Under the agreement from January 2009 about a green transport policy from January 2009, a pool of 400 million Kr. has been allocated until 2014 in an effort to reduce nuisance caused by traffic noise. The goal of the pool is to reduce pollution from traffic along the main roads and railways. Within the framework of this pool 10 millions Kr. are allocated to 2009 in order to develop new methods for noise abatement. The methods will help to meet the targets regarding noise abatement, including the optimization of noise emission and the maximization of the noise reduction effect per invested money.

The purpose of this project on traffic flow and noise is to provide a basis to take into account the noise in the design of roads and intersections. This pilot study will clarify whether there is a method which can be optimized and used when determining the noise impact of a design at junctions and roundabouts.

The report was written by Gilles Pigasse from the Danish Road Institute/Road Directorate (DRI). Bent Andersen and Hans Bendtsen from DRI have performed quality control of the report.
SUMMARY

Accelerating vehicles emit more noise than vehicles with constant speed and they are a major source of noise pollution in cities, especially near intersections where the driving pattern of a vehicle is likely to change. It is investigated whether there is a difference in noise emission at selected and significantly different roundabouts and intersections.

The two road designs that have been investigated in the present study are the conversion of a crossing into a roundabout (near Snoldelev) and the enlargement of an already existing small roundabout (on Willumsens Vej). In both cases the noise level at two different positions along the road has been predicted using the Nord2000 model before and after the change in their design. It was possible to predict a change in the noise level due to the change in the road layout and the resulting changed traffic conditions. These predictions are supported by in situ noise level measures. The measurements that were carried out in Snoldelev showed a decrease in noise level in the selected positions of up to 3.7 dB, and on Willumsens Vej the noise level increased slightly (max. 1 dB). There is a fairly good agreement between the measured and modelled levels, between 0.1 and 2.8 dB differences. Part of this difference can be explained by a different age and type of pavement before and after the reconstruction – rather than caused by the changed road configuration. Suggestions are made to further improve the measurements as well as the prediction methods.

Formålet med dette projekt om trafikafvikling og støj er at skabe grundlag for at tage hensyn til støjen ved udformning af vejnettets strækninger og kryds. Dette forprojekt skal klarlægge, om der findes en metode der kan optimeres til brug ved fastlæggelse af den støjmæssige betydning af udformningen af kryds og rundkørsler.

SAMMENFATNING

Accelererende køretøjer udsender mere støj end køretøjer med konstant fart og er en betydelig kilde til støjgener i byer, ikke mindst i nærheden af kryds, hvor køremønstre sandsynligvis ændres. Det klarlægges, om der er forskel i støjudsendelsen ved udvalgte, væsentlig forskelligt udformede rundkørsler og kryds, og der foretages sammenligninger til kørsel med jævn fart på en almindelig lige vejstrækning.

1. INTRODUCTION

Noise from road traffic is normally predicted in Denmark by the use of the Nord2000 method. The method is primarily developed for the prediction of noise from traffic with constant speed. In urban road networks, the traffic might be accelerating or decelerating. This can have an influence on the noise levels for example at intersections, roundabouts and where traffic calming measures have been established, e.g. with humps, narrowing the street or change of pavement.

The primary objective of building roundabouts is often to increase the safety on the roads and to improve the traffic flow. The consequence is often a change in the driving pattern of the vehicles, such as speed, acceleration or deceleration. The aim of this project is to investigate the relation between different road designs and traffic noise emission. The outcome of this project will be a better understanding of this relation as well as a framework to predict the noise level at a given point for a given road geometry. This can therefore be a powerful tool in the process of traffic management.

