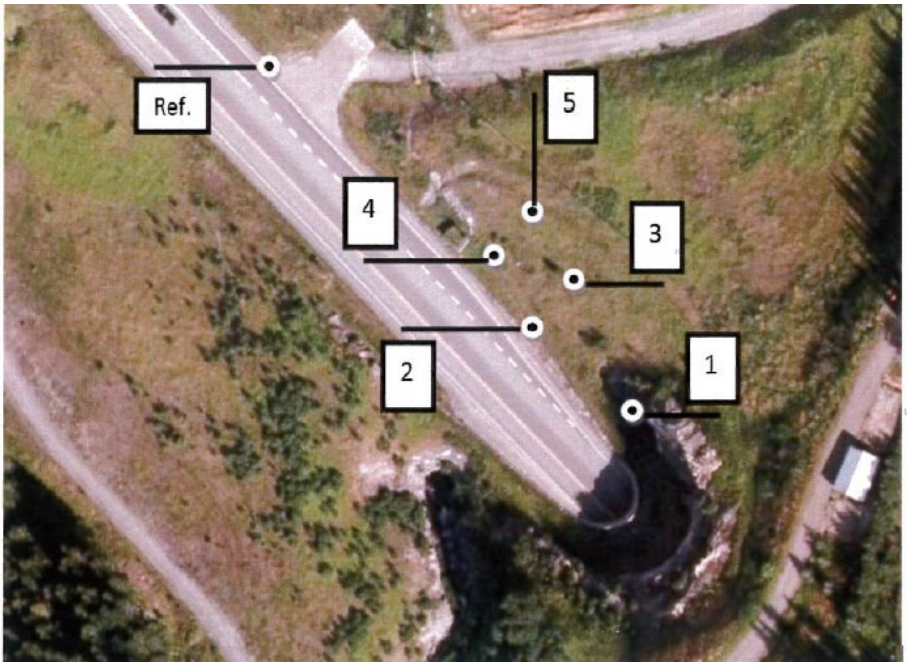
Appendix A: Norwegian tunnel cases

Viggja and Brekk tunnels

A series of traffic noise measurements were made utilising the method (Nordtest, 2002) described in Section 4.2 at two tunnel openings (Tørnquist, 2012), and the results were compared with results of calculations made by means of the Nordic prediction method for road traffic noise, Nord2000, using the NorStøy software. Figure 12 shows the microphone positions and their distance from the Viggja-tunnel and Figure 17 shows the measurement positions at the Brekk tunnel. Photographs of the tunnel openings are shown in Figure 13 and Figure 18, respectively. Note, that few of these positions are in the area shown in Figure 8 where one should expect the largest contributions from the tunnel opening.



Pos.	Dist from tunnel [m]
1	10
2	35
3	35
4	50
5	50
Ref.	110

Figure 12: Measurement positions at Viggja. All were 1.2 m above local terrain

Figure 13: Reference microphone and tunnel opening at Viggja

Noise levels were measured continuously at the reference position and simultaneously at one other microphone at a time, for 30 – 60 min per microphone position, while traffic intensity at Viggja was 358 – 553 vehicles/h; the average speed was 76 km/h and the percentage of heavy vehicles was 12 % - 17 %. Figure 14 - Figure 16 show calculated noise level contours from the tunnel opening, the traffic outside the tunnel, and the total, resp.

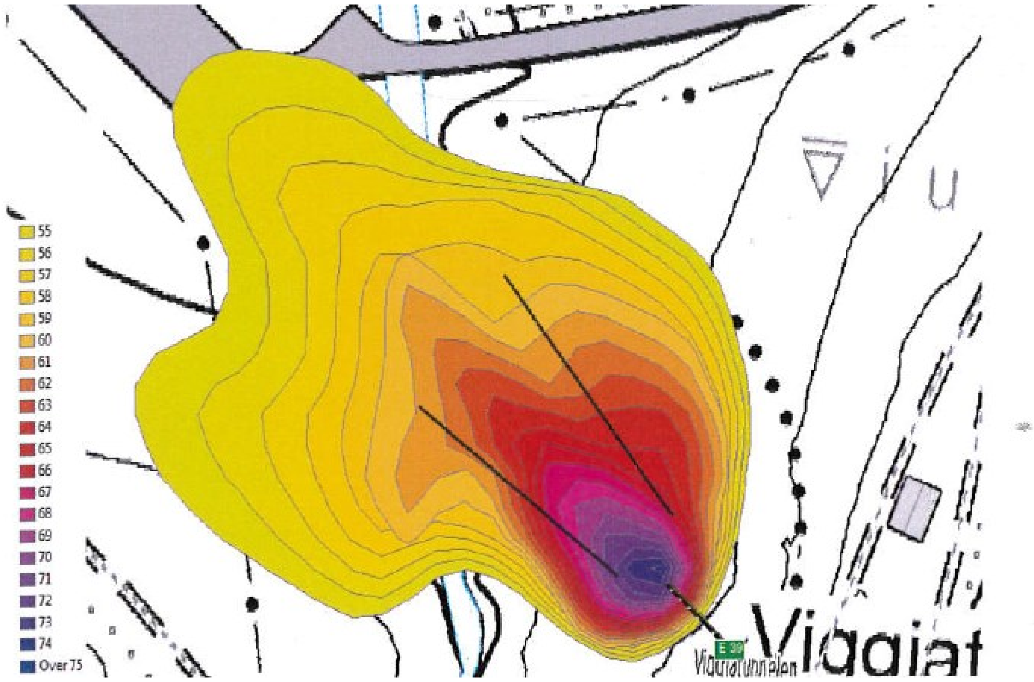


Figure 14: Calculated L_{Aeq} contours. Tunnel opening contribution at Viggja without contribution from the road in the open. Straight black lines represent low retaining walls

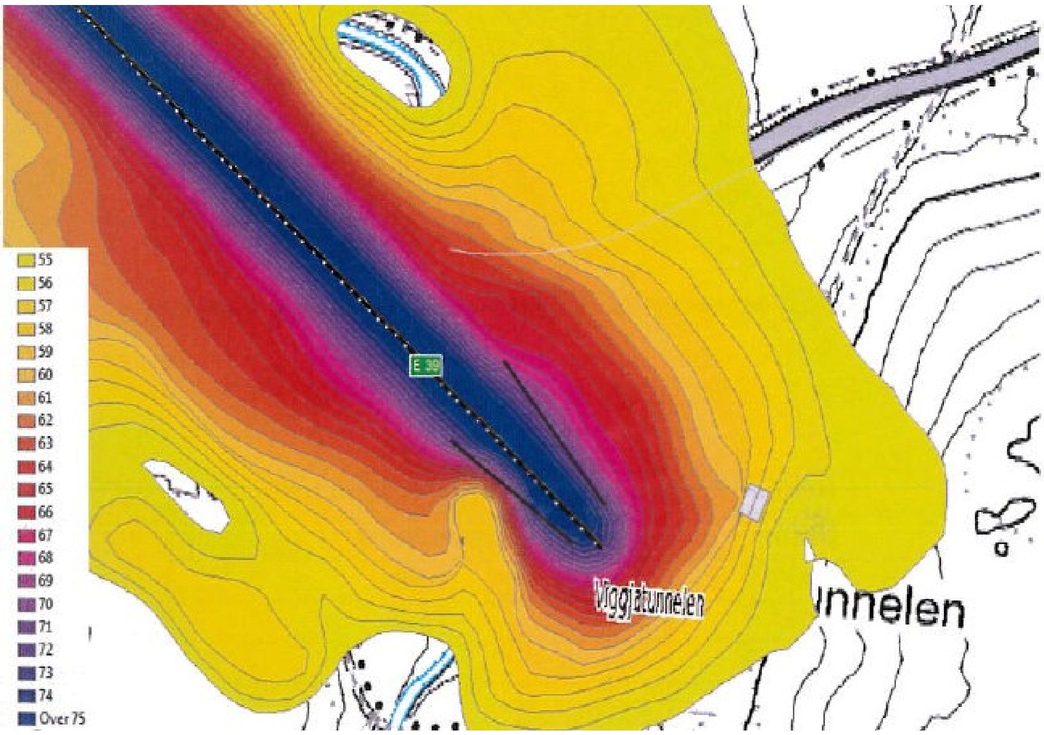


Figure 15: Calculated L_{Aeq} contours. Road contribution at Viggja without the contribution from the tunnel opening. Straight black lines represent low retaining walls

