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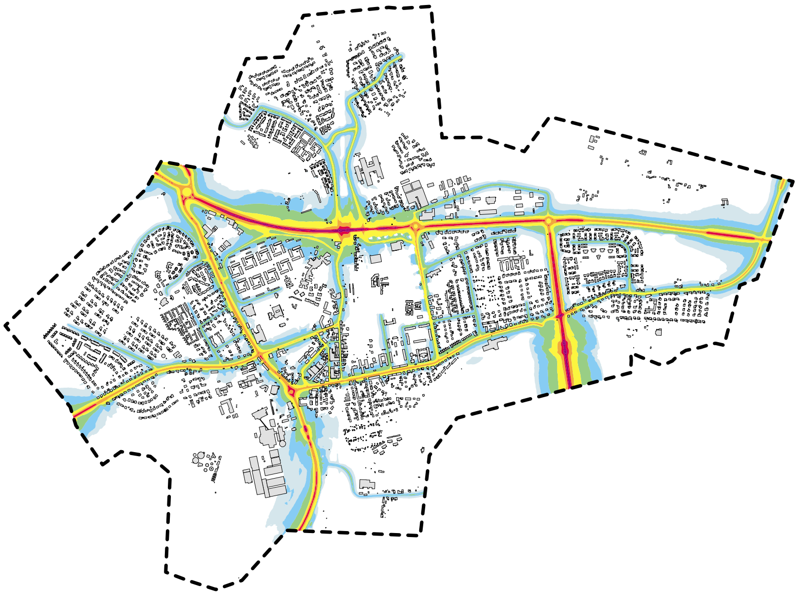

Improved noise map accuracy by using GPS acquired vehicle speeds

Study of predicted equivalent noise levels using the Nord96 and Nord2000 models

Master's thesis in MSc Sound and Vibration

MARIJA KONDIC

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
www.chalmers.se

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Supervisor: Pascal Kuta, Ramboll
Examiner: Jens Forssén, Department Architecture and Civil Engineering

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Department Architecture and Civil Engineering
Division of Acoustics
Chalmers University of Technology
SE-412 96 Gothenburg

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Abstract

The noise maps in Sweden have always been constructed with the Nord 96 calculation model using the signposted speeds. This project investigates the limitations of this model, as well as what differences arise when the signposted speeds are exchanged for the real recorded vehicle speeds. In this case, the GPS acquired speeds were used. Different steps in the Nord 96 calculation model that could influence the changes in the noise maps were addressed, as well as the differences between the Nord 96 and Nord 2000 models. The influence of the percentage of heavy vehicles, different vehicles categories and importance of the acceleration of vehicles is investigated.

The main goal of this paper was to investigate the possibility of creating a set of measures to be used as a correction for the current calculation model. This investigation is conducted on the subject area consisting of Kävlinge, Furulund, Löddeköpinge, and Björnstorp area. The Kävlinge area is closely investigated and the individual streets are analysed for the purpose of detecting the causes of sound pressure level differences on a small scale. Significant results were obtained, showing that difference in noise level can be up to ± 5 dB in some street segments, which is detectable by human ears. The correction of the current model is concluded not to be possible by just taking the average SPL difference for different street types and speed limits, thus the further investigation is needed.

Keywords: Noise maps, Nord96, Nord2000, GPS, Speed limit.

Acknowledgements

I would like to convey my gratitude to my professor, Jens Forssén, for his patience and feedback. I also could not have finished this journey without my mentor at the company Ramboll, Pascal Kuta, who generously provided practical knowledge. Thanks should also go to all of the professors and teaching assistants at the Division for Applied Acoustics at Chalmers, who impacted and inspired me.

I am also grateful to my friends and family, for their editing help, moral support and many meals they shared with me.

Marija Kondic, Gothenburg, June 2022

Nomenclature

Below is the nomenclature of parameters and variables that have been used throughout this thesis.

Variables

L	Sound pressure level
$L_{AE,10m}$	Sound exposure level at 10 m distance from the middle of the street
$L_{AEq,10m}$	Equivalent sound pressure level at 10 m distance from the middle of the street at specified speed and vehicle flow
L_{den}	Equivalent sound pressure level for 24h
L_{day}	Equivalent sound pressure level for day hours (06:00 h to 18:00 h)
$L_{evening}$	Equivalent sound pressure level for evening hours (18:00 h to 22:00 h)
L_{night}	Equivalent sound pressure level for night hours (22:00 h to 06:00 h)
$L_{WR}(f)$	Equivalent sound power level for rolling noise dependant on frequency
$L_{WP}(f)$	Equivalent sound power level for propulsion noise dependant on frequency
$L_{w,rolling}$	Equivalent sound pressure level for rolling noise
$L_{w,propulsion}$	Equivalent sound pressure level for propulsion noise
s	Distance
v	Vehicle speed
a	Acceleration/Deceleration
N	Number of vehicles
T	Time

Parameters

C	Acceleration/Deceleration coefficient
$a_R(f), b_R(f)$	Source power coefficients for rolling noise
$a_P(f), b_P(f)$	Source power coefficients for propulsion noise

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Introduction

1.0.1 Background

Community noise can have various different effects on human health. Some of those effects are: hearing impairment, speech intelligibility, sleep disturbance, physiological functions, social and behavioural effects etc.[1] The loudness and time exposure to these effects, as well as the frequency content are important to analyse the influence on human health. Because of this, it is of interest to investigate the differences that arise with using different input data for a noise mapping process, since loudness and frequency content can vary. Noise maps can be made with certain accuracy that is dependant on the calculation model used and how detailed the input data is. Currently, in Sweden, the noise maps are calculated using the Nord96 calculation model and signposted speeds for the traffic of the area of interest. Using the GPS data, which provides the real speeds of vehicles, can contribute to creating a more detailed noise map that can be used to estimate if and what kinds of measures, if any, should be undertaken to mitigate the existing noise. Additionally, using the updated and more detailed calculation model (Nord2000) will give a deeper insight into this issue. For this purpose, previously conducted noise studies at the company Ramboll will be used as basis for this project.

1.0.2 Aim

The aim of this project is the development of a methodology to be used for implementing speed data from GPS in noise mapping studies in order to achieve higher quality real time maps. For this purpose, the aim is to quantify the differences that arise when using the signposted and real speed data in terms of equivalent sound pressure levels (SPL) in dB.

1.0.3 Limitations

Limitations in this project come from the following:

1. **Lack of data**
   There is no data for acceleration of vehicles provided. This represents a limitation for a detailed investigation on how and to what extent the acceleration influences the noise levels. The accuracy wanted in this project is the highest one. In respect to this, the investigation of the accelerations of vehicles would be beneficial for a deeper analysis. In addition, there is no information about

the quantity of different vehicle categories in respect to the given speed data, thus the analysis of the frequency content according to the category could not be done.

2. **Calculation model**
   The calculation model that will be used in this project is Nord96. This model provides the noise levels as a single number in A-weighted levels. In contrast, the Nord2000 model provides more detailed information in one third octave bands. This is one of the factors influencing the level of detail of the noise maps. As a final part of the project, it is possible to implement the Nord2000 model and compare with the Nord96 model.

3. **Processing errors**
   Choices that will be taken throughout the analysis and processing of the speed data could set limitations and influence the accuracy of the noise maps. This could also apply to the software that will be used for processing.

1.0.4 Specification of issue under investigation

One of the challenges for this project is finding a way to calculate and analyse the results in a reproducible and understandable way and quantify the differences of the noise maps. In addition, the questions that need to be answered after analysis of the results are: what is the difference in respect to the expectations and what are the potential further outcomes?

1.1 Methodology

The investigation of differences in the SPL for the variation of vehicle speeds will be conducted on a small scale in order to develop a methodology for the processing of data. This will then be implemented on the larger scale. The goal of this project, in fact is the development of a methodology for cases like this one.

2
Theory

For the investigation of the influence of the speed changes on the difference of sound pressure levels the most important factor is the change in power and how it is modeled, which will influence the precision of the calculations. The environment is assumed to be the same for both cases of using the real and signposted speeds, so the corrections for the distance, ground type, reflections, scattering and obstacles are not included. This report explores different cases where the change in speed has an influence on the SPL which includes different vehicle types and the amount of light and heavy vehicles.

The equivalent sound pressure levels in this project are calculated according to the Nord96 [2] calculation model and for the deeper analysis for changes in the frequency content with the change of the speed the Nord2000 [3] calculation model was used. The Nord96 model incorporates the speeds of vehicles separately for light and heavy vehicles using equations 2.1 and 2.2.

$$
\begin{aligned}
L_{AE,10m}(light) &= 73.5 + 25 \cdot \log\left(\frac{v}{50}\right),\ v \geq 40 \text{ km/h} \\
L_{AE,10m}(light) &= 71.1,\ 30 \text{ km/h} \leq v < 40 \text{ km/h}
\end{aligned}
\tag{2.1}
$$

$$
\begin{aligned}
L_{AE,10m}(heavy) &= 80.5 + 30 \cdot \log\left(\frac{v}{50}\right),\ 50\ km/h \leq 90 \text{ km/h} \\
L_{AE,10m}(heavy) &= 80.5,\ 30 \text{ km/h} \leq v < 50 \text{ km/h}
\end{aligned}
\tag{2.2}
$$

where v stands for speed and where the base SPL are estimated for the distance of 10 m from the road center and where the reference speed is 50 km/h. As these equations show, the calculation of levels is influenced by the range of the speed. Levels for the speeds lower than 30 km/h are not defined which represents a limit for this calculation model. The same applies to the speeds larger than 90 km/h for the SPL of heavy vehicles. In order to incorporate speeds outside of this range, the levels for speeds lower than 30 km/h are calculated as for the 30 km/h.

The influence of the traffic flow is added in the equations 2.3 with calculation of the equivalent SPL(L_{AEq}) for light and heavy vehicles.

$$
L_{AEq,10m} = L_{AE,10m} + 10 \cdot \log\left(\frac{N}{T}\right) \tag{2.3}
$$

Table 2.1: Percentage of heavy vehicles according to the road type and functional road class (FRC) every road has in the street network.