In a previous report from the Danish Road Institute [1] different road designs that can lead to an improvement of traffic flow and safety and to a decrease of noise annoyance have been investigated. The different traffic flow measures include humps, chicanes, automatic traffic control and roundabouts. Experimental studies have shown how a change in the road design influences the noise level. The effect on noise can be caused by a change of the speed as well as by changing the driving pattern (acceleration/deceleration). With the use of Nord2000 it can be predicted that a decrease of 10 km/h yields a noise reduction of about 1 dB for a mixed traffic at normal urban driving speed [2] depending on the actual speed level. Different studies from the 90’s have shown the positive effect of using humps in urban areas. The direct consequence of building humps is a reduction of the speed and hence a reduction of the noise level. This noise reduction can be expected to be around 1-2 dB between the humps [3] or 2-4 dB if only light vehicles are considered [4] depending on the design of the humps. These results should be nuanced by the perception from the neighbours’ side. Surveys have indeed shown that people living next to the humps find the noise annoyance unchanged or even worse than before [5]. This has been explained by the impact sound produced between the hump and the vehicle, and is particularly important for heavy vehicles.
Building a chicane can also be a solution to reduce the noise level (see Figure 1). The effect of narrowing the carriageway has been measured in France [6] and it was shown that the noise level near the road can be decreased by 1 to 4 dB between chicanes (where the speed is lowest), while an increase of 1 to 5 dB has been observed at the entrance and exit of the site. This noise increase is mainly due to vehicles braking and accelerating.
The above mentioned solutions do not seem to satisfyingly reduce the traffic noise in the streets; perhaps roundabouts could be a good possibility to decrease the noise level at crossings. Experimental studies have investigated the effect of modifying a crossing into a roundabout [7, 8]. These studies showed that a decrease of the noise level between 1 and 4 dB is achievable near the intersection. It is believed that a change in the vehicles’ speed is responsible for this decrease. It would be of great interest to estimate the noise level at a roundabout before it is actually built. Plüss et al. [9] used the German RLS90 model to predict the noise level during day- and night-time for a roundabout in an urban area. Their experimental results show a decrease of the noise by 1.7 dB during daytime and 2.9 dB during night time, on a façade facing the crossing/roundabout. They also found a difference of 1.4 dB between predictions and experimental results at night and a 0.9 dB difference during daytime. Their model therefore seems to approximate well the noise behaviour at the roundabout. Chevallier et al. [10] used a microscopic traffic simulation tool to predict the noise level at a roundabout. They obtained a maximum deviation between prediction and measurement results of 2.7 dB.

There exist many methods to predict the noise level produced by urban traffic. Many countries have developed their own method, for instance Germany has the RLS90, Switzerland developed the STL86+ and SonRoad, France the NMPB, USA the TNM, Scandinavia Nord2000 and Japan the ASJ 2003. Different European projects have tried to standardize these different methods and create a common European model; such projects include RoTraNoMo and Harmonoise. These two models will be presented in the next section. The Harmonoise method is, to some extent, based on the same model framework as Nord2000 but it also includes facilities to predict the effect of uneven driving patterns. The next section will introduce these two models, followed by a comparison between experimental results at two roundabouts and results predicted with the Nord2000 model. From this comparison, conclusions are drawn regarding the accuracy of the Nord2000 model. The last section presents suggestions for further improving the measurement methods and prediction model.
2. DIFFERENT PREDICTION MODELS

2.1 ROTRANOMO

RoTraNoMo was a joint European EU project dealing with Road Traffic Noise Modelling [11] finalized in 2005. This model predicts the noise emission by separating the different sources of noise, on the one hand the rolling noise, coming from the contact between the tyres and the road and, on the other hand, the propulsion noise originating from the engine. RoTraNoMo is a "microscopic" traffic flow model that calculates the rolling noise and propulsion noise for each second and for each vehicle of the traffic flow. This requires a great number of parameters from the vehicles, e.g. the speed, the gear setting, the acceleration and the load of each vehicle (see Table 1). Determination of the load necessitates other parameters such as the driving resistance and the gear ratio which are given by the car manufacturers. To ease the calculations with this model, parameters are given in tables for each of six main vehicle categories. To summarize, predicting noise with RoTraNoMo requires very detailed information, knowing which vehicles travel on the road (type and model) and in which gear the vehicles are driving at the time and location for the predictions.

- Vehicle speed
- Vehicle acceleration
- Vehicle category
- Time of the day
- Road surface type
- Gearshift prescription
- Location on road network
- Driving resistance
- Gear ratio
- Power to mass ratio

Table 1. Examples of parameters that are required to run the RoTraNoMo model.

Noise prediction with RoTraNoMo gets more complicated for heavy vehicles than for light vehicles since the number of axles and the gearbox design vary from one heavy vehicle to another. In RoTraNoMo heavy vehicles are divided into eight subcategories, which makes it hard to record correct vehicles categories during traffic counts.

Other parameters required by RoTraNoMo are the time of the day, the road surface properties and the location of the vehicle on the road network, each having a given influence on the noise emission. RoTraNoMo has quite a complex requirement for input data, but it has the advantage that with all detailed data available it can also predict the noise during accelerations and deceleration as well as for vehicles driving with constant speed.
It should be pointed out that RoTraNoMo is a source model. This means that given a source, it will provide the noise level, in 1/3 octave bands, at a reference distance (7.5 m from the driving path and 1.2 m above road level). RoTraNoMo does not provide a way to predict how the sound propagates from that reference point. It does not provide a model for outdoor sound propagation, and therefore requires to be coupled with a propagation model such as Harmonoise or Nord2000.