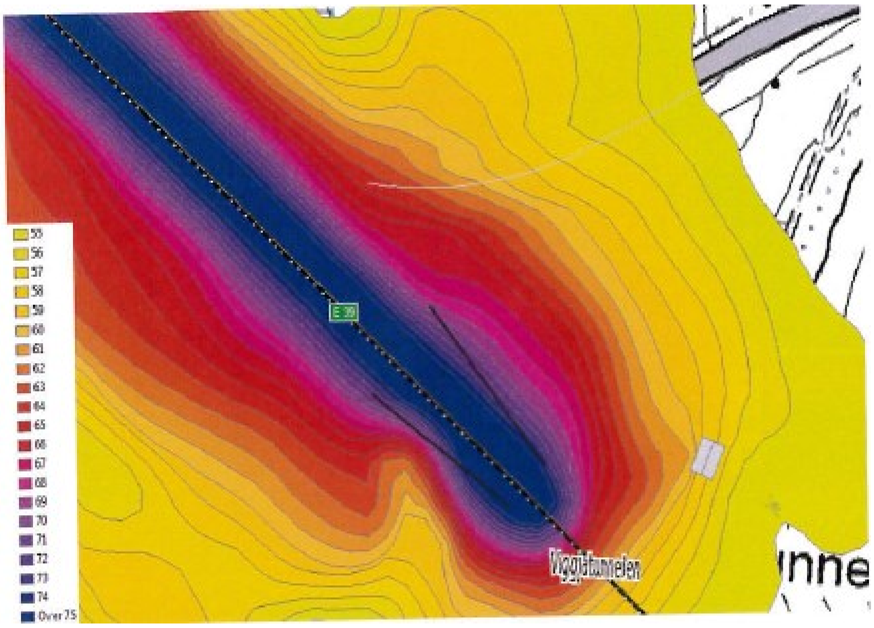
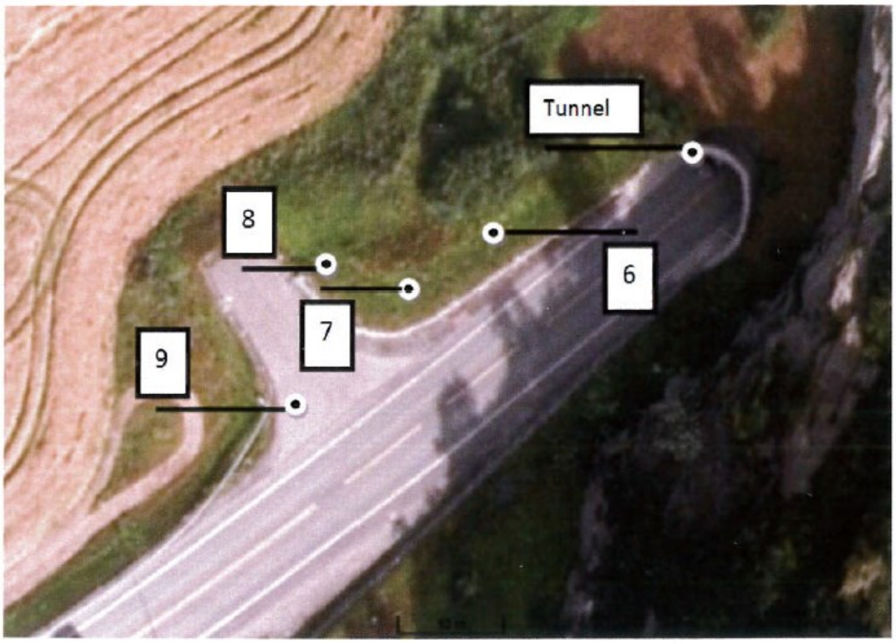


Figure 16. Calculated L_{Aeq} contours. Total noise level from the road at Viggja including the contribution from the tunnel opening. Straight black lines represent low retaining walls

Noise levels were measured at Brekk in the same way as at the Viggja tunnel, for 30 – 60 min per combination of microphone positions, while traffic intensity was 431 – 772 vehicles/h; the average speed was 78 km/h and the percentage of heavy vehicles was 10 % - 17 %.



Pos.	Dist. from tunnel [m]
6	20
7	30
8	35
9	45
Ref.	198

Figure 17: Measurement positions at Brekk. All were 1.2 m above local terrain

Figure 19 shows the calculated noise level contours from the tunnel opening at Brekk, and Table 1 shows the differences between measured noise levels, after normalisation to AADT as specified in (Nordtest, 2002), and calculated noise levels assuming AADT at Viggja and Brekk. Measured noise levels were 1.3 – 5.3 dB higher than the calculated noise levels. This trend for measured noise levels to be higher than calculated noise levels also apply for the reference positions, where noise levels should not at all be influenced by noise from the tunnel opening.

Figure 18: Reference microphone and tunnel opening at Brekk

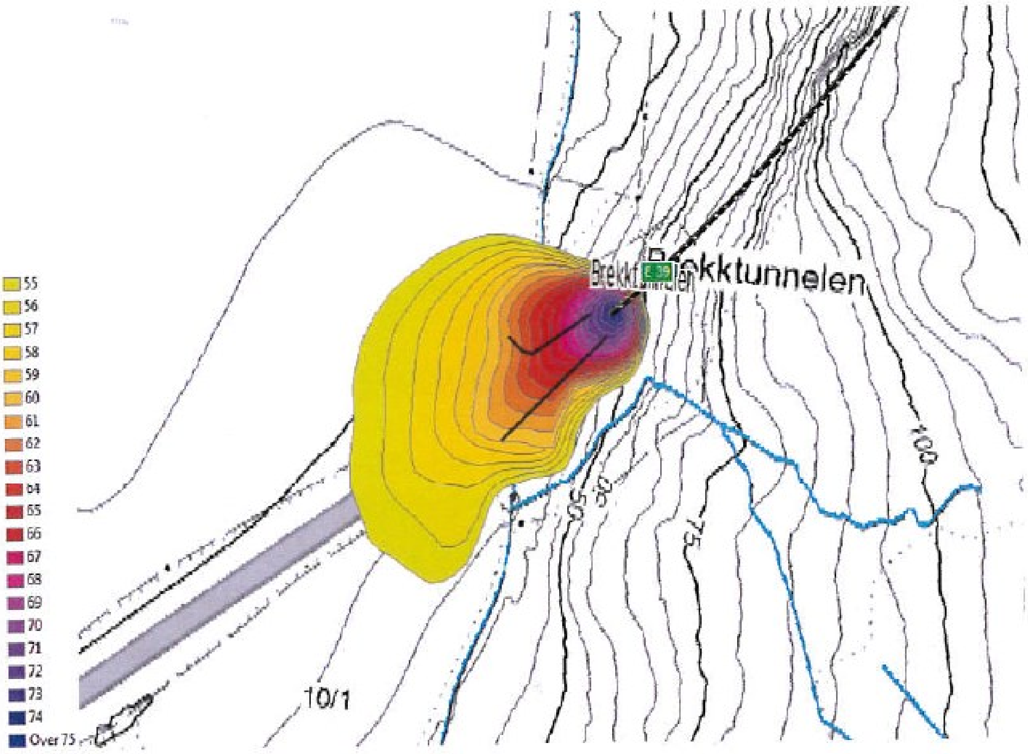


Figure 19: Calculated L_{Aeq} contours. Tunnel opening contribution at Brekk without contribution from the road in the open. Straight black lines represent low retaining walls