Road type	FRC	Percentage of heavy vehicles
Low traffic (<500f/d)	-	0 %
Local streets	8,9	0 %
Collection streets	6,7	5 %
Main streets	3,4,5	7 %
Highway ramps	1	10 %
Highways, countryside	0,2	12 %

where N represents the number of light or heavy vehicles for a time T in s. The number of heavy and light vehicles are calculated according to the percentage showed in Table 2.1 which corresponds to functional road class (FRC) every road has in the street network. In order to get the mixed levels which contain the influence of both vehicle type, the equivalent levels for light and heavy vehicles are combined according to equation 2.4.

$$L_{AEq,10m,mixed} = 10 \cdot (10^{L_{AEq,10m,light}} + 10^{L_{AEq,10m,heavy}}) \tag{2.4}$$

In order to calculate SPL for different parts of the day, the resulting levels calculated for every hour are averaged using equation 2.5 where n stands for the number of hours and L_i for equivalent SPL calculated for one hour.

$$L = 10 \cdot \log\left(\frac{1}{n} \cdot \sum_{i=1}^{n} 10^{\frac{L_i}{10}}\right) \tag{2.5}$$

The averaged levels for the hours between 06:00 h and 18:00 h give the day levels (L_{day}), between 18:00 h and 22:00 h the evening levels ($L_{evening}$) and between 22:00 h and 06:00 h the night levels (L_{night}). These are then combined using equation 2.6 to get the equivalent SPL for 24 h.

$$L_{den} = 10 \cdot \log\left(\frac{1}{24}(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}})\right) \tag{2.6}$$

The Nord2000 calculation model presents a way of getting more accurate results for the purpose of this report with possibility of investigating the frequency content, influence of different vehicle categories and better defined vehicle noise sources. As well as for the Nord96 calculations, the corrections for distance and type of ground are not included and only the free field SPL is taken into account. In Nord2000 the equivalent sound pressure levels are calculated separately for three different vehicle categories, as well as for rolling and engine noise using equations 2.7 where

$v_{ref} = 70\ km/h$ and coefficients a_R, b_R, a_P and b_P are taken from Table B.1. The frequency range used is 25 Hz to 5000 Hz.

$$\begin{aligned} L_{WR}(f) &= a_R(f) + b_R(f)\log\left(\frac{v}{v_{ref}}\right) \\ L_{WP}(f) &= a_P(f) + b_P(f)\log\left(\frac{v - v_{ref}}{v_{ref}}\right) \end{aligned} \tag{2.7}$$

The traffic corrections for light and heavy vehicles are calculated according to equation 2.8.

$$\Delta L = 10 \cdot \log\left(\frac{N_{per\ hour}}{T}\right),\ T = 60 \cdot 60\ s \tag{2.8}$$

The category used for heavy vehicles is category 3 for the purpose of comparison of the two models and the difference of category division of the two models will be discussed in Subsection 2.1.3. The percentage of heavy vehicles is also taken from Table 2.1. The correction in equation 2.8 is applied for each vehicle type and the levels calculated for the rolling and engine source are combined such that 20 % of the other source is included according to equation 2.9.

$$\begin{aligned} L_{w,rolling} &= 10 \cdot \log\left(0.8 \cdot 10^{\frac{L_{w,rolling}}{10}} + 0.2 \cdot 10^{\frac{L_{w,engine}}{10}}\right) + \Delta L_w \\ L_{w,engine} &= 10 \cdot \log\left(0.2 \cdot 10^{\frac{L_{w,rolling}}{10}} + 0.8 \cdot 10^{\frac{L_{w,engine}}{10}}\right) + \Delta L_w \end{aligned} \tag{2.9}$$

The levels are then combined for the source type and vehicle type to obtain the mixed levels. Finally, they are summed over frequency in order to be able to compare the two calculation models. The summation of levels is always made energy-wise, as in equation 2.5.

2.1 Sensitivity study

For the purpose of accuracy investigation, a theoretical sensitivity study has been made for the cases that have an influence for the difference in sound pressure levels for the two calculation models. This includes the speed, percentage of heavy vehicles, acceleration and number of road lanes.

2.1.1 Speed sensitivity

In Fig. 2.1 the difference in sound pressure levels for the speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with a change of ±10 % are presented. The reference values are subtracted from levels calculated for the speeds with ±10 %, so the positive SPL in dB represent the difference for the +10 % and the negative values for the -10 %. The light, heavy and mixed vehicle types are differentiated and the percentage of heavy vehicles is 7 %. This simulates the difference between the levels calculated with the signposted speeds (30 km/h to 60 km/h) and levels calculated with speeds with the ±10 % difference. As it is shown in the figure, with the increase of the speed, the difference in SPL also increases. The difference for speeds with +10 % margin shows increase with increased reference speed for both vehicles types, with the light vehicles starting at the lower reference speeds. The difference varies in the range of ±0.6 dB to ±1.4 dB. The level difference for the light vehicles is more sensitive to the speed increase than the heavy. For the speed of 30 km/h for all vehicle types, there is no level difference. This is the because of the limit of the calculation model Nord96 for the speeds lower or equal than 30 km/h addressed at the beginning of this chapter.

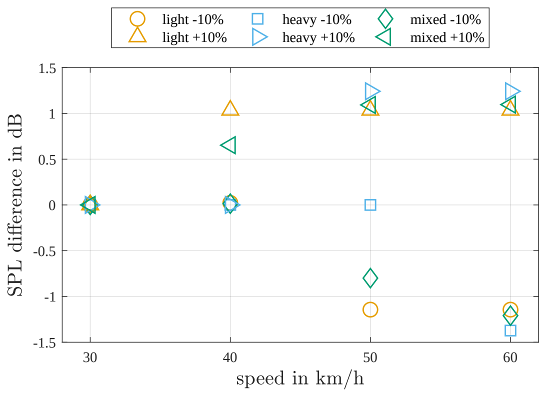


Figure 2.1: Difference in equivalent SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of ±10 % for light, heavy and mixed vehicles with 7 % of heavy vehicles calculated with Nord96 model.

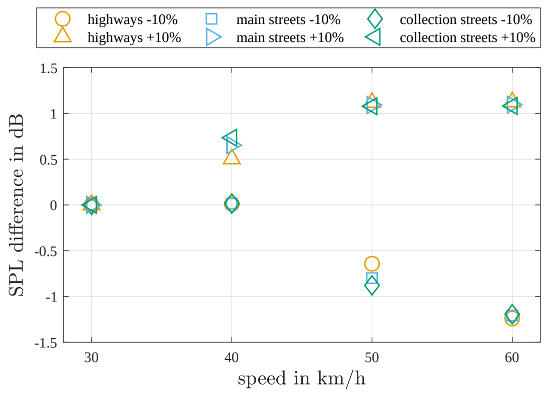


Figure 2.2: Difference in equivalent SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of ±10 % for highways, main and collection streets for mixed vehicles calculated with Nord96 model.

Fig. 2.2 shows the behaviour of difference in SPL for the mixed SPL related to the change of percentage of heavy vehicles according to the Table 2.1. Only the highways, main streets and collection streets are taken into account because those street types are encountered in the provided data set. The percentage of heavy vehicles does not present to be a very significant factor. For the speed of 40 km/h the level difference for the +10 % change in speed shows some differences between the road types, but they are not significant. The same happens for the speed of 50 km/h for the −10 % change in speed.

In Fig. 2.3 and Fig. 2.4 the speed sensitivity with level differences calculated with the Nord2000 model is showed. The set up for the calculations is the same as for the Nord96 and results presented in Fig. 2.1 and Fig. 2.2. The same observation as for the Nord96 model can be made: the difference in levels increases with the increase of speed (Fig. 2.3). In this case, the difference is noticeable for all speeds and the increase is smoother. The small changes between the vehicle types are noticeable for the low speeds and become lesser with speed increase.The light vehicles always

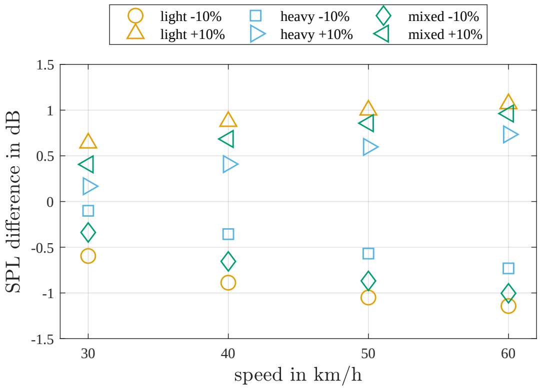


Figure 2.3: Difference in equivalent SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of ±10 % for light, heavy and mixed vehicles with 7 % of heavy vehicles calculated with Nord2000 model.

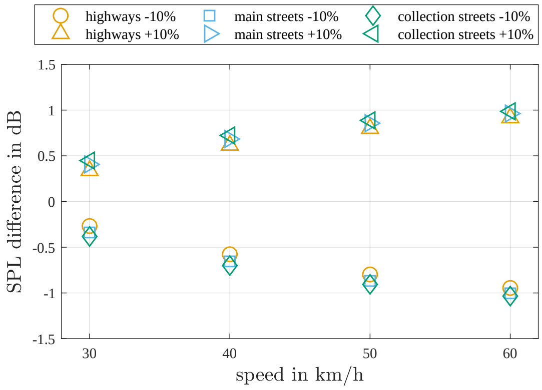


Figure 2.4: Difference in equivalent SPLs for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of ± 10 % for highways, main and collection streets for mixed vehicles calculated with Nord2000 model.

have a bigger difference than heavy vehicles. Fig.2.4 shows insignificant difference between road types for the level difference in dB.

The Fig. 2.5 and Fig. 2.6 show the difference in the frequency content calculated with the Nord2000 model for the same setup and frequency range 25 Hz to 5000 Hz. Only the level differences for the case of the speed change of − 10% is presented, with the other case being identical and vertically symmetrical to the 0. For the light vehicles, the biggest level difference is around 1 kHz and is, depending on the speed, -1 dB to -1.3 dB. For the lower frequency range, the positive difference is present. This would mean that for the speed lower by 10 % the lower frequencies gain power, while the higher loose it. In the case of the +10 % speed difference, the

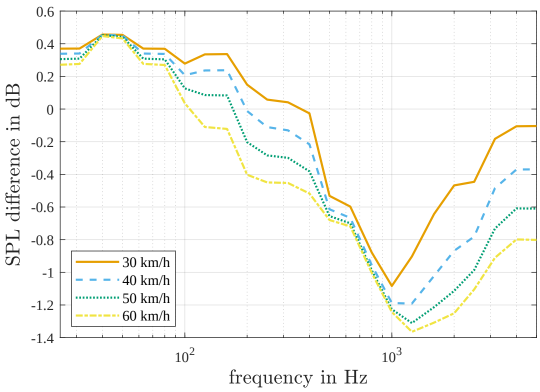


Figure 2.5: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10% for light vehicles with 7 % of heavy vehicles calculated with Nord2000 model.

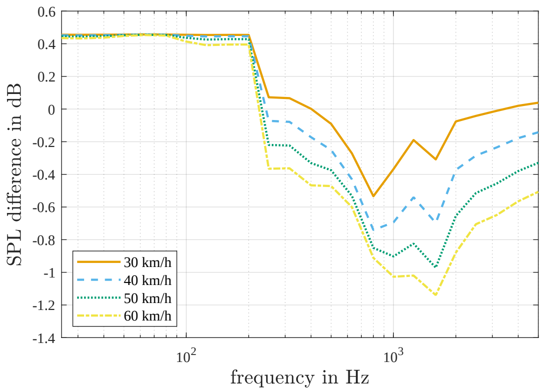


Figure 2.6: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10% for heavy vehicles with 7 % of heavy vehicles calculated with Nord2000 model.

lower frequencies would be attenuated, while the higher frequencies enhanced. With the increase of speed the frequency content changes. The frequency ranges with the biggest change are 100 Hz to 500 Hz and 1000 Hz to 5000 Hz. For these ranges, the level difference increases with the increase of speed. Additionally, the peak around 1 kHz becomes broader, including higher frequencies. The increase in level becomes less pronounced with the increase of speed.

The the frequency content for heavy vehicles is presented in Fig. 2.6. The level difference is not as big as for light vehicles with two dips at 800 Hz and 1700 Hz. The constant negative difference of -0.4 dB is present for frequency range 25 Hz to 220 Hz which shows that this range is more important for heavy vehicle category. The difference of lower and higher frequency range for both vehicle types could be because both of the sources (rolling and propulsion) are taken into account. With the increase in speed, the behaviour of the curve shows similar behaviour as for light vehicles. The frequency range of 250 HZ to 5000 Hz is affected with the biggest difference of 1.1 dB for 60 km/h.