2.2 HARMONOISE / NORD2000
Harmonoise was an EU-funded project running from 2001 to 2005 [12]. One of the outcomes of this project was a method to predict road traffic noise levels. The idea was to reach a harmonized method for noise mapping in all EU member states. The part of the Harmonoise project that dealt with road noise modelling was based on the Nordic general noise prediction model Nord2000 [13]. This latter model was developed between 1996 and 2001, and was updated in 2006 based on the latest findings of e.g. the Harmonoise project. These two models are therefore strongly interrelated.

Various important factors are taken into account by Harmonoise and Nord2000, for example spherical divergence, air absorption, reflections from the ground and diffraction from barriers, energy losses during side reflections, effects of scattering zones and meteorological conditions.

One of the few differences between these two models is the number of ground categories. Nord2000 has eight ground categories (from very soft to hard surfaces) and Harmonoise has ten ground categories. Each category has different acoustic impedance and therefore leads to different sound propagation behaviour.

Regarding vehicle categories, both Harmonoise and Nord2000 have five different vehicle categories each of which is subdivided into several different subcategories.

Unlike the RoTraNoMo model presented earlier, Harmonoise and Nord2000 predict both noise generation and noise propagation separately [12, 13]. On the noise emission side, the sound power of each vehicle type is allocated to two different point sources, each at a different height. The required parameters to calculate the rolling noise and the propulsion noise are the vehicle category and the speed of the vehicle. All other parameters are set to the default values, which correspond to the reference conditions, i.e. a constant speed, 20 °C and a default road wearing course based on an average of dense asphalt concrete and stone mastic asphalt with 11 mm nominal maximum aggregate size. If the actual conditions differ from these values, correction coefficients can be calculated thereby taking into account acceleration/deceleration, actual road surface (type, age), road temperature, road wetness, winter tyres, and regional corrections.
The sound power level of the rolling noise is defined by

\[
L_{WR}(f) = a_R(f) + b_R(f) \log \left( \frac{v}{v_{ref}} \right)
\]

(1)

where \(a_R\) and \(b_R\) are parameters depending on the vehicle category, \(v\) is the vehicle speed and \(v_{ref}\) is the reference speed (70 km/h). 80% of the rolling noise is assigned to a point source 0.01 m above road level and the remaining 20% are assigned to a point source 0.3 m above road level for light vehicles or 0.75 m for heavy vehicles. \(f\) is the centre frequency of 1/3 octave bands from 25Hz to 10 kHz. The parameters \(a_R\) and \(b_R\) are tabled in [13].

In the same way, the sound power level of the propulsion noise is defined by:

\[
L_{WP}(f) = a_P(f) + b_P(f) \left[ \frac{v - v_{ref}}{v_{ref}} \right]
\]

(2)

The parameters \(a_P\) and \(b_P\) are given in 1/3 octave bands from 25Hz to 10 kHz. 20% of the propulsion noise is assigned to the 0.01m high point source and the remaining 80% are assigned to the 0.3 m or 0.75 m point source.

The correction for acceleration/deceleration is given by

\[
\Delta L_{acc} = C \cdot a ; \quad -2 \text{ } m \cdot s^{-2} \leq a \leq 2 \text{ } m \cdot s^{-2}
\]

where \(a\) is the acceleration (\(a>0\))/deceleration (\(a<0\)) in \(m \cdot s^{-2}\) and the coefficient \(C\) is 4.4 for light vehicles and 5.6 for heavy vehicles.

2.3 COMPARISON BETWEEN THE TWO MODEL PRINCIPLES

As mentioned earlier, RoTraNoMo requires knowing a lot more parameters than Harmonoise, for instance the gear the vehicles are in at any time. These are parameters that are normally not obtained when counting traffic and measuring speed. The gear setting can be assumed from the speed but depends on the actual vehicle model. The prediction with RoTraNoMo gets even more complicated for heavy vehicles since the number of axles and gearbox design varies a lot from one heavy vehicle to the other.
Another issue with RoTraNoMo is that it needs to be coupled with an outdoor sound propagation model in order to predict the noise level at a certain position along a road. Harmonoise incorporates both a noise emission and a noise propagation model. This is a clear advantage of Harmonoise compared to RoTraNoMo. All in all, RoTraNoMo was deemed too complicated for the purpose of this project and Harmonoise / Nord2000 will be used in this project.
3. A CASE STUDY: NOISE LEVEL PREDICTION AT TWO ROUNDABOUTS

3.1 METHOD
In order to investigate the accuracy of the Harmonoise / Nord2000 model, the noise level at two positions close to two roundabouts was predicted using this model and also measured in situ. This chapter first describes the two roundabouts and then explains the parameters chosen to run the Nord2000 model. A more detailed description of the measurements can be found in [14]. Finally the results of the predictions and measurement are compared and discussed. The results of this latter investigation were presented at the Inter-noise conference 2010 [15].