Viggja		Brekk	
Position	L_{Aeq}(meas) - L_{Aeq} (calc)	Position	L_{Aeq}(meas) - L_{Aeq} (calc)
[-]	[dB]	[-]	[dB]
1	4,4	6	2,9
2	2,3	7	3,9
3	4,1	8	3,8
4	3,2	9	5,3
5	4,1		
Ref	1,4	Ref	1,3

Table 1: Differences between measured and calculated noise levels at Viggja (left) and Brekk (right). Without normalisation for differences found at the reference positions

Assuming that model calculations for the reference positions are correct, the higher measured than calculated noise levels in these positions may be due to several things mentioned in (Tørnquist, 2012), for example

- 10 % or so of the vehicles at Viggja, but less than 2 % at Brekk, used studded tyres, the effect of which is not included in NorStøy
- many cars were noticed during the measurements to run on the profiled stripes on the road; this is not included in NorStøy
- the measured speeds of a sample of the passing vehicles may not be totally representative

(Tørnquist, 2012) normalised all calculation results by 1.3 dB or 1.4 dB, respectively, so there was zero deviation in the reference positions. Table 2 shows the differences between these normalised calculation results and the measured noise levels. These differences are between 0.9 dB and 4.0 dB with an average of 2.4 dB, thus indicating that prediction systematically underestimates noise level contributions from the tunnel opening.

Position	L_{Aeq}(meas) - L_{Aeq} (calc)
[-]	[dB]
1	3,0
2	0,9
3	2,7
4	1,8
5	2,7
6	1,6
7	2,6
8	2,5
9	4,0
Avg	**2,4**

Table 2: Summary of differences between measured and calculated noise levels at Viggja and Brekk after normalisation for differences found at the reference positions

Other possibilities mentioned in (Tørnquist, 2012) is that sound reflections from rock or retaining walls adjacent to the tunnel openings may have caused higher noise levels than predicted by the model, or even that software developers may not have implemented the Nord2000 model properly. To the present author, inaccuracies in the topographical information input to the software would seem more likely.

Mannsfjell-tunnel

Figure 20 - Figure 21 show a tunnel opening where Norwegian consultants performed noise traffic noise measurements according to (NS 8174-1:2007 + A1:2008) for the Norwegian road administration and, after having normalised measured $L_{Aeq,30min}$ values to AADT, compared them with noise levels calculated for the AADT (Bekkos, 2015). Noise from vehicles outside the tunnel was calculated using the Nordic prediction method (TemaNord 1996) implemented in CadNaA software version 4.5, while the noise level contribution from the tunnel was calculated according to a procedure proposed in (Probst, 2010), based on simulations made by means of software for predicting sound propagation in rooms. This latter procedure allows for determining a point source strength representative of the tunnel opening, based on noise levels measured inside the tunnel. Attenuations during propagation from this source to the receiver points shown in Figure 21 were calculated using the Nordic prediction method for environmental noise from industrial plants (Kragh, 1982). The noise levels calculated with and without the tunnel contributions are shown in Table 3. The increase in calculated noise levels due to the introduction of a tunnel sub-source varied between 0.1 dB and 3.2 dB.

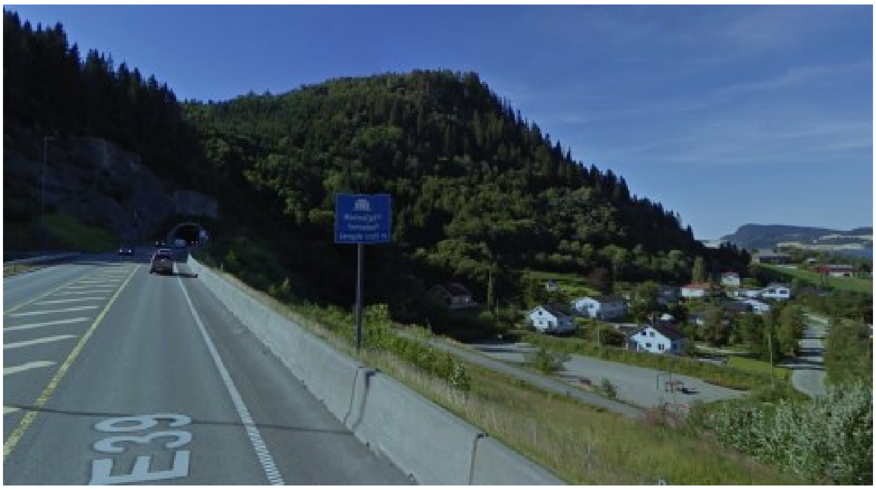
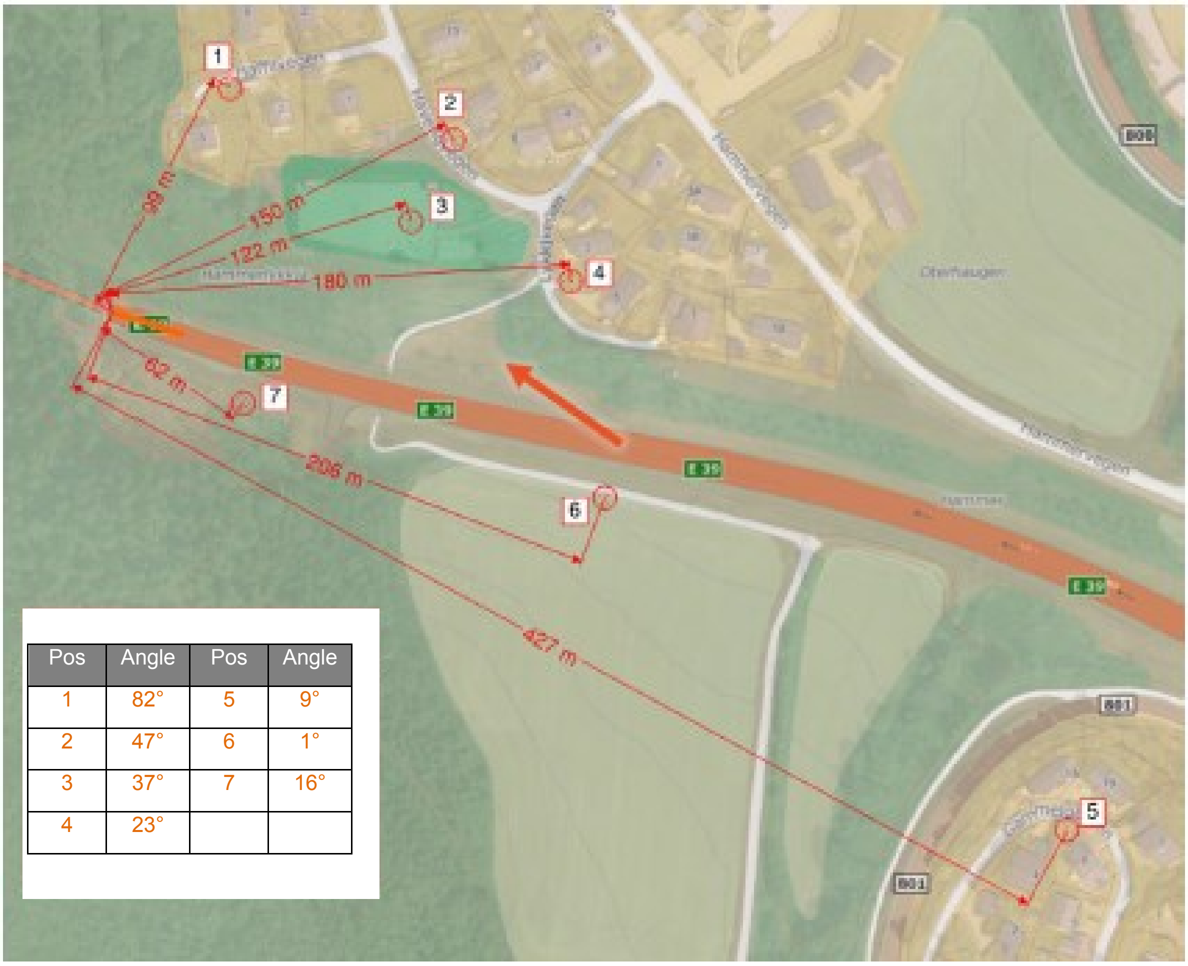


Figure 20: Manfjell-tunnel opening and surrounding terrain. From Google Streetview, 2010

Table 4 shows the calculated noise levels including the tunnel contribution and the measured noise levels. Measured noise levels were from 4.3 dB lower than calculated to 1.9 dB higher than calculated. Interestingly, the largest difference was found in position 6 where no effect of the tunnel opening should be expected. This could have to do with

- Measurement uncertainty
- Incorrect prediction model or topographical information
- Incorrect implementation or use of the prediction model in the software

or unknown factors. The text in (Bekkos, 2015) suggests that the difference in Pos. 6 could be due to differences between the topography in the model and the real topography. The general impression is that one cannot expect to decide whether or not the calculated noise levels are correct or not based on a single set of measurements as performed here.