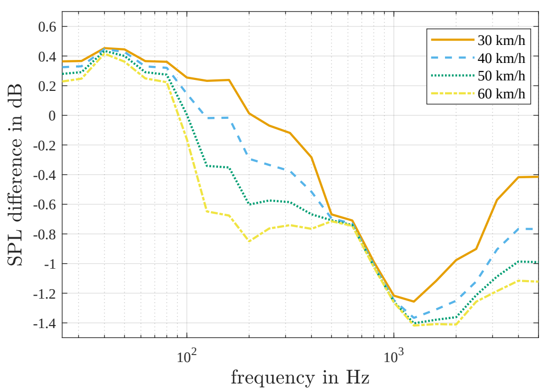


Figure 2.7: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10 % for light vehicles, rolling noise with 7 % of heavy vehicles calculated with Nord2000 model.

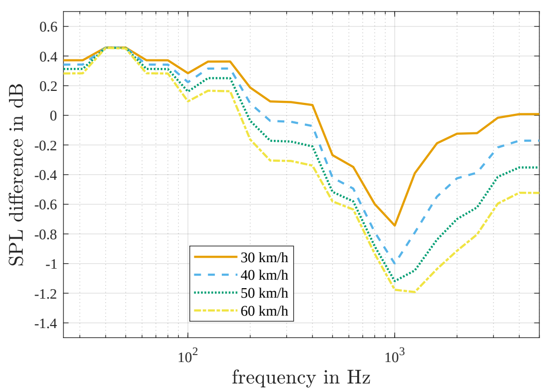


Figure 2.8: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10 % for light vehicles, engine noise with 7 % of heavy vehicles calculated with Nord2000 model.

Figures 2.7 and 2.8 show the behaviour of the frequency content for the light vehicles, for rolling and engine noise respectively. It can be seen that the rolling noise contributes to the SPL difference mostly in the frequency range of 100 Hz to 500 Hz. The engine noise shows a slightly lower difference than the rolling noise. Both sources of noise contribute to the biggest SPL difference in the frequency range above 1 kHz.

On the other hand, for the heavy vehicle category (cat 3), both rolling and engine noise contribute to the difference mostly in the frequency range of 200 Hz and up, with the rolling source being the biggest contributor (Figures 2.9 and 2.10). For the range lower than 200 Hz, the engine noise is more constant for the speed change than the rolling noise, implying that no matter the speed, the engine source will have a constant influence.

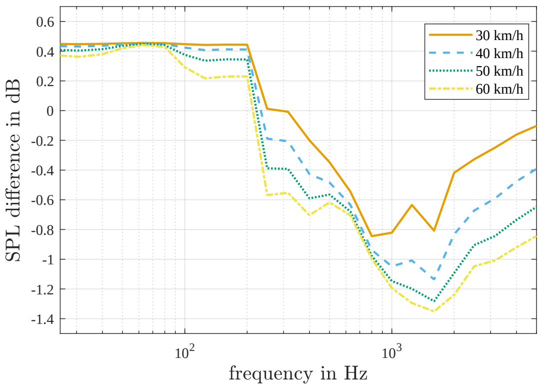


Figure 2.9: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10 % for heavy vehicles, rolling noise with 7 % of heavy vehicles calculated with Nord2000 model.

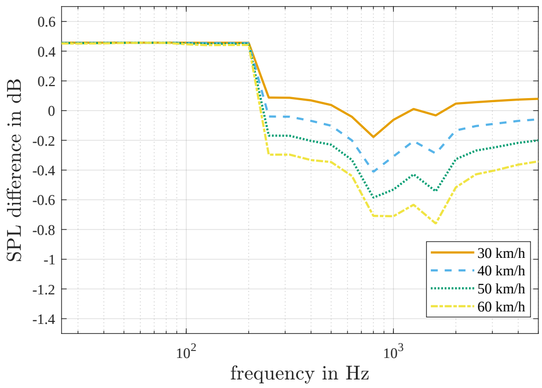


Figure 2.10: Difference in SPL for speeds of 30 km/h, 40 km/h, 50 km/h and 60 km/h with variation of − 10 % for heavy vehicles, engine noise with 7 % of heavy vehicles calculated with Nord2000 model.

2.1.2 Acceleration sensitivity

The calculation model Nord96 does not take into account the noise coming from the acceleration of the vehicles. This presents a limit for constructing a more exact noise map. In the Nord2000 calculation model, the acceleration/deceleration a is included asin equation 2.10 and the coefficients according to the vehicle category presented in the Table 2.2. This correction is applied for all frequency bands.

$$\Delta L_{acc} = C \cdot a, |a| > 2\ m/s^2 \tag{2.10}$$

Table 2.2: Acceleration/deceleration coefficient.[3]

Vehicle category	C in dB
Category 1	4.4
Category 2	5.6
Category 3	5.6

The data provided for this project does not include any data for acceleration/deceleration of vehicles. Because of this, in the cases where acceleration/deceleration should be excluded or included, the SPL is calculated only with speed data without the correction in equation 2.10. Depending on the length of the segment, the acceleration/deceleration will show a behaviour presented in Fig.2.11. Here, one segment of the street is considered and the speed value representative for that segment is taken as an average value for a speed change on the ends of that segment. For this investigation the average speed used is 50 km/h, the difference in speed goes from 0 km/h to 8 km/h and the acceleration is calculated according to equation 2.11:

$$a = \frac{v_2 - v_2}{\frac{s}{v_{avg}}}, \qquad v_{avg} = \frac{v_1 + v_2}{2} \tag{2.11}$$

where v_1 and v_2 represent starting and ending speed during the acceleration/deceleration. The figure shows that for short distances for the bigger change of speed, the acceleration/deceleration goes over the 2 m/s^2 limit. According to the study on the driving patterns in Västerås written by Eva Ericsson [6], the acceleration/deceleration of 2.5 m/s^2 for all street types represented in the study is always represented with less than 0.7 %. Lead by this, the cases for short distances i.e. resulting in $|a| > 2.5$ m/s^2 would be the ones to filter out from the data, assuming they are short time events and not present in the continuous flow of traffic.

On the other hand, for bigger distances, the constant acceleration/deceleration would be present, especially for the roundabouts, crossings, steep or curved roads and street segments near these spatial formations. This would mean that the correction in equation 2.10 should be applied along most of the streets. This matter will be discussed in Section 4 for the individual street analysis. This analysis will be most important for the heavy vehicles, since the acceleration/deceleration has a bigger impact on the noise levels for this category.

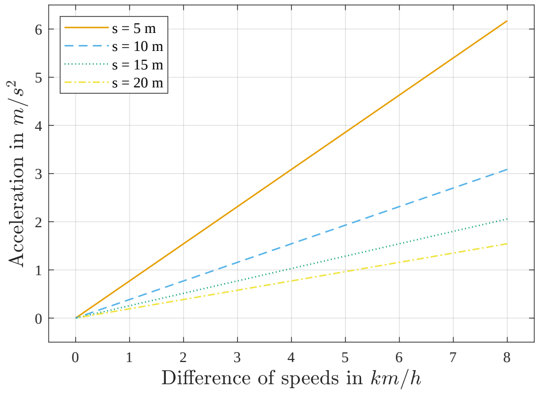


Figure 2.11: Change of acceleration depending on the length of the street segment and speed change for that length.

2.1.3 Vehicle categories

The percentage of heavy vehicles is differently determined for the two calculation models. The Nord2000 model accounts for three different vehicle types, as well as time of the day (Table 2.3), while Nord96 calculates for two vehicle categories and does not have a distribution for the time of the day. Differences in these distributions would have an influence mainly on the total level. With the bigger percentage of heavy vehicles, it is safe to assume that the the total level would be increased and vice versa for the case of lower percentage. In addition, the frequency content will be affected.

For the purpose of comparison, the correction for the time of the day is calculated for both models with heavy part for Nord96 taken from Table 2.1 for Nord2000 taken from the Table 2.3 amd both calculated for day, evening and night hours. The number of vehicles for the whole day is constant and the equation used for the calculation is 2.12 where T equals 12 h for the day, 4 h for the evening and 8 h for the night and p_1 stands for percentage of light/heavy vehicles applied for the number of vehicles and p_2 stands for the percentage according to the time of the day. The street types taken into account are highways, main and collection streets in the Nord96 model which correspond to the motorway, main and urban road in the Nord200 model. The heavy vehicle category for the Nord96 model is compared with both category 2 and 3 for the Nord2000 model.

$$\Delta L_{Nord96} = 10 \cdot \log(\frac{N \cdot p_1}{T})$$
$$\Delta L_{Nord2000} = 10 \cdot \log(\frac{N \cdot p_1 \cdot p_2}{T}) \quad (2.12)$$

The difference in levels for the traffic correction is presented in Fig. 2.12. The negative values indicate that Nord96 correction is lower which means that for the same base equivalent SPL, the SPL calculated with the Nord96 will be louder. The positive values indicate the opposite. It can be seen that the difference for vehicle category 1 and 3 is the same, no matter the time of the day. The difference for category 1 is always around -0.3 dB and for categorey 3 in the range of -4 dB to -1.5 dB. The difference for category 2 is more significant and varies in the range of -5 dB to 2 dB. Of this vehicle category the Nord96 model is generally louder for the highways, but quieter for the main streets, while it varies for the collection streets. This is expected, since this category is not defined for the Nord96 model.

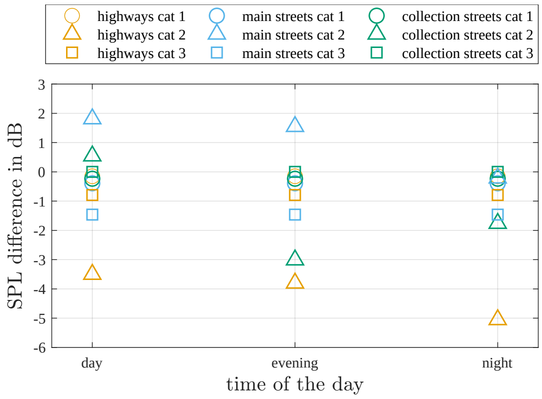


Figure 2.12: Difference in traffic correction for two calculation models depending on the street type, time of the day and vehicle type.

Table 2.3: Default traffic distribution on day, evening and night on various types of roads.[4]

Description	Distribution Cat. 1 in %			Distribution Cat. 2 in %			Distribution Cat. 3 in %		
	Day	Eve.	Night	Day	Eve.	Night	Day	Eve.	Night
Motorway 100-130 km/h	80	10	10	75	10	15	70	10	20
Urban motorway	80	10	10	75	10	15	70	10	20
Main road 80-90 km/h	80	10	10	85	5	10	80	5	15
Urban road 60-70 km/h	80	10	10	85	5	10	75	10	15
Urban road 50 km/h or feeder road	80	10	10	85	5	10	75	10	15
Residential road 30-40 km/h	80	10	10	85	5	10	75	10	15

2.1.4 Influence of two sources

In case of a two-lane road, the difference in equivalent SPL of the two lanes could be taken into account forimproved accuracy. With the signposted speeds, the levels for both lanes would be calculated with the same speed which would imply the addition of +3 dB for all street segments calculated using equation 2.13.

$$L_{two\ lanes} = 10 \cdot \log(10^{\frac{L_{dir1}}{10}} + 10^{\frac{L_{dir2}}{10}}) \tag{2.13}$$

If it is assumed that the lanes would have different speed behaviours, then the sound pressure levels would also differ and the sum of the two directions would not always be +3 dB.

Fig.2.13 shows how the difference of speed for two lanes would influence the behaviour of the SPL difference for the added levels. The difference is calculated for three speeds with the change of ± 10 %. For the higher speeds the difference in levels is higher. The difference in SPL for two directions can also be influenced by the spatial formation. For example, if one lane has a street flowing into it and the other does not, then the speed behaviour will be different, which then influences the difference in SPL. Another cause could be difference in speed limit of adjoining segments. This topic will be further discussed in the Section 4 with real examples.