3.1.1 DESCRIPTION OF THE ROUNDABOUTS
The first roundabout studied in this project was built at the intersection of major road 138 and Smedegade in Snoldelev, Denmark. This crossing is, hereafter, referred to as "Snoldelev" and is shown in Figure 3. The purpose of this roundabout is to make it safer to cross the major road (east-west) when coming from the minor road (north-south) by decreasing the speed of the vehicles on this right-of-way road. The speed limit was 70 km/h before construction and is now 60 km/h for the four roundabout legs. The average daily traffic on the main road was 10 238 vehicles in 2008 (before construction of the roundabout). Also shown in Fig.2 are the two measurement points along the major roads, located 100 m away from each other.

Figure 3. Sketch of the roundabout in Snoldelev. The two red crosses represent the measurement points, located 100 m away from each other.
The second roundabout investigated is located on JF Willumsens Vej, major road 522 east of Frederikssund. This roundabout has been extended from a one-lane to a two-lane roundabout due to the congested traffic. On the four roads leading to the roundabout the speed limit is 80 km/h and about 150 m before signs indicate 60 km/h. The new roundabout is shown in Figure 4 and is referred to as “Willumsens Vej”. The two points where the noise level is measured and estimated are 100 m away from each other and are indicated with a red cross. The average daily traffic on this road was about 13 000 vehicles in 2006 (before modification of the roundabout).

![Figure 4. Sketch of the two-lane roundabout at Willumsens Vej after modification. The two red crosses represent the measurement points, located 100 m away from each other.](image)

### 3.1.2 IN SITU MEASUREMENTS

For each roundabout, the sound level was measured at two positions simultaneously before and after the construction/enlargement of the roundabouts. The close position is 60 m from the roundabout centre and the far position is 100 m from the first position. The microphones were located 4 m above the road level and 20 m from the centre line of the nearby road. The measurement positions are shown in Figures 2 and 3. With this configuration the same vehicles are passing by each microphone and only their speed and driving pattern change between the two measurement points. The speed of the vehicles was not recorded. For each point, the A-weighted sound level $L_{Aeq}$ was measured during three or four 10-minute periods. During the measurement periods, the traffic was manually counted and classified in two categories: light and heavy vehicles.
In order to compare all the measurement periods before and after the building of the roundabouts, the sound levels were normalised to a traffic density of 1000 light vehicles per hour. The difference in noise emission between a heavy and a light vehicle is taken as 10.8 dB at 50 km/h [6]. In this way, all results are comparable and independent of the actual traffic flow during the measurements. Any difference in level therefore relates to changes in speed and driving pattern (acceleration and deceleration).

The air temperature was also measured and the sound level was normalized to a temperature of 20 °C using:

\[ L_{20°C} = L_{\text{measured}} - 0.04 \times (20 - T_{\text{measured}}) \]  

(3)

where T and L are the temperature and the sound level respectively [7].

The pavement type also has an influence on the noise. In Snoldelev there was no change in wearing course near the measurement positions when the roundabout was built, no correction is therefore needed. On the contrary, in Willumsens Vej the asphalt was a four-year old UTLAC 8 before the rebuilding of the roundabout. After reconstruction, a SMA11 was laid. It has been calculated [8] that the new pavement is expected to decrease the noise emission by only 0.4 dB compared to the old asphalt. This difference was deemed negligible and no correction was made in the following analysis.

3.1.3 DESCRIPTION OF THE MODEL

The calculations were made using the software SPL2000, which is an implementation of the latest version of the Nord2000 model; this software was developed by Birger Plovsing from Delta. SPL2000 gives the sound pressure level at a given point, specifying its height and distance from the road. The input parameters for the software (temperature, vehicle speed, vehicle category, road and terrain type...) are based on the experimental conditions at the two roundabouts described in Section 3.1.2. Only contribution from the road section nearest to the measurement positions are taken into account. Since the speed of the vehicles was not recorded it was evaluated based on observations during the measurements. The acceleration was calculated based on the distance and the speed of the vehicles. The assumed values of these parameters for each vehicle category are shown in Table 3.
Table 3. Values chosen to model the sound levels at the close and far positions for the two roundabouts before and after their (re)construction. “To roundabout” is the direction for the vehicles driving to the west, towards the roundabout. “From roundabout” is for vehicles travelling to the East, away from the roundabout.