Pos	Angle	Pos	Angle
1	82°	5	9°
2	47°	6	1°
3	37°	7	16°
4	23°		

Figure 21: Measurement positions and distances from tunnel opening. The table shows the measurement position angles [°] relative to the road direction at the tunnel opening. The photo in Figure 20 was taken in the direction shown by the arrow

Situation	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
Calc without tunnel contribution L_{den} [dB]	50,1	50,0	51,6	52,6	51,7	72,3
Calc with tunnel contribution L_{den} [dB]	50,4	53,2	54,2	54,4	52,3	72,4
Diff with rel. without tunnel contribution [dB]	0,3	3,2	2,6	1,8	0,6	0,1

Table 3: Traffic noise levels calculated with and without the tunnel opening contribution and the differences between them, after (Bekkos 2015)

Situation	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
Calc with tunnel contribution L_{den} [dB]	50,4	53,3*)	54,2	54,4	52,3	72,4
Measured L_{den}(meas),$_{AADT}$ [dB]	50,2	54,0	56,1	55,5	54,0	68,1
Diff measured - calculated [dB]	-0,2	0,7	1,9	1,1	1,7	-4,3

*) slightly different from result in Table 3; copied from (Bekkos, 2015)

Table 4: Calculated and measured traffic noise levels and the differences between them, after (Bekkos 2015)

A reverse engineering exercise based on the measurement data collected at the Manfjell-tunnel would not seem likely to lead to any improvement, primarily due to uncertainties in the measurement results and in the calculated transmission path attenuation. For example, results from Pos. 5 – 6 indicate that the source noise level used in the prediction could be 4.3 dB too high (Pos. 6), while the source noise level at the same time seems to have been 1.7 dB too low (Pos. 5). Had an extra measurement position, close to the road and with no contribution from the tunnel opening, been included in which the attenuation during transmission from sources to receiver could be considered well known, then a source calibration might have been feasible and the uncertainty of the vehicle noise source model might have been reduced.

Appendix B: Danish fly-under case

Figure 22 shows the intersection between Copenhagen motorways M3 and M12. Eastbound lanes of M12 pass under the westbound lanes of M12, M3 and local road Jyllingevej; see Figure 23 and Figure 24; while the westbound exit to Jyllingevej from southbound lanes of M3 fly over Jyllingevej, and the southbound approach from Jyllingevej to M3 flies over M12.

East of M3 are residential areas, originally protected for many years from M3 traffic noise by an earth berm with trees on it and now, after widening M3 from 4 to 6 lanes and building M12, which opened to traffic in 2012, some of them are also protected by a supplementary inclined noise barrier as illustrated in Figure 25.

Figure 22: Aerial view of motorway M12 connection to M3 with aproaches from and exits to the local road, Jyllingevej. Source: Kortdata © Google 2015

Extracts of a noise contour map is shown Figure 26. Yearly average L_{den} was calculated in points 1.5 m above local ground in a 25·25 m grid by means of the Nordic prediction method, Nord2000, applying SoundPLAN ver. 7.0/update 051110 and using modelled traffic data for the new M12 and traffic forecasts for M3. The calculations assumed AADT on M3 to be 85,000 vehicles south of M12 and 89,000 north of M12, with 10.5 % heavy, and speeds 120 km/h for light and 90 km/h for heavy vehicles. On M12 the AADT was assumed to be 15,000 with 9.7 % heavy, all driving 90 km/h. The local road Jyllingevej carries an AADT of 40,000 at an average of 52 km/h, with 6.1 % heavy vehicles.

Tyre/road noise was assumed to be reduced by 2 dB compared with standard Danish motorway asphalt, SMA 11, by applying noise reducing thin asphalt layers. Digital terrain data, building contours and data on building heights were taken from the road construction project and from commonly used Danish registers (Kort & Matrikelstyrelsen; Top10DK; BBR).

Figure 27 shows dwellings exposed to noise levels at their façade as given in the legend. Most dwellings are exposed to noise levels not exceeding L_{den} = 58 dB, which is the Danish

Figure 23: Eastbound lanes of M12 passing under M3

Figure 24: Eastbound lanes of M12 passing under westbound lanes of M12

Figure 25: Northbound lanes of M3 with noise barrier where M12 joins M3 north of Jyllingevej