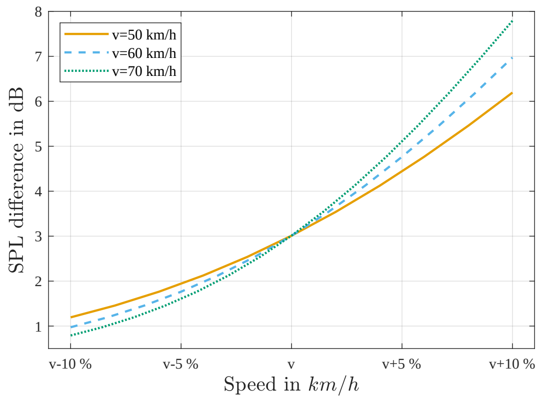


Figure 2.13: Difference in SPL for the addition of two lanes calculated for speeds of 50 km/h, 60 km/h and 70 km/h.

3
Implementation

The area that is the subject of this project encompasses Kävlinge, Furulund, Löddeköpinge and Björnstorp area as it can be seen in Fig. 3.1. The Majority of streets in these areas have only two lanes with the exception of highways, which have six. The speed data as well as the traffic data (number of vehicles) was provided by the acquisition system of the TomTom mapmaking company, including all vehicle types. This data is collected anonymously and does not provide information about the number of different vehicle types. The data was collected hourly, during the whole week, for the year of 2021. Not all of the street segments have the speed data, nor the traffic data and are marked in red in Fig. 3.1.

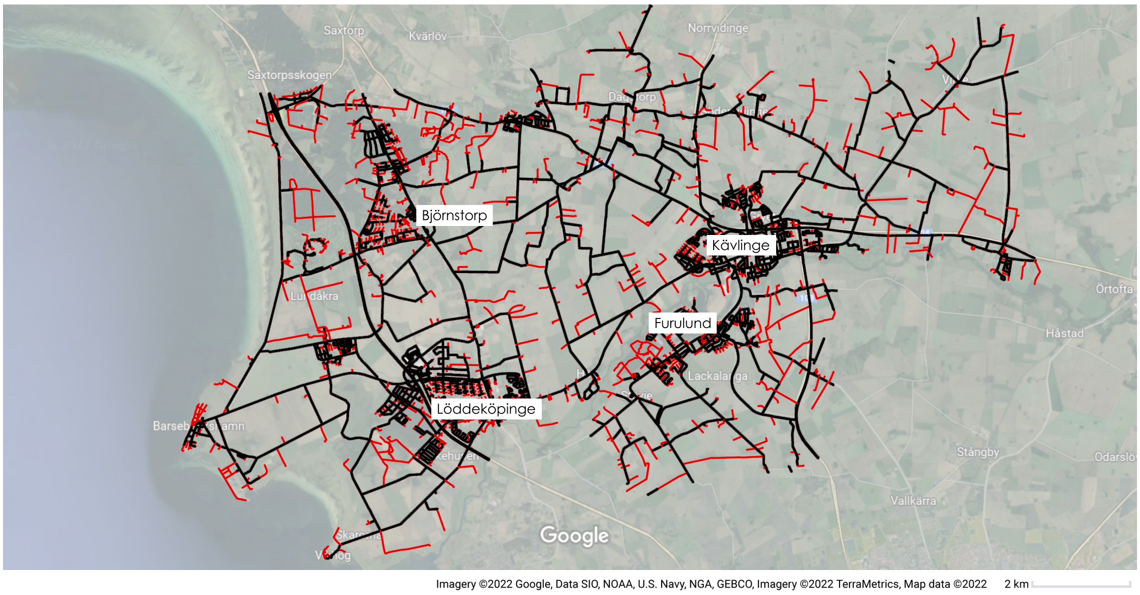


Figure 3.1: Map of the study area with the street links marked in black and red lines, where red indicates that there is no data for this link. The source for the base map in this picture is Google Maps.

The topic of this project is something that has not been investigated previously, so there is no data on methods about how the speed data should be processed. The data provided has street segments with different street types, road classes and speed limits. Represented street types are highways, main streets and collection streets and the road classes are 0, 3, 4, 5, 6 and 7. The distribution of speed limits for the street types is presented in Fig. 3.2 for the main streets and Fig. 3.3 for the collection streets. The speed limit for the street segments of the highways is always 110 km/h. From the data provided, only the street segments that have the information for the vehicle speeds for all 24 h is used which gives 3972 data points as opposed to the 8872 data points for the whole area of study. For the investigation of the speed behaviour and removing outliers the most represented speed limits for a street type is chosen. This would be 30 km/h, 40 km/h, 50 km/h, 60 km/h, 70 km/h and 80 km/h for the main streets and 30 km/h, 40 km/h, 50 km/h and 70 km/h for the collection streets. The speed limits of 45 km/h, 65 km/h and 75 km/h are mostly assigned for the segments that belong to the roundabouts, so they are excluded from the analysis in Section 3.0.1 and will be addressed later in Section 4.

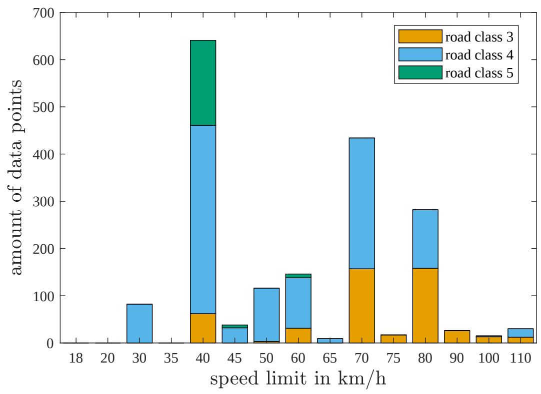


Figure 3.2: Distribution of speed limits for main streets (road class of 3,4 and 5).

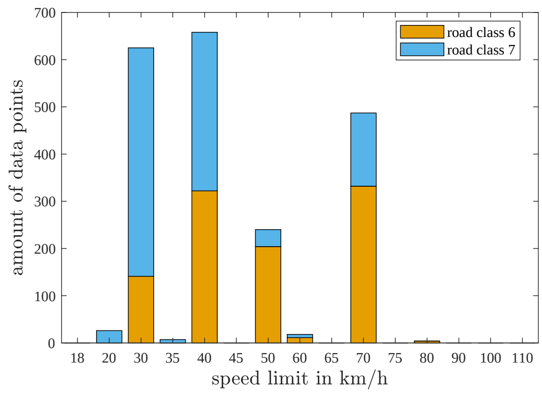


Figure 3.3: Distribution of speed limits for collection streets (road class of 6 and 7).

The speed data was provided in the form of shapefiles, a data format suited for the program ArcGIS. This program was used to connect the speed data with the traffic and spatial data provided by the company Ramboll. In order to be able to get efficient and fast results for big data sets a toolbox for calculation of sound pressure levels and the difference between signposted and real speed data with the Nord96 calculation model was developed using Python. After connection, the data was used to produce noise maps for signposted and real speeds, as well as the difference between them, using the program SoundPLAN. The noise maps produced in SoundPLAN were calculated using the average speeds for 24 h. On the other hand, the calculation for producing the resulting distribution of SPL differences in Section 4 is made as is described in Section 2. This can cause differences in results.

3.0.1 Analysis of the behaviour of speeds for different road classes and speed limits

The speed data can be separated according to the street types and then speed limits. In this case, one street type will contain different road classes which will give a bigger data pool. On the other hand, if the different road classes have different speed behaviour and distribution related to the time of the day, than it is better to group the speed data also according to the road classes, which has been made here in order to investigate this matter.

Distribution of hourly speeds GPS acquired with GPS for highways (road class 0 and speed limit of 110 km/h) going from the 5th to 95th percentile is shown in Fig. 3.4. The speeds vary in the range of 100 km/h to 115 km/h and the behaviour throughout the hours changes. During the night hours, the speeds go from the highest to the lowest for the whole day, while during the day hours, the it oscillates around the speed limit. The outliers are found with the interquartile range method where the thresholds are 5th and 95th percentile. For this speed limit, outliers are always above the speed limit.

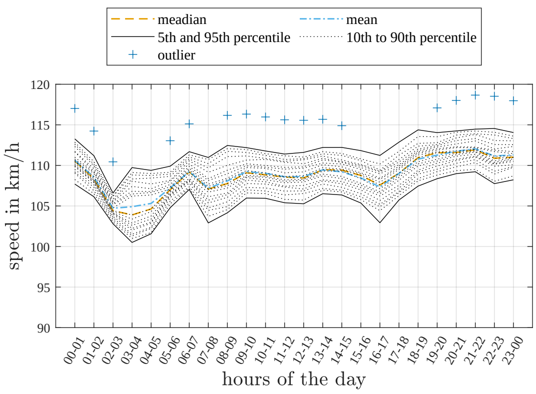


Figure 3.4: Distribution of hourly speeds for highways (road class 0 and speed limit of 110 km/h) with the sample number of 71.

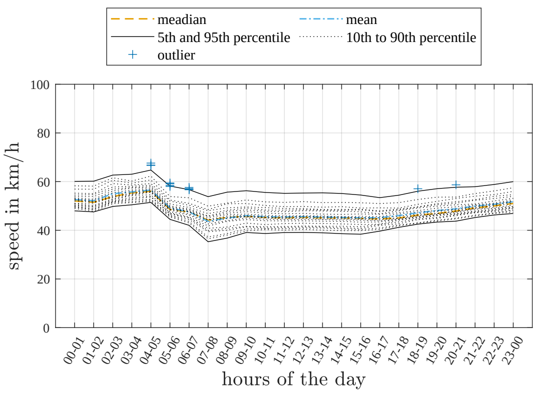
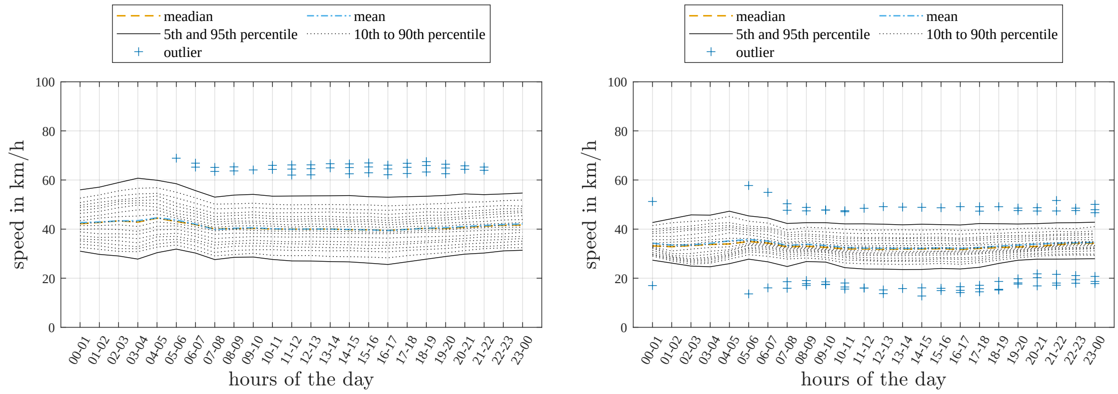


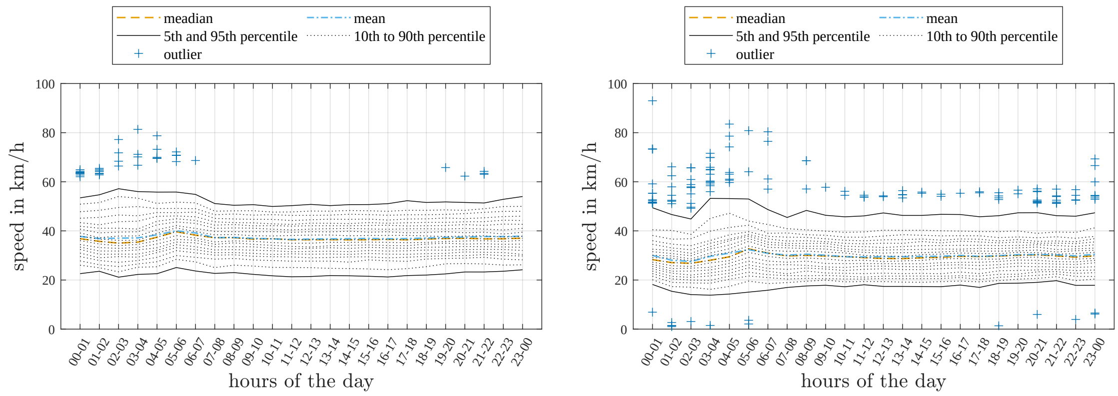
Figure 3.5: Distribution of hourly speeds for main streets with road class 3 and speed limit 40 km/h with the sample number of 62.