<table>
<thead>
<tr>
<th></th>
<th>Snoldelev</th>
<th>Willumsens Vej</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_L$</td>
<td>$V_H$</td>
</tr>
<tr>
<td><strong>Before roundabout:</strong></td>
<td>$a_L$</td>
<td>$a_H$</td>
</tr>
<tr>
<td>Close position</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Far position</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td><strong>After:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To roundabout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close position</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Far position</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>From roundabout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close position</td>
<td>44</td>
<td>40</td>
</tr>
<tr>
<td>Far position</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

$V_L$ and $V_H$ are the light and heavy vehicles velocities in km/h and $a_L$ and $a_H$ are the light and heavy vehicles accelerations in m/s² respectively. The speed and acceleration change according to the vehicle direction: decelerating towards the roundabout and accelerating when leaving the roundabout. In the case where no roundabout is present (Snoldelev-before), the speed is constant on the main road.

### 3.2 RESULTS

#### 3.2.1 NOISE REDUCTION ACHIEVED

This section presents the noise reduction that can be achieved by modifying a crossing into a roundabout and by extending an already existing roundabout. The difference in noise level before/after these modifications are presented for the measurements carried out in situ and also for the prediction made with the Nord2000 model.

As explained in Section 3.1.2, the sound levels recorded during the 10-minute periods are normalized to 1000 light vehicles during one hour. The levels predicted by the model are also for 1000 light vehicles during one hour. The obtained differences in levels before and after the construction of the roundabout in Snoldelev are shown in Table 4.
Table 4. Measured and predicted differences in noise level at two positions before and after the construction of the roundabout in Snoldelev [8].

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A_{eq}, 1h}$, after $- L_{A_{eq}, 1h}$, before</td>
<td>Close position</td>
<td>-3.7 dB</td>
</tr>
<tr>
<td>$L_{A_{eq}, 1h}$, after $- L_{A_{eq}, 1h}$, before</td>
<td>Far position</td>
<td>-1.7 dB</td>
</tr>
</tbody>
</table>

The results show that the noise level is lower after the construction of the roundabout, both at the close and far positions. The measured noise reduction is however more important for the position closest to the roundabout (3.7 dB), this is probably due to a change in the speed of the vehicles approaching the roundabout. Compared with the before situation, the vehicles have to decelerate when approaching the roundabout and accelerate when leaving the roundabout. The noise emitted during acceleration is compensated by the lower speed of the vehicles. The model predicts a decrease of 2.8 dB at the close position; this is lower than the measured 3.7 dB and with the measurement uncertainty of ± 1 dB, it can be concluded that the predicted level are in very good agreement with the measured level.

At the far position, it seems that the construction of the roundabout has lead to a decrease of the speed, hence yielding a 1.7 dB decrease in the measured noise level. The level decrease predicted by the model is also 1.7 dB, which means that the model is very reliable in this case.

Table 5. Measured and predicted differences of noise level at two positions before and after the modification of the roundabout in Willumsens Vej [8].

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A_{eq}, 1h}$, after $- L_{A_{eq}, 1h}$, before</td>
<td>Close position</td>
<td>+0.3 dB</td>
</tr>
<tr>
<td>$L_{A_{eq}, 1h}$, after $- L_{A_{eq}, 1h}$, before</td>
<td>Far position</td>
<td>+1.0 dB</td>
</tr>
</tbody>
</table>

The results for Willumsens Vej, where the existing roundabout was widened are shown in Table 5. In this case, both the predictions and the measurements show that the modification of the roundabout actually lead to an increase in noise level. The increase is very small (0.3 or 1.0 dB) for the close position and 1 or 2.4 dB for the far position. The noise increase from this roundabout modification is more important far from the roundabout. Since the roundabout is wider, the vehicles pass through it with a higher speed than before, hence increasing the noise level. The model predicts a larger than measured increase, probably because the assumed speed (60 km/h) is lower than the actual speed in the “before” situation.
3.2.2 DIFFERENCES BETWEEN MEASURED AND PREDICTED LEVELS

After evaluating if the Nord2000 model could predict the noise levels at the roundabouts, it is now possible to calculate the noise level for the same conditions than the ones measured (numbers of light and heavy vehicles with their speed and acceleration). The levels calculated with the model are hence for the number of vehicles that actually passed by the microphones during the 10-minute periods, these levels are not normalized to 1000 light vehicles per hour. This section compares the noise levels measured and predicted.