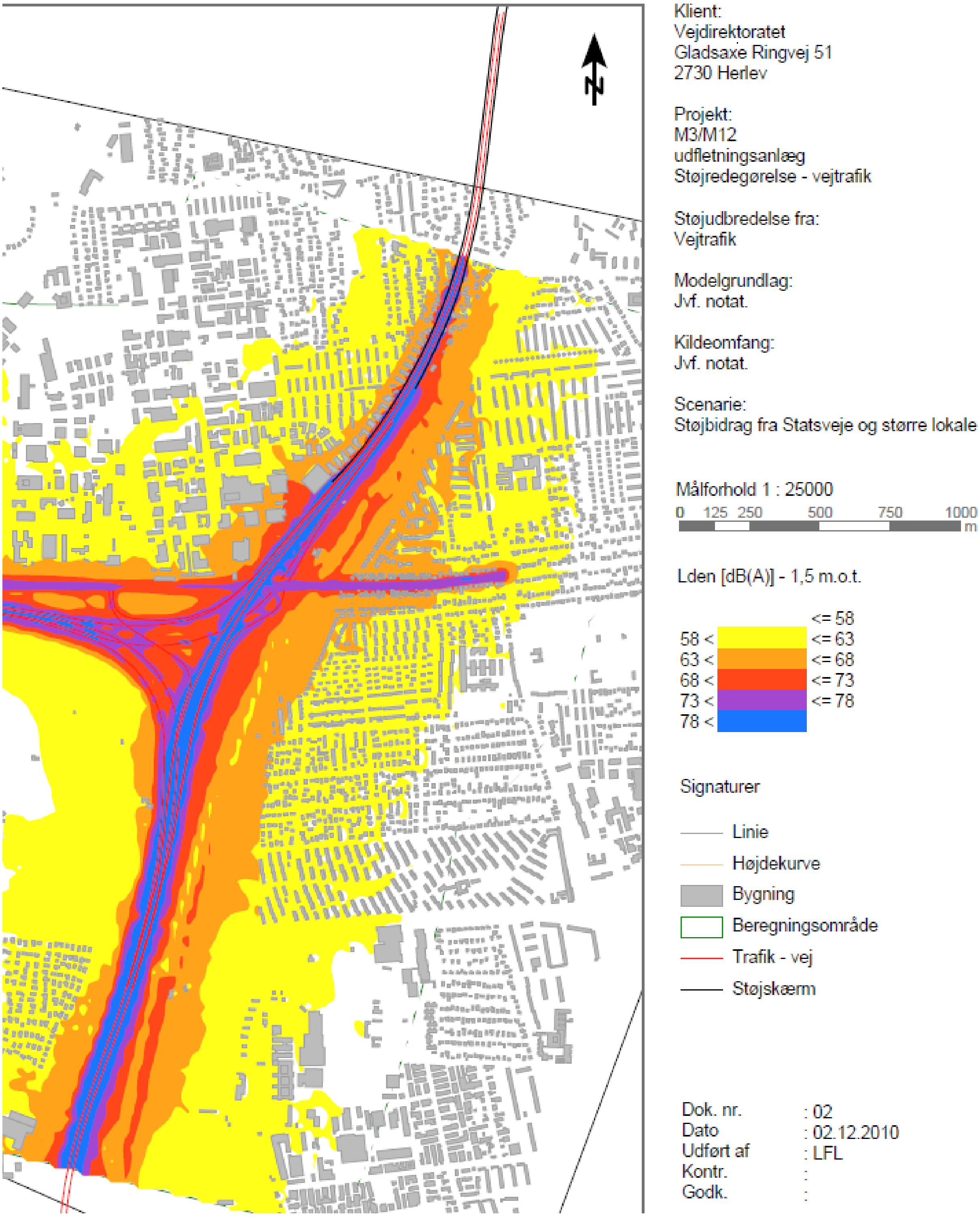


Figure 26: Extract of noise level contours at a Copenhagen motorway intersection

Environmental Protection Agency guideline noise limit for traffic noise exposure of residential areas. Some dwellings were found to be exposed to noise levels between 58 dB and 68 dB, primarily the first row of houses east of M3 at the elevated section of M3 flying over M12 and Jyllingevej. The highest noise exposures, 68 – 73 dB yearly average L_{den}, were found at houses closest to the local road, Jyllingevej.

The shape of the noise contours and the situation of the dwellings identified as being heavily noise exposed indicate that the main sources of noise at these dwellings are the vehicles driving on M3 nearest to the residential area and situated above the surrounding terrain. Noise from vehicles driving on the flyovers south of Jyllingevej contribute less, partly because they are farther away from the residential area, partly because they are much fewer than the vehicles driving on the M3. In this connection, also the noise level contributions from the fly-under road sections are of no significance. On top of this, noise from vehicles when driving on road sections in cuttings is attenuated significantly more during propagation than noise emitted from vehicles driving on the elevated parts of M3.

It would not be possible to define a measurement strategy to improve prediction accuracy other than proposed in Section 6.2, i.e. to measure noise levels near different road sections to improve the accuracy of the noise source input data. However, noise measurements could indeed be used to validate the noise map in individual positions or to document the effect of a taken noise mitigation measure as indicated in Section 4.

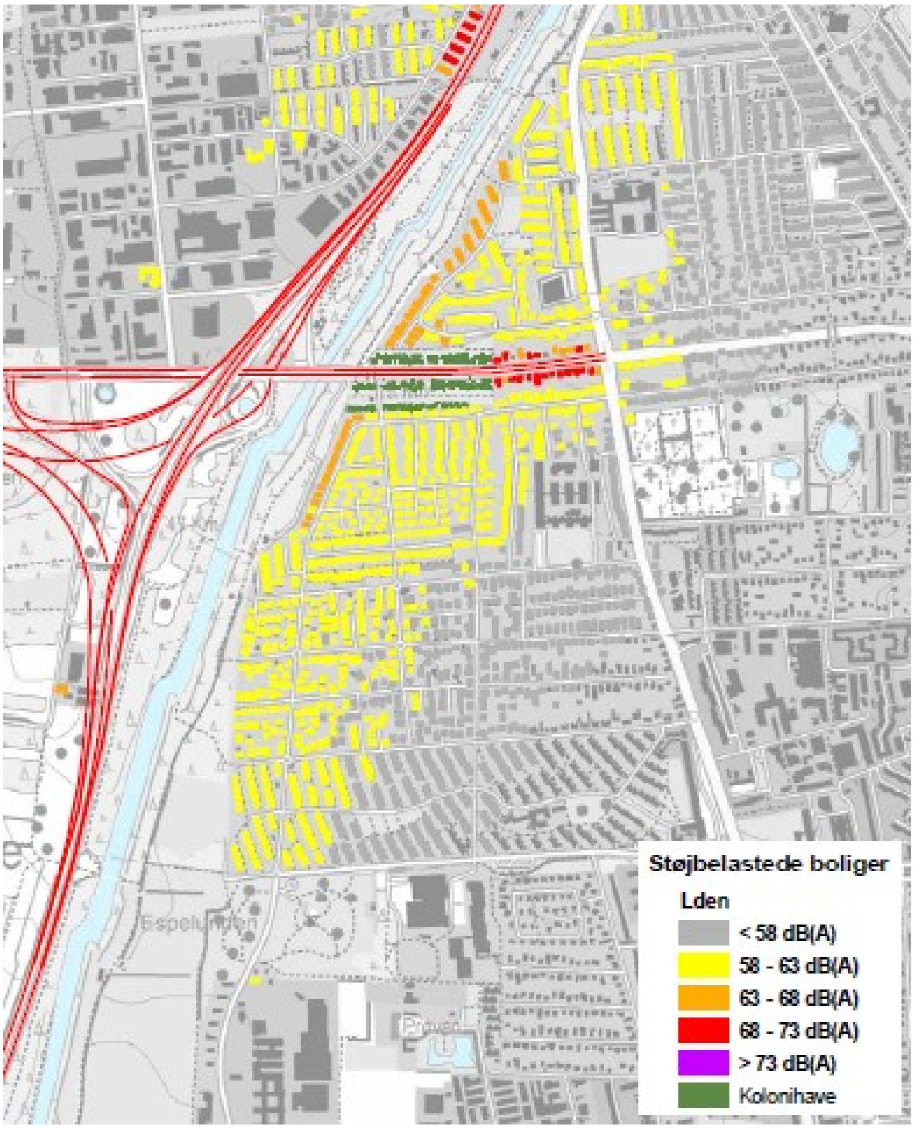


Figure 27: Dwellings[6)] exposed to L_{den} ≥ 58 dB in 5 dB classes

6) Green signature marks allotment gardens

Appendix C: Norwegian flyover case

Figure 28 shows a map of motorway E18 on a flyover passing through Drammen, 40 km or so southwest of Oslo, Norway. The AADT is between 35,000 and 55,000 vehicles per day with, 10 % heavy and average traffic speed 90-100 km/h. The illustrations in this section were received from Helena Axelsson, Norwegian Public Roads Administration. In Figure 29, a residential area is seen to the northwest of the motorway just north of the water. Part of this area is shown in the photograph in Figure 30, which also shows the flyover as seen from a local road under it. Transparent screens are mounted on top of the concrete crash barrier.