Figures 3.5 and 3.6 show the distribution of the speeds for the main streets with road class 3, 4 and 5 for the speed limit 40 km/h. As it can be seen, the behaviour is different for each road class. For road class 3, the median speed is the highest, ranging from 40 km/h to 60 km/h and the highest speeds occur during the night hours. The distribution for each hour is narrow compared to the other road classes. The median speed for road class 4 oscillates around 40 km/h with slight increase during the night hours and all of the outliers are above 60 km/h. The median speed for the road class 5 is below the speed limit and oscillates around 33 km/h. The outliers are this time, both above and below the speed limit. These figures show that for different road classes, the behaviour is different.



(a) **(b)**

Figure 3.6: Distribution of hourly speeds for main streets with (a) road class 4 with the sample number of 399 and (b) road class 5 with the sample number of 180 and speed limit 40 km/h.



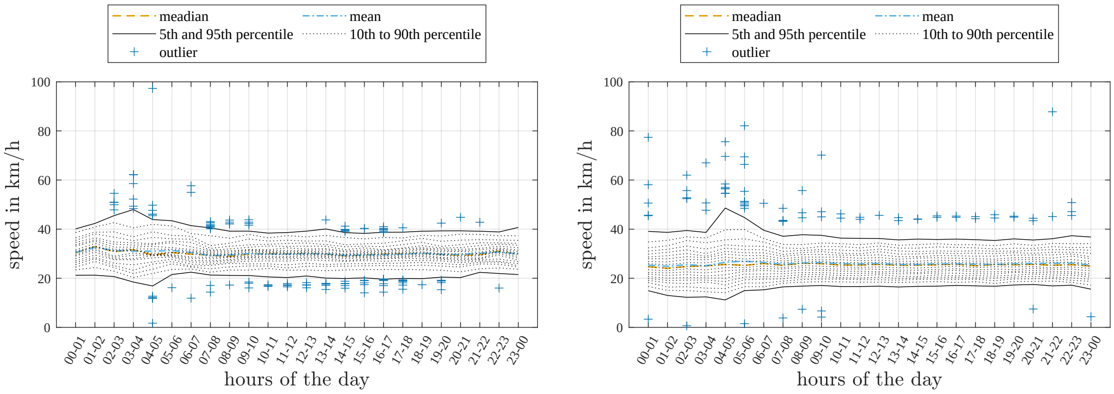
(a) **(b)**

Figure 3.7: Distribution of hourly speeds for main streets with (a) road class 6 with the sample number of 322 and (b) road class 7 with the sample number of 336 and speed limit 40 km/h.

Speed behaviour for the speed limit of 40 km/h for the collection streets (road classes 6 and 7) is presented in Fig. 3.7. Road class 6 shows a similar behaviour as road class 4 with the slightly different behaviour during the night hours. Road class 7, on the other hand, shows a similar behaviour as the road class 5 with the median speed below the speed limit, oscillating around 30 km/h, but with a wider distribution for each hour.

In Fig. 3.8 the speed behaviour for the speed limit of 30 km/h for the collection streets (road classes 6 and 7) is shown and Fig. 3.9 displays the same for road class 4. The sample numbers for the collection streets are much bigger than for the main streets, showing that this is a more typical speed limit for the collection streets. The behaviour for road classes 6 and 7 is very similar with the wider distribution by the hour for the night hour with the median for road class 7 being slightly lower than the speed limit. On the other hand, road class 4 has a median oscillating around

40 km/h and higher speeds during the night.



(a) **(b)**

Figure 3.8: Distribution of hourly speeds for main streets with (a) road class 6 with the sample number of 141 and (b) road class 7 with the sample number of 484 and speed limit 30 km/h.

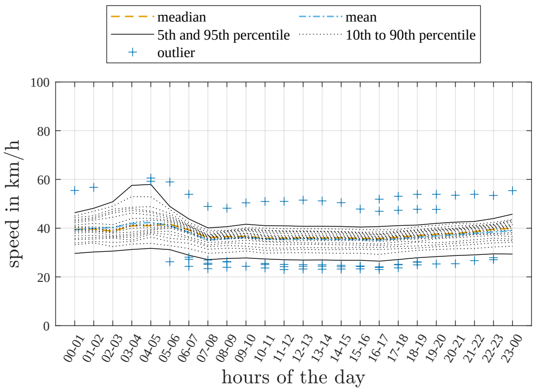


Figure 3.9: Distribution of hourly speeds for main streets with road class 4 and speed limit 30 km/h with the sample number of 82.

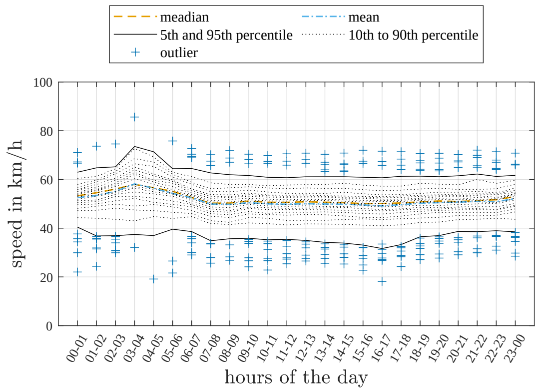
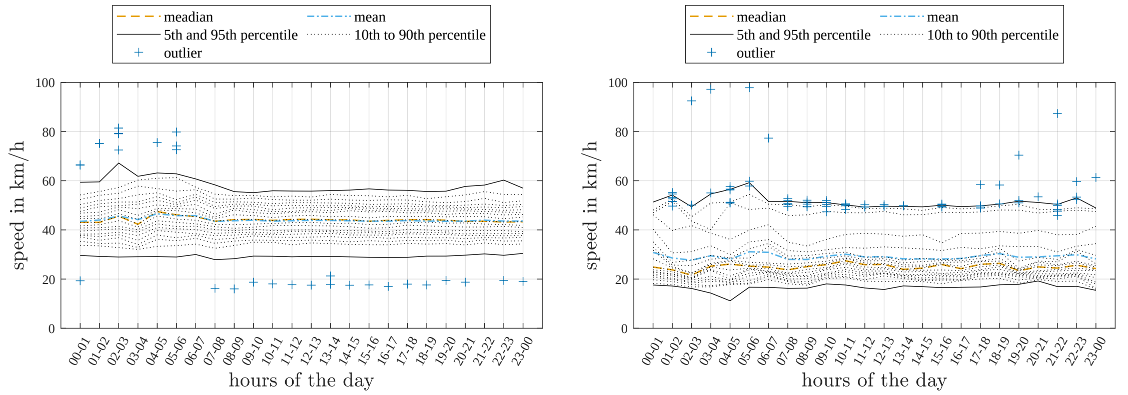


Figure 3.10: Distribution of hourly speeds for main streets with road class 4 and speed limit 50 km/h and sample number of 113.

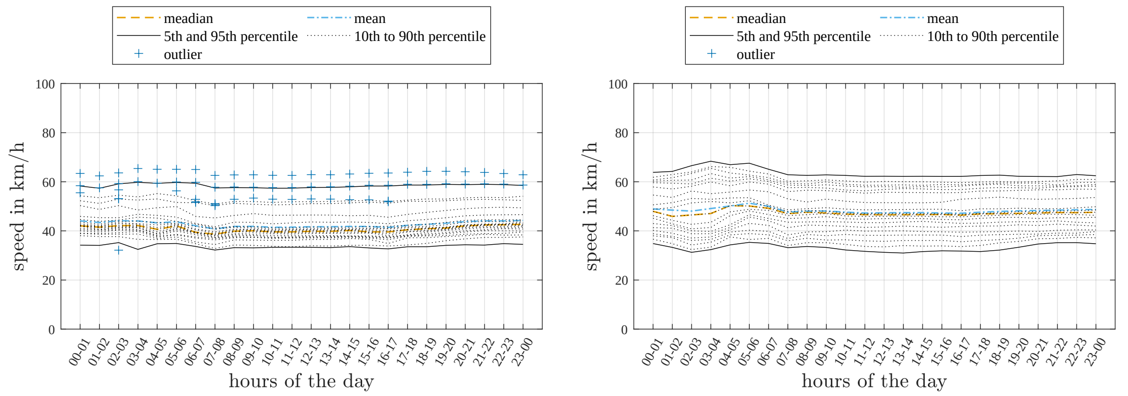
For the speed limit of 50 km/h the behaviour of real speeds is presented in Figures 3.11 and 3.9. Road class 4 shows the median oscillating around the speed limit with increase during the night hours and outliers both above and below the speed limit. For road class 6 the median speed is lower then the speed limit as is for road class 7 where the behaviour shows a skewed distribution.

The speed behaviour for the speed limit of 60 km/h for main streets is presented in Fig. 3.12. The sample number for road class 3 is low and the median values are around 40 km/h with outliers in the range of 60 km/h. The median for the road class 4 is always around 50 km/h with a bigger sample number.



(a) **(b)**

Figure 3.11: Distribution of hourly speeds for main streets with (a) road class 6 with the sample number of 204 and (b) road class 7 with the sample number of 36 and speed limit 50 km/h.

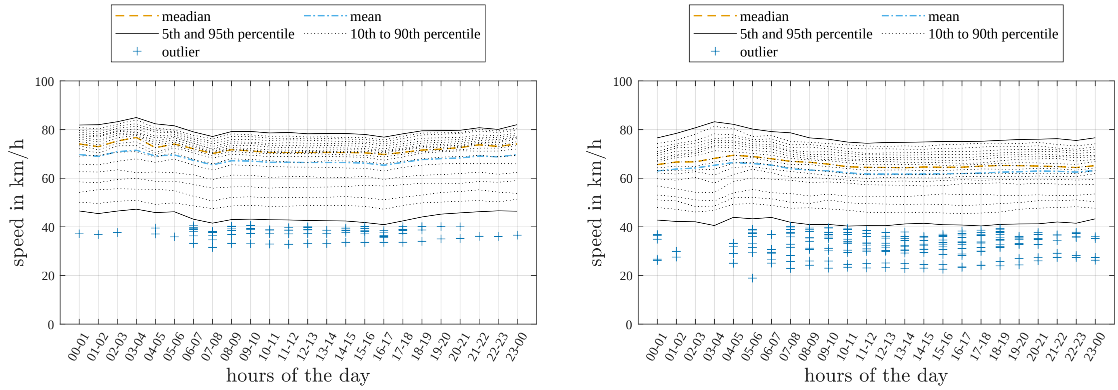


(a) **(b)**

Figure 3.12: Distribution of hourly speeds for main streets with (a) road class 3 with the sample number of 30 and (b) road class 4 with the sample number of 107 and speed limit 60 km/h.