3.2.3 SNOLDELEV

The results obtained from modelling the noise emission at two positions in Snoldelev are shown in Table 6.

Table 6. Difference between the measured and the modelled sound levels in Snoldelev not normalized to 1000 light vehicles. The values are A-weighted noise levels in dB.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th></th>
<th>After</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Close</td>
<td>Far</td>
<td>Close</td>
<td>Far</td>
</tr>
<tr>
<td>Measured</td>
<td>70.0</td>
<td>70.0</td>
<td>65.8</td>
<td>67.7</td>
</tr>
<tr>
<td>Modelled</td>
<td>67.2</td>
<td>67.6</td>
<td>65.5</td>
<td>65.7</td>
</tr>
<tr>
<td>Difference</td>
<td>-2.8</td>
<td>-2.4</td>
<td>-0.3</td>
<td>-2.1</td>
</tr>
</tbody>
</table>

The model underestimates the sound level in all cases. The difference is larger in the “before” situation, with 2.8 dB and 2.4 dB difference. One configuration where the model is near the measured level is in the close position after the construction of the roundabout with only 0.3 dB difference.

3.2.4 WILLUMSENS VEJ

In Willumsens Vej, the model better approximates the noise emission (see Table 7). Still, the levels calculated are below the measured levels but the difference is very small in the far position both before and after (0.4 dB and 0.1 dB respectively).

Table 7. Difference between the measured and the modelled sound levels in Willumsens Vej. Values are A-weighted noise levels in dB.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th></th>
<th>After</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Close</td>
<td>Far</td>
<td>Close</td>
<td>Far</td>
</tr>
<tr>
<td>Measured</td>
<td>65.1</td>
<td>65.4</td>
<td>65.9</td>
<td>66.7</td>
</tr>
<tr>
<td>Modelled</td>
<td>63.4</td>
<td>65.0</td>
<td>63.8</td>
<td>66.6</td>
</tr>
<tr>
<td>Difference</td>
<td>-1.7</td>
<td>-0.4</td>
<td>-2.1</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
The noise level at the close position seems to be harder to approximate, the differences are 1.7 dB before and 2.1 dB after. The actual driving pattern may differ from the one assumed in the model, this point is discussed in the next section.

3.3 DISCUSSION
There can be different explanations for the discrepancy observed between the measured and the modelled sound levels.

3.3.1 SNOLDELEV

The differences between measured and modelled noise levels in Snoldelev might be explained by the age and type of the pavements on the roundabout. They differ from the average type and age of pavements included in the noise emission database of the model. The noise of a pavement increases with years so if the pavement assumed by the model is younger than the actual pavement, the model will underestimate the noise emission.

Furthermore, observations made during the measurements showed that the speed of the vehicles was above the speed limit. This would induce an increase in measured noise level. To verify this hypothesis, the values for the speed and acceleration parameters were changed in the model. The values taken and the results obtained are presented in Table 8.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Close</td>
<td>Far</td>
</tr>
<tr>
<td>$V_L$ [km/h]</td>
<td>90 (70)</td>
<td>90 (70)</td>
</tr>
<tr>
<td>$V_H$</td>
<td>80 (70)</td>
<td>80 (70)</td>
</tr>
<tr>
<td>$a_L$ [m/s²]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$a_H$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Modelled [dB]</td>
<td>68.9 (63.4)</td>
<td>69.1 (65.0)</td>
</tr>
<tr>
<td>Measured [dB]</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Difference [dB]</td>
<td>-1.2</td>
<td>-0.8</td>
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For the “before” situation, it is now assumed that the light vehicles have a constant speed of 90 km/h (instead of 70) and the heavy vehicles drive at 80 km/h (instead of 70). With these new values, the model approximates very well the measured sound level values. The highest difference is now only 1.2 dB.
For the “after” situation, the far microphone was located at the same place as the new “60 km/h” sign. This means that, at that location, the vehicles probably have a speed higher than 60 km/h. The speed values are therefore changed for the far point from 60 to 80 km/h (light vehicles) and from 60 to 70 km/h (heavy). This assumption leads to the exact same sound level.

It can be concluded that the assumed speeds are close to the actual values and that this can explain the higher noise level calculated in the far position before the roundabout was built. In their study from 2003, Plüss et al. also concluded that the difference between the measured and modelled sound level was due to a higher speed than assumed.