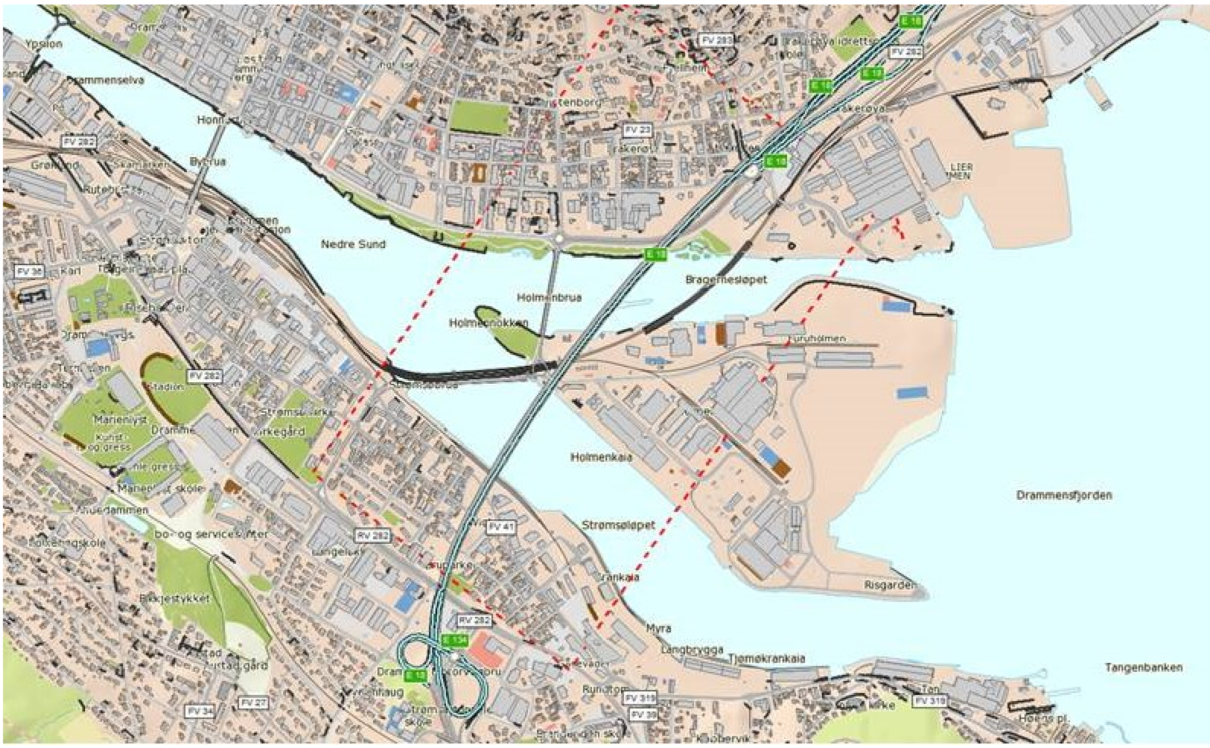


Figure 28: Map of Norwegian flyover

Calculations were made according to Nord2000 by means of the NorStøy software. In Figure 31 contours of calculated noise levels 2 m above the terrain are shown for the total traffic on local roads and on the flyover, based computation points in a 5·5 m grid. Overall, noise from other roads than the flyover dominates the total traffic noise. Noise from local traffic under the flyover is reflected from the underside of the flyover when vehicles pass under it. Such reflected sound could partly "destroy" the screening effect of the wooden hoarding shown in Figure 30, but as illustrated in the figure, vehicles at other times are much closer to the residential area, so that sound reflected from the flyover structure is likely to be second order contributions only.

A second computation was made in which only noise from traffic on the flyover was included. Figure 32 shows the first result of this calculation as noise level contours 2 m above the local ground from the traffic on the flyover, including its ramps at both ends of the bridge. The present author's first overall impression was that these noise contours should reasonably accurate representations of the noise exposure at the façades of the first row of houses, as mentioned in connection with Figure 10. The NorStøy software applied for the computations by default includes 3rd order reflections, but with simplifications made in the reflection calculations in order to save computation time (Olsen, 2011). The shape of the noise level contours indicate that in positions between the buildings and behind the first row of buildings, these simplifications have led to an underestimation of noise levels in some areas, but this is difficult to judge.

After closer inspection, however, it turned out (Axelsson, 2015) that for unknown reasons

- the barriers on the bridge were missing in the input data for the calculations
- the road was only 3,8 m wide in the model, which is erroneous
- an error in the latest software version caused contributions from local roads to contribute extremely high noise levels

The input data were revised and the computation was repeated using an earlier software version. The results are illustrated in Figure 33 which differs dramatically from Figure 32. This underlines the obvious need for verifying that

- model input is correct
- the software yields correct results

Figure 29: Residential area northwest of the flyover seen from the motorway flyover; from Google Street view 2014

Figure 30: Residential area northwest of the flyover seen from the local road; from Google Street view 2014

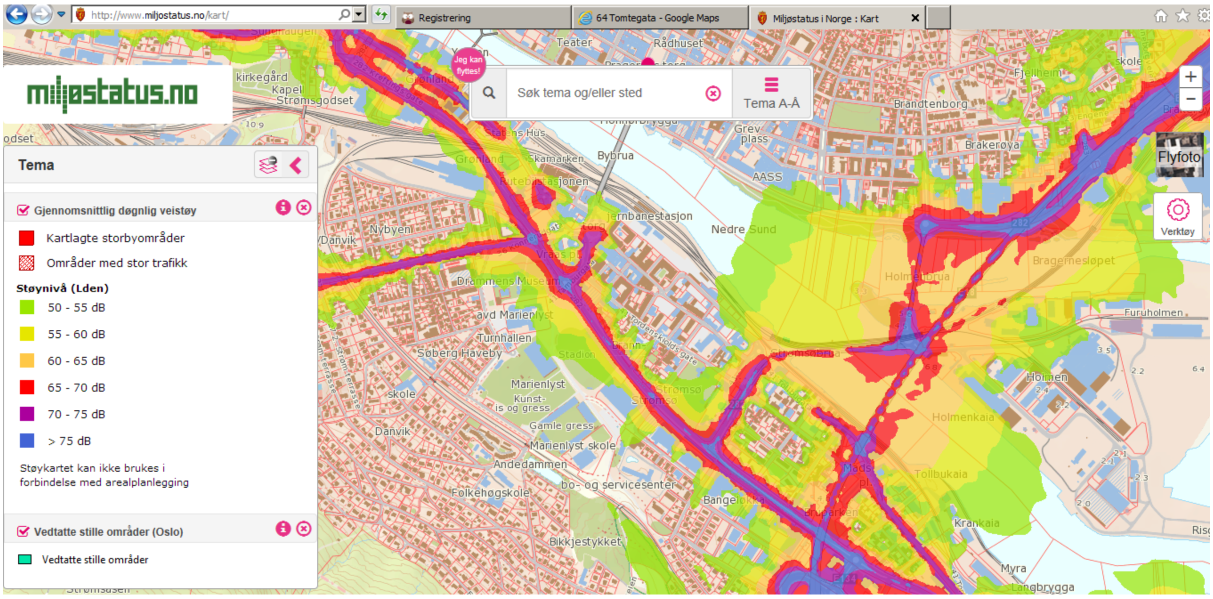


Figure 31: Noise level contours. Total noise from all roads included in the mapping