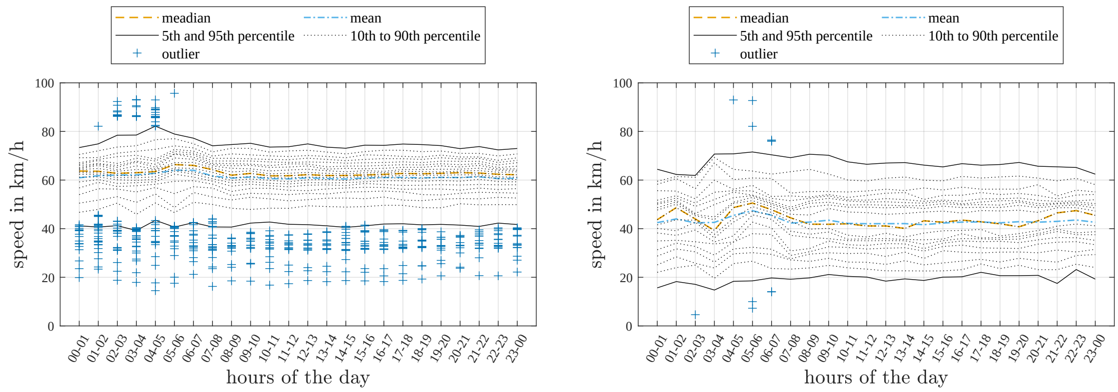
The speed limit of 70 km/h is represented for road classes of 4, 3, 6 and 7 and the behaviour of speeds is shown in Figures 3.13 and 3.14. Road classes 3 and 4 show similar behaviour with the median oscillating around the speed limit and most of the outliers below the speed limit. The range of speeds spans from 40 km/h to 80 km/h. Road class 6 shows similar behaviour as for the main streets with a lower median oscillating around 50 km/h. Road class 7 has the widest distribution among all road classes, with a speed range from 20 km/h to 70 km/h and median oscillating around 40 km/h with most extremes during the night hours.

The speed behaviour for speed limit of 80 km/h is presented in Fig. 3.15 for collection streets. Road class 3 shows the median oscillation around 70 km/h with a very skewed distribution for each hour and outliers in the range of the 5th and 95th percentiles. The road class 4 shows similar behaviour with the median speed closer to the speed limit and outliers below the 5th percentile. For both road classes,



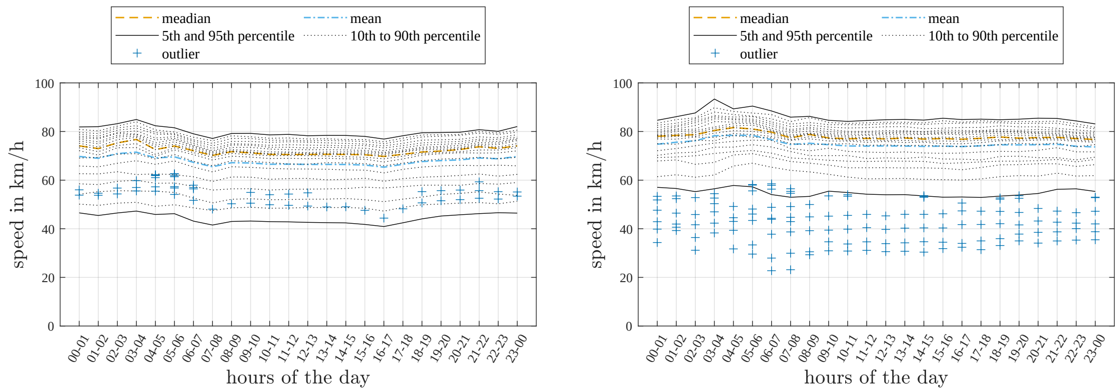
(a) (b)

Figure 3.13: Distribution of hourly speeds for main streets with (a) road class 3 with the sample number of 157 and (b) road class 4 with the sample number of 277 and speed limit 70 km/h.



(a) (b)

Figure 3.14: Distribution of hourly speeds for main streets with (a) road class 6 with the sample number of 332 and (b) road class 7 with the sample number of 155 and speed limit 60 km/h.



(a) (b)

Figure 3.15: Distribution of hourly speeds for main streets with (a) road class 3 with the sample number of 158 and (b) road class 4 with the sample number of 124 and speed limit 80 km/h.

during the night hours is when the peaks or dips appear. Finally, the vehicle speeds for speed limits of 90 km/h and 100 km/h have a very low sample number and a driving speed below the speed limit as can be seen in Figures 3.16 and 3.17. The distribution of vehicle speeds for the speed limit of 100 km/h is skewed towards speeds lower than the speed limit. For both speed limits, the speed increases during the night hours.

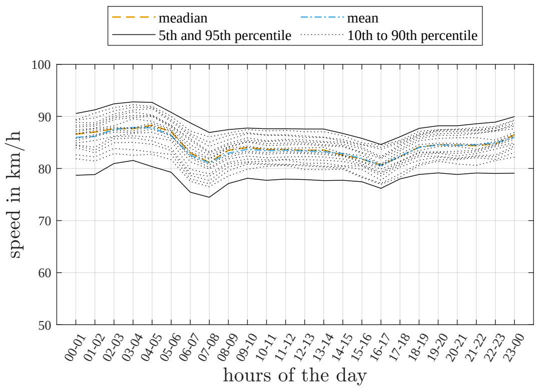


Figure 3.16: Distribution of hourly speeds for main streets with road class 4 and speed limit 90 km/h with the sample number of 26.

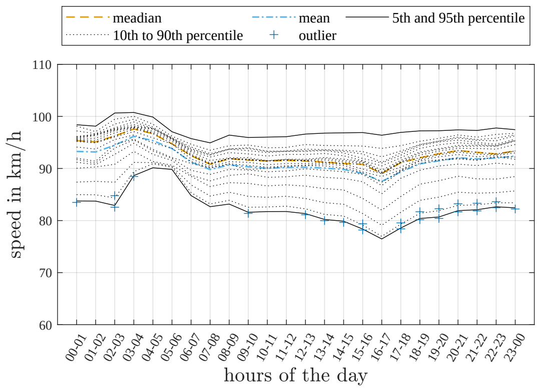


Figure 3.17: Distribution of hourly speeds for main streets with road class 4 and speed limit 100 km/h and sample number of 13.

Overall, the collection streets (road class 6 and 7) usually have a lower driving speed when compared to the main streets (road class 3, 4 and 5) for the same speed limit. During the night hours, the distribution of speeds for each hour is usually wider and has either dips or peaks for certain hours. During the day is when the behaviour of the driving speeds stays constant and during the evening is when it usually starts increasing. For lower speed limits, the outliers are above the speed limit, while for the higher speed limits, the outliers are below the speed limit. Since for some of the road classes showed very different driving speed behaviour from what is expected for the speed limit it is expected to find noticeable differences in sound pressure levels for these cases. The cause of this may be the wrong assignment of speed limits for the road classes. The calculation model Nord2000 recognizes a range of speed limits for the specific street types. This would provide a more accurate reference during the calculation process.

Since different behaviours were noticed for different road classes, outliers were removed by dividing the data first to the road classes and than speed limits.

4

Results

4.1 Analysis of the differences in the provided data sets

For the purpose of SPL difference analysis in this Section, only the street segments that have the speed data for all 24 h are included, as for the analysis of the speed behaviour in the Section 3. The difference is calculated so that the positive values represent the case where the speed exceeds the speed limit (higher SPL) and the negative values represent the case where the speed is lower than the speed limit, hence the SPL is also lower. The traffic data and percentage of heavy vehicles measured for the year 2021 and provided by the company Ramboll also encompass a certain number of street segments for which the majority has the data for all 24 h. The traffic correction is done with the two sets of the traffic data, provided by the TomTom company and Ramboll company. Additionally, the percentage of heavy vehicles is calculated from Table 2.1 and with the percentages provided by Ramboll.

Fig. 4.1a shows the distribution for the calculated percentage of heavy vehicles with Table 2.1 and percentage provided by Ramboll, only for the street segments for which the data is available. It can be seen that the percentage of the heavy vehicles provided by Ramboll is much more spread out than the calculated one. Calculated heavy percentage has peaks for 5 %, 7 % and 12 %, which corresponds to the road classes represented in the data. The biggest percentage for the heavy part provided by Ramboll is around 3 %. Most of the data is in the range from 3 % to 9 %. In addition, there is a peak at 0 %.

In Figures 4.1b, 4.1c and 4.1d the difference in SPL for the two provided traffic data sets is presented. The difference is calculated by subtracting the levels calculated with the Ramboll traffic data from the TomTom traffic data for the same base equivalent SPL, where the positive number indicates that the SPL calculate with the TomTom traffic data is higher. In Fig. 4.1b, the applied percentage of heavy vehicles is the one calculated with Table 2.1 and the SPL is calculated for the mixed vehicles and 24 h. This Figure shows significant amount of data points to have the difference in SPL in the range of 4 dB to 8 dB, but not a lot of difference for different percentage of heavy parts used.This shows that for the majority of street segments, the TomTom traffic data gives a lower correction. This data is chosen for all further calculations because of the availability of data for each hour.

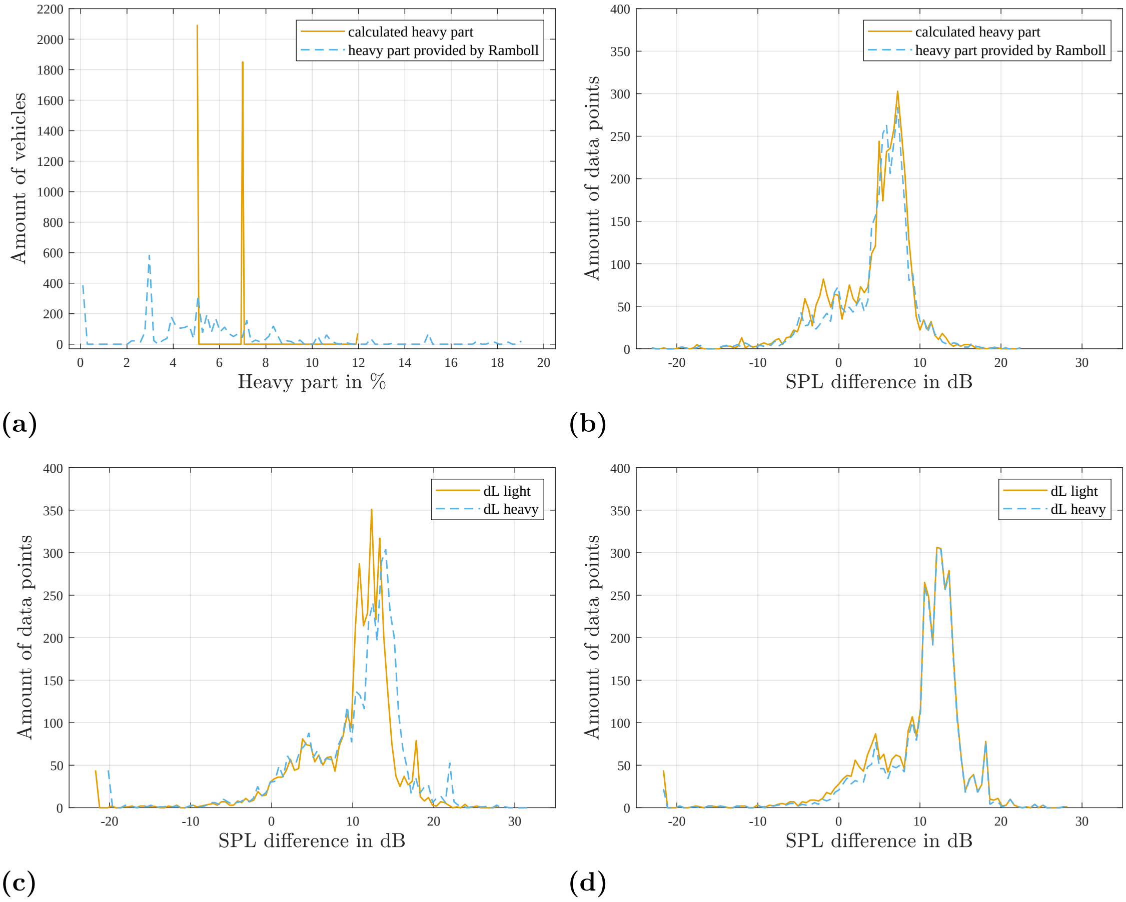
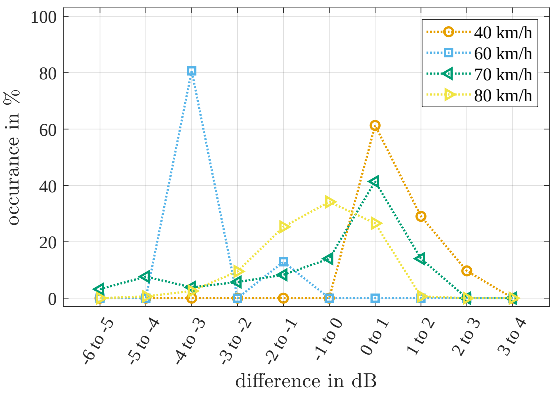