3.3.2 WILLUMSENS VEJ

In Willumsens Vej, the highest difference between calculated and measured sound levels occurs at the close position. The microphones used for the experiment are omnidirectional, this means they capture sound from all directions, this includes the main road and, in the close position, the roundabout and the crossing road as well. The consequence is that noise coming from vehicles circulating on the roundabout is recorded by the close microphone, hence increasing the noise level at this position. Since the model only takes noise contribution from the road along the measurement positions into account, this could partly explain the difference between measured and modelled levels in the close position at Willumsens Vej. In the far position, the model calculated very similar levels compared to the experiment. This indicates that the driving pattern assumed at this position is correct (i.e. 60 or 80 km/h for light vehicles and 65 km/h for heavy vehicles).

Similarly to Snoldelev, the difference in the age and type of the pavements between the model and the measurement could explain the underestimation of the noise level.

3.4 CONCLUSION ON THE CASE STUDY

When a crossing was replaced by a roundabout, measurements showed a decrease in noise level of up to 3.7dB (Snoldelev) in two selected positions (25 m from the centre line of the road, and 60/160 m from the crossing). This is probably due to a decrease in the speed of the vehicles. In the other case where a roundabout is widened from one to two lanes (Willumsens Vej), the noise level increased slightly (max. 1 dB). This can be explained by a better traffic flow in the roundabout, leading to a higher exit speed and hence a higher noise level despite lower acceleration.
These two situations were modelled with the Nord2000 source model. In the absence of speed measurement results, the model can only give an approximation of the noise levels. It was however possible to reach a reasonably good agreement between the measured and the modelled values. The model predicted quite well the decrease in noise level in Snoldelev and overestimated the increase in noise level on Willumsens Vej. Part of the difference between the measured and modelled levels can be explained by a different age and type of pavement on the road leading to the roundabout. For instance in Snoldelev the road was 14 years and the model includes an eight years road.

Another explanation could be the high velocity of the vehicles. Assuming the vehicles had a higher speed than allowed, the model underestimated the measured values by only up to 1.2 dB (Snoldelev). For the roundabout in Willumsens Vej, the largest difference (2.1 dB) is explained by the proximity of the close microphone, picking up noise contribution from the adjacent roads and the circulation area itself. These contributions were not included in the predicted noise levels.
4. SUGGESTIONS FOR FURTHER MEASUREMENTS AT ROUNDABOUTS

The previous case study showed that it is possible to predict the noise level at certain positions using the Nord2000 model. This tool could be used in the future to predict noise emission at other roundabouts as long as all parameters are given. A few parameters were indeed missing in order to use the model accurately, e.g. the actual vehicle speed and the acceleration at different road segments. In the previous study vehicles were divided into two categories (light and heavy), it would improve the precision of calculation if the traffic was separated into more categories, e.g. the ones from the Nord2000.

The following points are suggestions to improve the results of model predictions, in the case of future comparison with in situ measurements:

- Record the number of vehicles passing in front of each microphone in different categories (e.g. categories 1, 2, 3, 4 and 5 from Harmonoise / Nord2000).
- A video recording during the measurement period could help this registration.
- Measurement of the actual average speed and acceleration for each vehicle category at each position.
- Distance between the microphones and the roads.
- Precise recording of position of the microphones, possibly with a GPS.
- The microphones should be positioned in a way that the noise coming from side roads is negligible – alternatively noise from side roads and circulation area should be included in the modelling.
- Air temperature should be recorded and normalized.
- The type of asphalt and terrain should be registered in order to estimate their absorption.
There do exist some commercial solutions that would ease the measurement process. For example Autoscope\(^1\) is a video detection system that can detect passing vehicles, and can give their type and speed. Another solution is the all-in-one software solution that has been developed by ENTPE and CSTB in France, via the SYMUBRUIT tool\(^2\).

\(^{1}\) [http://autoscope.com/](http://autoscope.com/)
5. CONCLUSION

The aims of this project were to examine if current traffic noise models could accurately predict noise level near road crossings and roundabouts for a given traffic and also to investigate the relation between different road designs and traffic noise emissions. The two road designs that have been investigated in the present study are the conversion of a crossing into a roundabout (Snoldelev) and the enlargement of an already existing small roundabout (Willumsens Vej). In both cases the noise level at two different positions has been predicted using the Nord2000 model before and after the changes in their design. It was possible to predict the change in terms of noise level due to the change in the road profile. Furthermore, the model predictions were supported by in situ measurements.