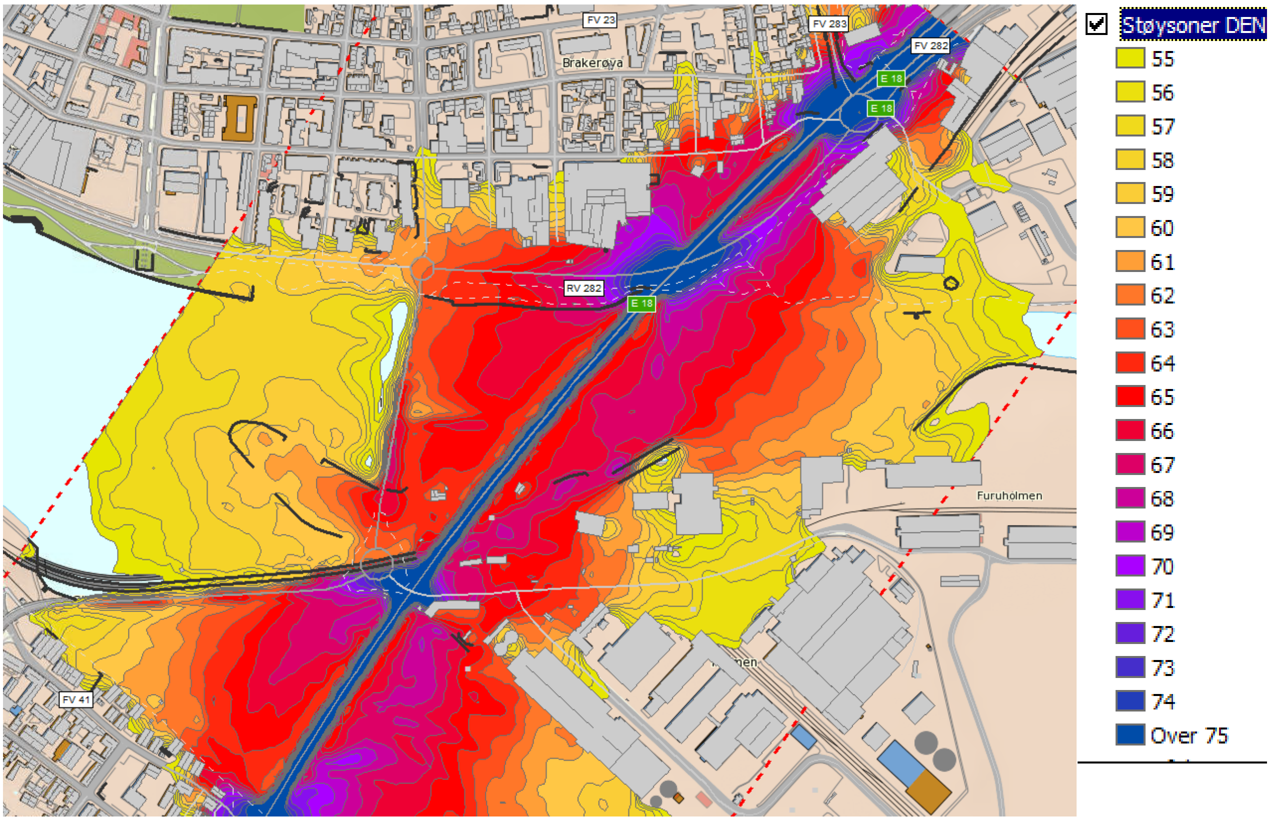


Figure 32: L_{den} noise level contours of flyover contributions, including ramps, but without taking the barriers at the edges of the bridge deck into account, erroneously assuming the road to be 3.8 m wide and applying a defective software version

It would not be possible to define a measurement strategy to improve prediction accuracy other than proposed in Section 6.2 for improving the noise source models, i.e. to measure noise levels near different sections of the road to improve the accuracy of the noise source input data. However, noise measurements could indeed be used to validate the noise map in selected points or to document the effect of a taken noise mitigation measure as indicated in Section 4.

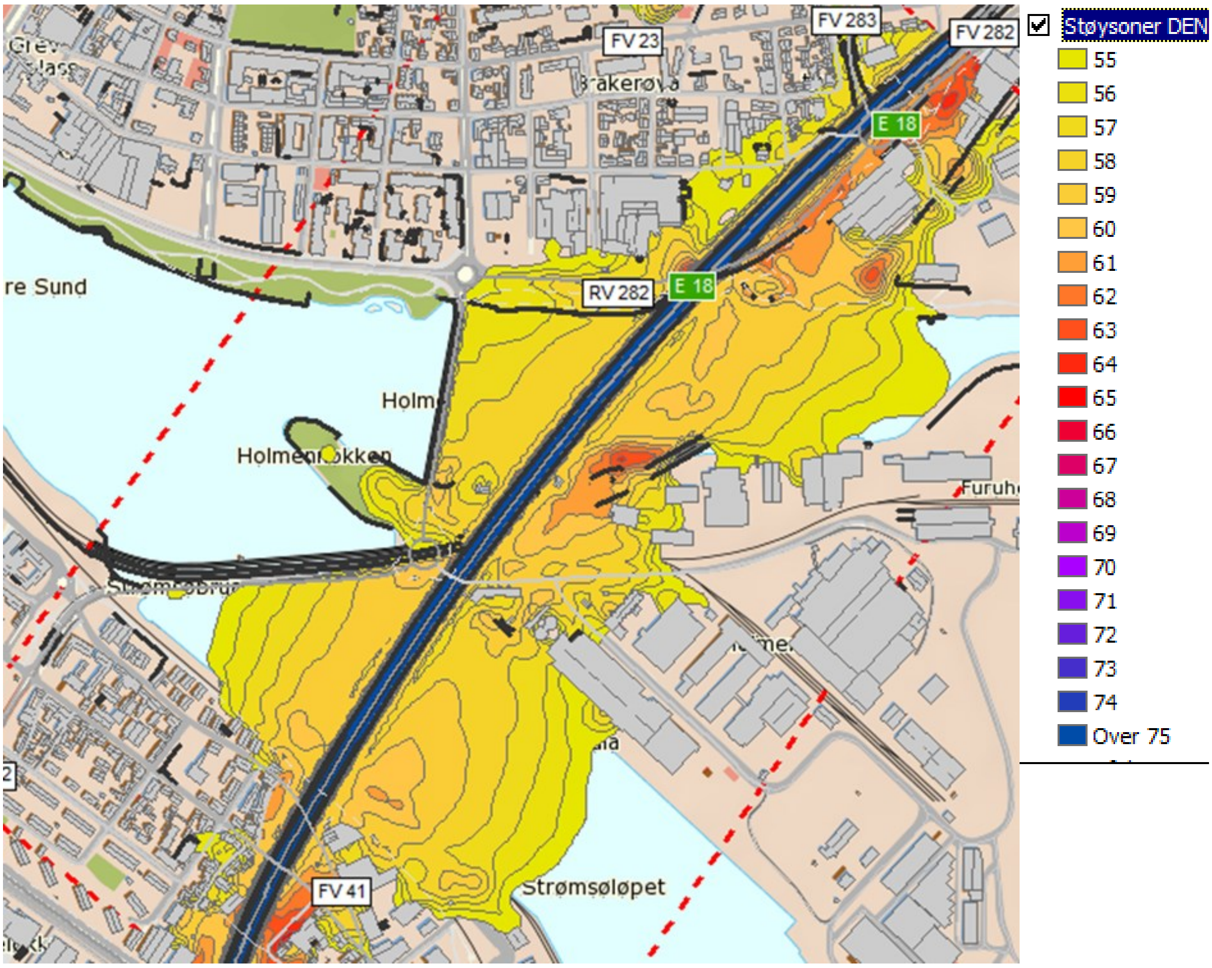


Figure 33: L_{den} noise level contours of flyover contributions, including ramps, taking the barriers at the edges of the bridge deck into account and presuming the road to be 20 m wide

Appendix D: Method for measuring yearly average L_{den} or L_{night}

Note: This text is reproduced from ISO/DIS 1996-2 with a special permission from ISO.

The procedure for determining the traffic noise level L_{den} is given in Figure 34 and Figure 35, based on long-term and short term noise measurements, respectively. Figure 36 explains the principles for normalising the measured noise level to reference conditions such as the yearly average, and Figure 37 describes how to determine the measurement uncertainty.

10.6 Determination of L_{den}

10.6.1 Determination from long-term L_{eq} measurements

Carry out calculations using the following steps:

1) Remove unwanted data. Some guidance on how to do that is given in Annex E;

2) stratify the data into the different windows and correct for residual sound and to reference conditions;

3) use Formula (6) together with frequency of occurrence according to meteorological statistics to determine L_{day}, $L_{evening}$ and L_{night};

4) calculate L_{den}.

10.6.2 Determination from long-term L_E measurements of individual events

The principle is to determine the average L_E for each type of event, convert it to energy and then add up all events predicted to occur during the time period under study and finally to convert it to L_{eq} for the time period in question.

1) Remove unwanted events;

2) Stratify the measured events into relevant source categories and meteorological windows;

3) For each meteorological window, k, average each relevant source category, i, determine the average sound exposure level $L_{E,ik}$

   For each meteorological window k calculate $L_{day,k}$ from

$$L_{day,k} = 10\lg\left(\sum_i N_{ref,i} \cdot 10^{0,1 L_{E,ik}}\right)\mathrm{dB} - 10\lg\left(t_{day} \cdot 3600\right)\mathrm{dB} \qquad (20)$$

   where

   $N_{ref,i}$ is the statistical yearly day average of number of single events of source category i,

   t_{day} is the numerical value of the duration of the day, in hours.

   Corresponding formulae are valid for $L_{evening}$ and L_{night}.

4) Use Formula (6) together with frequency of occurrence according to meteorological statistics to determine L_{day}, $L_{evening}$ and L_{night};

To be continued

Continued

5) Calculate L_{den}.