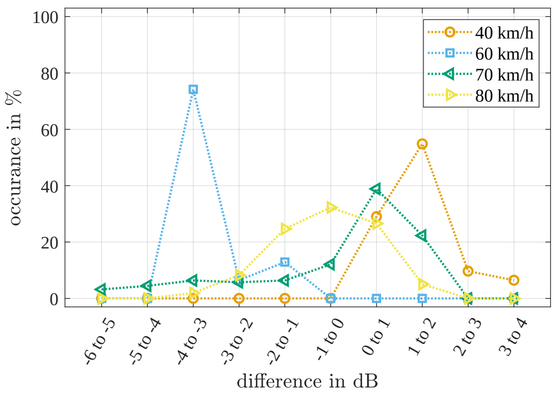
Figure 4.1: (a) Distribution of the percentage of heavy vehicles calculated with Table 2.1 and the Ramboll data. (b) Difference in SPL for two provided traffic data sets with applied percentage of heavy vehicles as in (a) calculated for mixed vehicles and 24 h. (c) Difference in SPL for two provided data sets for heavy and light vehicles with applied calculated percentage of heavy vehicles. (d) Difference in SPL for two provided traffic data sets for heavy and light vehicles and applied percentage of heavy vehicles provided by Ramboll.

Fig. 4.1c and Fig. 4.1d show the difference in traffic correction calculated with the calculated heavy part (c) and heavy part provided by Ramboll (d) for both light and heavy vehicles. It can be seen that the difference for both has the highest peaks in the range from 10 dB to 15 dB. The difference between the light and heavy vehicles is bigger for the calculated percentage and almost zero for the heavy part provided by Ramboll. This shows that in some cases the SPL of the heavy vehicles can be overestimated when using the calculated ones. Nevertheless, the calculated percentage of heavy vehicles is used in order to be able to calculate for a bigger pool of speed data, since the amount of data point for the percentage provided by Ramboll is limited.

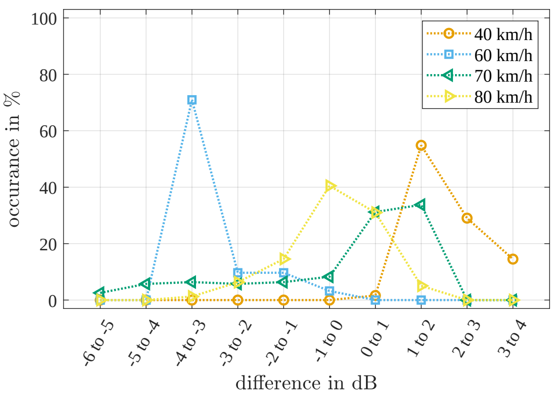
4.2 Analysis of the distribution of difference in equivalent SPL



(a)



(b)



(c)

Figure 4.2: Percentage of SPL difference for streets with the road class 3 for representative speed limits for day (a), evening (b) and night hours (c).

Difference of equivalent SPLs is presented in the form of percentages for every 1 dB change. In Fig. 4.2 the SPL difference for road class 3 with the representative speed limits (40 km/h, 60 km/h, 70 km/h and 80 km/h) for day, evening and night hours is presented. The levels are calculated with the Nord96 model. All of the data points for this road class show difference in SPL to be in the range of -6 dB to 4 dB. Difference for 40 km/h speed limit is mostly in the range of 0 dB to 1 dB (around 60 %), than 1 dB to 2 dB with 30 % for day hours. For evening hours, the biggest percentage goes from 1 dB to 2 dB (near 60 %), and this trend continues for the night hours where the increase for the range of 2 dB to 3 dB happens. This indicates that during the night, on these streets, the driving speed becomes higher. For the 60 km/h speed limit, the biggest percentage is in the range of -4 dB to -3 dB with around 80 % of data points. The sample number for this speed limit is also low (30), so this result can be be considered as unreliable. It also does not change significantly for different times of the day. For The 70 km/h speed limit

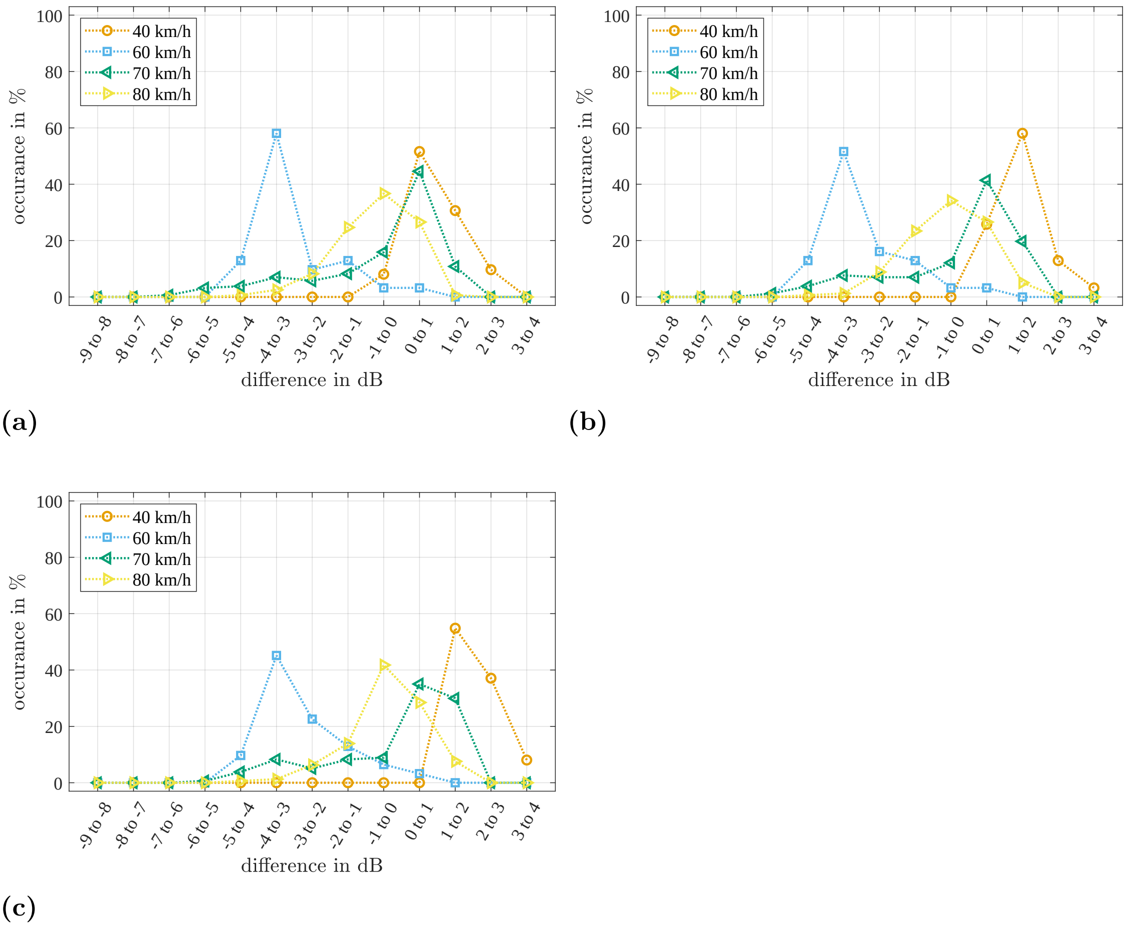
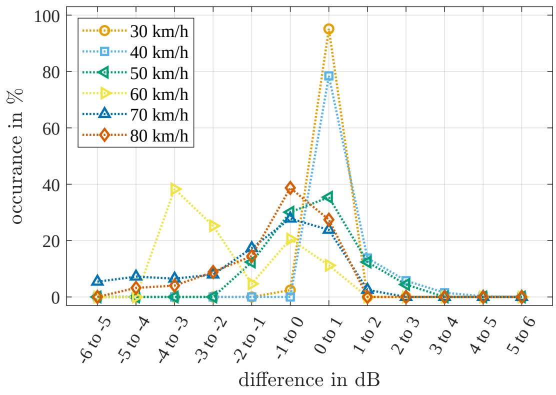


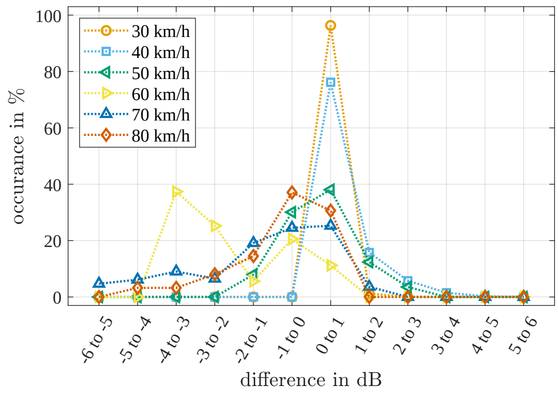
Figure 4.3: Percentage in SPL difference for streets with the road class 3 for representative speed limits for day (a), evening (b) and night hours (c) calculated with the Nord2000 calculation model.

there are more samples (above 150) and the biggest percentage of data points is in the range of 0 db to 1 dB (40 %). This also changes for the time of the day where the percentage for the range of 1 dB to 2 dB increases significantly and the percentages for the ranges in the negative numbers decrease. For the speed limit of 80 km/h a wider range is present with the biggest percentage being in the ranges of -1 dB to 0 dB (35 %), -2 dB to -1 dB (25 %) and 0 dB to 1 dB (25 % for day hours. This shows that both higher and lower speeds compared to the speed limit are represented. This distribution changes slightly in the positive direction of the x-axis for the night hours, again indicating the increase in speed during the night.