The measurements carried out in Snoldelev showed a decrease in noise level of up to 3.7dB, which is probably caused by reduced vehicle speed due to the construction of the roundabout. At Willumsens Vej the noise level increased slightly (max. 1 dB) and this can be explained by a better traffic flow in the new double-lane roundabout, leading to a higher exit speed and hence a higher noise level despite lower acceleration. There was a fairly good agreement between the measured and modelled levels. Part of this difference can be explained by a different age and type of pavement between the actual road and the model. In order to model the noise levels the speed and acceleration of the vehicles had to be assumed and this could be improved in future prediction.

The two cases studied here show that the behaviour of a given road design can be predicted using the Nord2000 model. The conclusions are however only for these two types of changes, i.e. modification of a crossing into a roundabout and extension of a roundabout. More studies are therefore needed to draw broader conclusions and achieve a larger and more accurate picture of the significance for the noise level of changes in design of road intersections. It would be interesting to gather more data about other types of crossing, roundabouts as well as other road designs.

Future projects should therefore be concerned with data gathering and a combination of in situ measurements and modelling would be the way to go. At a later stage predictions from the model will be accurate enough to be taken into account at an early stage of road construction.
6. REFERENCES


[2] Calculations made with the Nord2000 model, which is based on in situ noise measurements.


<table>
<thead>
<tr>
<th>Nr. No.</th>
<th>Titel/Title</th>
<th>Forfatter/Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>162</td>
<td>Optimized thin layers for urban roads - Paper for Acoustics ’08 in Paris</td>
<td>Bent Andersen, Hans Bendtsen</td>
</tr>
<tr>
<td>163</td>
<td>Råstofforsyning i Danmark</td>
<td>Caroline Hejlesen, Michael Larsen</td>
</tr>
<tr>
<td>164</td>
<td>Livscyklusvurdering af vejbeafæstelser - Projekt Bording - Funder MV</td>
<td>Knud A. Pihl, Jørn Raaberg, Helle Blæsbjerg, Michael Quist, Morten Bendesen, Harpa Birgisdóttir</td>
</tr>
<tr>
<td>165</td>
<td>Two-layer porous asphalt - lifecycle - The Øster Søgade experiment</td>
<td>Lars Ellebjerg, Hans Bendtsen, Jørgen Kragh</td>
</tr>
<tr>
<td>166</td>
<td>ISAP Symposium Zürich - 2008 Asphalt Pavements &amp; Environment</td>
<td>Erik Nielsen, Erik Olesen</td>
</tr>
<tr>
<td>167</td>
<td>Urban Thin Quiet SMA Pavements Paper TRB in Washington 2009</td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>168</td>
<td>Øster Søgade 8 år med 2-lag drænasfalt</td>
<td>Jørn Raaberg, Annette Neidel</td>
</tr>
<tr>
<td>169</td>
<td>Temperature influence on road traffic noise Californian OBSI measurement study</td>
<td>Hans Bendtsen, Qing Lu, Erwin Kohler</td>
</tr>
<tr>
<td>170</td>
<td>ABM type c til broer Indstampingstemperaturens indflydelse på material parametre ved Marshall-fremstilling og - prøvning.</td>
<td>Erik Nielsen</td>
</tr>
<tr>
<td>171</td>
<td>Acoustic aging of asphalt pavements A Californian / Danish comparison</td>
<td>Hans Bendtsen, Qing Lu, Erwin Kohler</td>
</tr>
<tr>
<td>173</td>
<td>Highway noise abatement Planning tools and Danish examples</td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>174</td>
<td>Noise Barrier Design Danish and some European Examples</td>
<td>Hans Bendtsen</td>
</tr>
<tr>
<td>175</td>
<td>Paper Temperature influence on noise measurements EURONOISE 2009 - Edinburgh</td>
<td>Hans Bendtsen, Qing Lu, Erwin Kohler, Bruce Rymer</td>
</tr>
<tr>
<td>176</td>
<td>Bituminous binders - Results of Danish Round Robins for CEN test methods from 2000-2009</td>
<td>Erik Nielsen</td>
</tr>
<tr>
<td>177</td>
<td>Ageing of bituminous binders</td>
<td>Erik Nielsen</td>
</tr>
<tr>
<td>178</td>
<td>DVS-DRI. Super Quiet Traffic International search for pavement providing 10 dB noise reduction</td>
<td>Jørgen Kragh</td>
</tr>
<tr>
<td>179</td>
<td>Stejreduktion med tolags drænasfalt Øster Søgade – de første otte år</td>
<td>Lars Ellebjerg, Hans Bendtsen</td>
</tr>
<tr>
<td>180</td>
<td>Traffic Flow and noise – A method study</td>
<td>Gilles Pigasse</td>
</tr>
</tbody>
</table>
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