Figure 34: Method for measuring L_{den} from road traffic based on long-term noise measurements. Extract from ISO/DIS 1996-2

10.6.3 Determination from short-term measurements

In this case the measurements have either taken place

a) at a short distance, see Formula (13) minimizing the influence of weather conditions, or

b) under favourable propagation conditions as described in 8.2, or

c) under mixed propagation conditions.

In case a) use the prediction method to normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night. The values thus obtained are taken as L_{day}, $L_{evening}$ and L_{night} respectively. For industrial noise sources each source has to be time-weighted to take into account the actual times of operation.

In case b) and c) proceed as follows:

1) Normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night.

2) Use meteorological statistics to determine the ratio of time p_i for each meteorological window M*i*, see 8.1, distinguishing between day, evening and night.

3) Let the favourable conditions during the measurements be represented either by meteorological window M3 (most common during day-time) or M4 (most common during night-time).

— Case b): Use the prediction method to calculate the sound pressure levels for each of the 4 meteorological classes as described in Table 3. Calculate the difference Δ_i between each meteorological class i and M3 or M4 (Δ_4 = 0 dB), whichever was measured.

The prediction method is used to calculate L_{eq} using the same operating conditions for each of the 4 meteorological windows M1 to M4. For each of these the difference is determined to the window measured (M3 or M4). These differences are applied to the measured value to get the simulated measured values for the other meteorological conditions.

— Case c): Use the measured noise levels in selected propagation condition in order to estimate the differences Δ_i between each meteorological window i and M3 respectively M4 (Δ_4 = 0 dB).

4) Calculate L_{day} using Formula (21):

$$L_{\text{day}} = 10\lg\left(\sum_{i=1}^{4} p_i 10^{0,1(L_i+\Delta_i)}\right)\text{dB} \qquad (21)$$

where L_i is the measured value during meteorological window M*i* corrected to be valid for the traffic flow of the yearly average day and averaged over the number of measurements carried out under the condition M*i*.

5) Calculate $L_{evening}$ accordingly.

6) Calculate L_{night} accordingly.

7) Calculate L_{den}.

Figure 35: Method for measuring L_{den} from road traffic based on short-term noise measurements. Extract from ISO/DIS 1996-2

D.2 Road traffic

D.2.1 Calculation of correction to reference condition

Modern prediction models [11] are based on sound power levels of different vehicle categories. Propulsion noise and rolling noise are separated. The sound power level is a function of speed and temperature for rolling noise and of speed and acceleration for propulsion noise. Because of the complexity due to the number of variables and equations involved it is recommended to use a complete prediction method to determine the correction to reference condition as shown in the following example where relevant notations are shown in Table D.1:

Table D.1 — Overview of notations and parameters used for the computations

		Number	Speed	Temperature	Measured	Calculated
Measured	Category 1	N_1	v_1			
	Category 2	N_2	v_2	t	L'_{eq}	L'_{eq}(calc)
	Category 3	N_3	v_3			
Calculated	Category 1	$N_{1,ref}$	$v_{1,ref}$			
	Category 2	$N_{2,ref}$	$v_{2,ref}$	t_{ref}	—	$L_{eq,ref}$ (calc)
	Category 3	$N_{3,ref}$	$v_{3,ref}$			

NOTE 1 As an alternative to working with several different vehicle categories each vehicle in a category can be converted into an equivalent number of another category, e.g. one medium heavy vehicle equals *y* light vehicles and one heavy vehicle equals to *x* light vehicles. The numbers *x* and *y* have to be taken from a data base and they will vary with speed and other operating conditions.

The measured value corrected to reference conditions is given by

$$L_{eq,ref} = L'_{eq} + L_{eq,ref}(\text{calc}) - L'_{eq}(\text{calc}) \qquad \text{(D.5)}$$

NOTE 2 Depending on program used for the calculations the correction for atmospheric attenuation according to D.1 may be included in the result given by Formula (D.5).

Figure 36: Method for normalising measured road traffic noise levels to reference conditions. Extract from ISO/DIS 1996-2

D.2.2 Calculation of uncertainty

The basic formula for L_{eq} for one category of vehicle is

$$L_{eq} = L_E - 10\lg(T)\text{dB} + 10\lg(N)\text{dB} = L_W(v,t) + \Delta L_{tf} - 10\lg(v)\text{dB} + 10\lg(\frac{N}{T})\text{dB} \qquad \text{(D.6)}$$

where

L_W is the total sound power level,

ΔL_{tf} is the total transfer function between L_W and sound exposure level,

v is the speed,

T is the time,

N is the number of vehicles during the time T.

According to Harmonoise the speed dependence of L_W, if focussed on tyre/road noise and assumed that the noise level is dominated by light vehicles, is approximately 30 lg(v), but here it will be assumed that it is 35 lg(v) (see [10]). The temperature dependence is $-K(t-20)$. Formula (D.6) can now been written as follows:

To be continued

Continued

$$L_{eq} = L_W(v = v_0, t = t_0) + \Delta L_{tf} + 25\lg(\frac{v}{v_0})dB + 10\lg(\frac{N}{T})dB - 10\lg(v_0)dB - K(t - t_0) \quad (D.7)$$

or, for the reference condition

$$L_{eq,ref} = L'_{eq} + 25\lg\left(\frac{v_{ref}}{v}\right)dB + K(t_{ref} - t) + 10\lg\left(\frac{N_{ref}}{N}\right)dB \quad (D.8)$$

Thus the sensitivity coefficient, c_v, for speed is

$$c_v = \frac{\partial L_{eq}}{\partial v} = -25\frac{1}{v}\lg(e) = -\frac{10{,}9}{v} \quad (D.9)$$

and

$$c_{v_{ref}} = \frac{\partial L_{eq}}{\partial v_{ref}} = 25\frac{1}{v_{ref}}\lg(e) = \frac{10{,}9}{v_{ref}} \quad (D.10)$$

and for traffic flow

$$c_N = \frac{\partial L_{eq}}{\partial N} = -\frac{10}{N}\lg(e) = -\frac{4{,}3}{N} \quad (D.11)$$

$$c_{N_{ref}} = \frac{\partial L_{eq}}{\partial N_{ref}} = \frac{10}{N_{ref}}\lg(e) = \frac{4{,}3}{N_{ref}} \quad (D.12)$$

and for temperature

$$c_t = \frac{\partial L_{eq}}{\partial t} = -K \quad (D.13)$$

$$c_{t_{ref}} = \frac{\partial L_{eq}}{\partial t_{ref}} = K \quad (D.14)$$

The total combined standard uncertainty of Formula (D.8) is then given by

$$u_{L_{eq,ref}} = \sqrt{(c_{L'}u_{L'})^2 + (c_{v_{ref}}u_{v_{ref}})^2 + (c_v u_v)^2 + (c_N u_N)^2 + (c_{N_{ref}}u_{N_{ref}})^2 + (c_t u_t)^2 + (c_{t_{ref}}u_{t_{ref}})^2} \quad (D.15)$$

Assuming that the uncertainty of the measurement conditions is equal to the uncertainty of the reference conditions the following is obtained:

$$u_{L_{eq,ref}} = \sqrt{u_{L'}^2 + 2\left(\frac{10{,}9}{v}\right)^2 u_v^2 + 2\left(\frac{4{,}3}{N}\right)^2 u_N^2 + 2K^2 u_t^2} \quad (D.16)$$

If further assumed that the standard uncertainty in average speed and average number corresponds to 5 %, that K = 0,1 (typical number according to Harmonoise) and that u_t = 1, the following is obtained:

$$u_{L_{eq,ref}} = \sqrt{u_{L'}^2 + 0{,}60 + 0{,}09 + 0{,}02} \quad (D.17)$$

NOTE The numbers are just examples. They have to be estimated in each case.

$u_{L'}^2$ is evaluated from the measurement(s) according to the guidance given in the main body of the standard.

Figure 37: Method for determining measurement uncertainty. Extract from ISO/DIS 1996-2