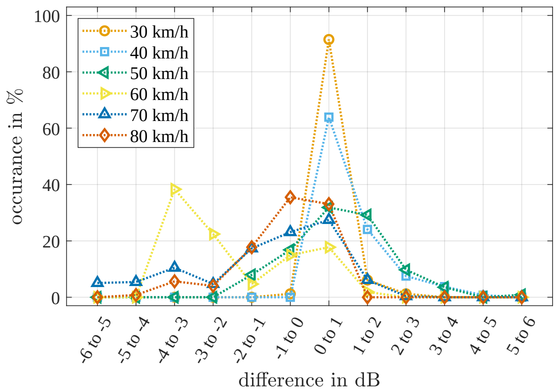
Difference in SPL for road class 3 calculated with the Nord2000 model is shown in Fig. 4.3. The differences of the two calculation models are noticeable. For the speed limit of 40 km/h the distribution shows smaller percentage for the range of 1 dB to 2 dB with bigger accumulation for the range of 2 dB to 3 dB. The same happens for the speed limit of 60 km/h, with lower percentage for -4 dB to -3 dB and bigger accumulation for the rages in the positive x-axis direction.



(a)



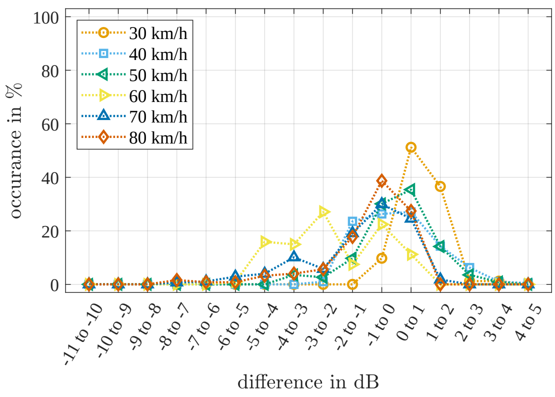
(b)



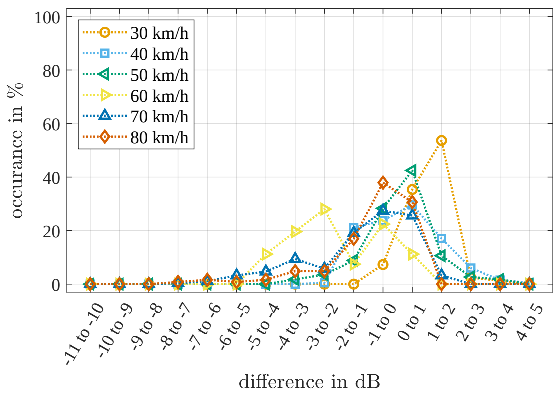
(c)

Figure 4.4: Percentage of SPL difference for streets with the road class 4 for representative speed limits for day (a), evening (b) and night hours (c).

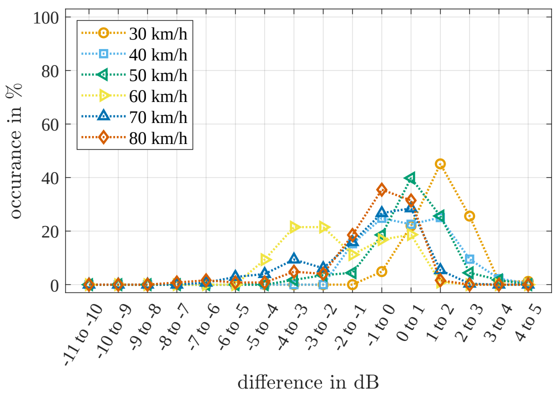
Fig. 4.4 shows the difference in SPL for road class 4. The bigger variety of speed limits is present for this road class. The 30 km/h speed limit shows most of the data points in the range of 0 dB to 1 dB (60%) for the day hours. This could be because of the limit of the Nord96 calculation model. This changes for the night hours where we have around 70 % for the range of 0 dB to 1 dB, indicating higher speeds. For 40 km/h speed limit, the range of 0 dB to 1 dB is mostly represented with around 80 % which drops to 65 % during the night and range 1 dB to 2 dB increases to 23 %. The speed limits of 50 km/h, 70 km/h and 80 km/h have a very similar behaviours. The distribution is concentrated in the range from -2 dB to 1 dB. This changes for 50 km/h in the night hours where the percentage for the range of 1 dB to 2 dB becomes bigger following the same behaviour for the time of the day as for 30 km/h and 40 km/h speed limits. The 70 km/h and 80 km/h always have the bigger percentage in the negative numbers, indicating slower driving speed. The curve for the 60 km/h speed limit behaves differently from the others. The biggest percentage of data points is for the range of -4 dB to -3 dB (40 %) and around 23 % for -3 dB to -2 dB range, while there is also a distribution around 0 dB. Difference in SPL in the range of -11 dB to 5 dB dB is present but in small percentages.



(a)



(b)

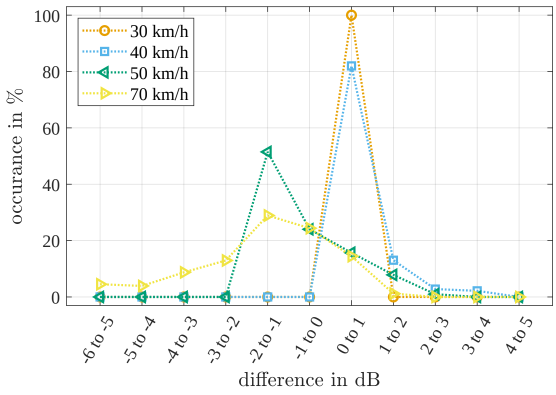


(c)

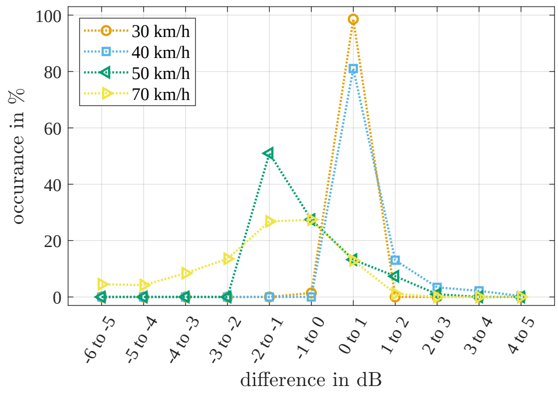
Figure 4.5: Percentage of SPL difference for streets with the road class 4 for representative speed limits for day (a), evening (b) and night hours (c) calculated with the Nord2000 calculation model.

Comparing Figures 4.5 and 4.4, differences between the calculation models for the road class 4 can be seen. The extremes that existed for the speed limits of 30 km/h and 40 km/h for the Nord96 calculations are not noticeable in Fig. 4.5 and a similar pattern is present for all of road classes. The SPL difference accumulates around the 0 dB showing both positive and negative numbers and no distinct number for a certain road class or speed limit.

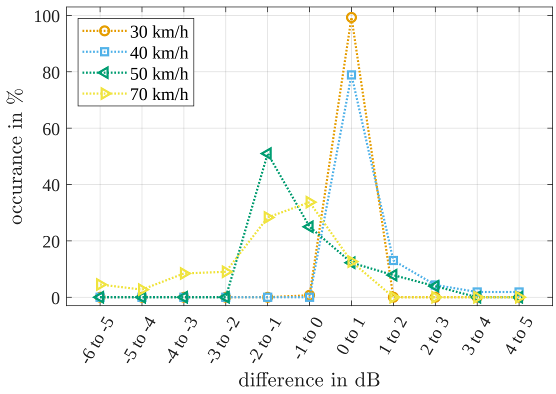
The SPL difference for road class of 6 is shown in Fig. 4.6 for the 30 km/h, 40 km/h , 50 km/h and 70 km/h speed limit. For the speed limit of 30 km/h and 40 km/h, the biggest percentage is in the range 0 dB to 1 dB: 100 % and 80 % respectively for the day hours. This does not change for the evening and night hours. The behaviour of the curves for 50 km/h and 70 km/h shows more significant results. Both curves have the biggest percentage in the negative numbers indicating slower speeds. The 50 km/h speed limit has the biggest percentage in the range of -2 dB to -1 dB (52 %) as well as 70 km/h speed limit (30 %) for the day hours. The distribution is more spread out for the 70 km/h speed limit and at night and the percentage for the range of -1 dB to 0 dB increases.



(a)



(b)



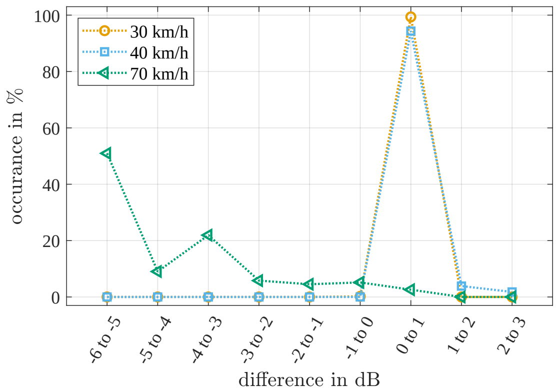
(c)

Figure 4.6: Percentage of SPL difference for streets with the road class 6 for representative speed limits for day (a), evening (b) and night hours (c).

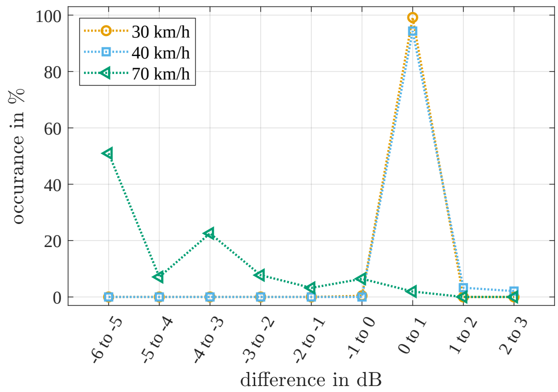
The difference in SPL for the road class 7 is presented in Fig. 4.7 for the speed limits of 30 km/h, 40 km/h and 70 km/h. The behaviour of the 30 km/h and 40 km/h curves is very similar as for road class 6 with percentages showing around 100 %. The behaviour of the 70 km/h curve shows biggest percentage for the range from -6 dB to -5 dB (50 %) and the distribution for range -4 dB to -3 dB. During the night, the percentage moves in the positive direction, now having around 40 % for the -6 dB to -5 dB range.

Data points for road class 0 and 5 have only one speed limit present (110 km/h for road class 0 and 40 km/h for road class 5). Difference in SPL for road class 0 for most of the data points is in the range of -1 dB to 1 dB, while for road class 5 the most od the data is in the range of 0 dB to 1 dB. This does not change in when comparing day, evening and night hours.

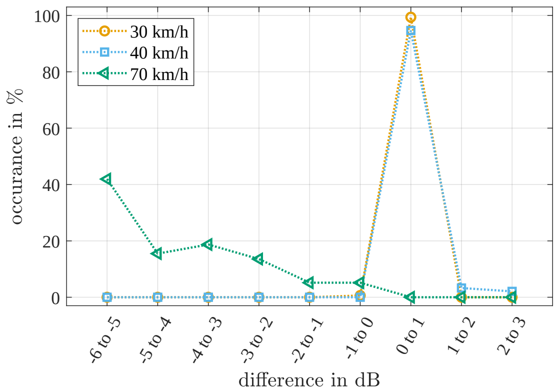
Throughout the whole data set a few patterns are noticed. Usually, during the night the speed increases and so does the SPL difference. For higher speed limits, usually the GPS acquired speeds are slower then the signposted, thus the difference is nega-



(a)



(b)



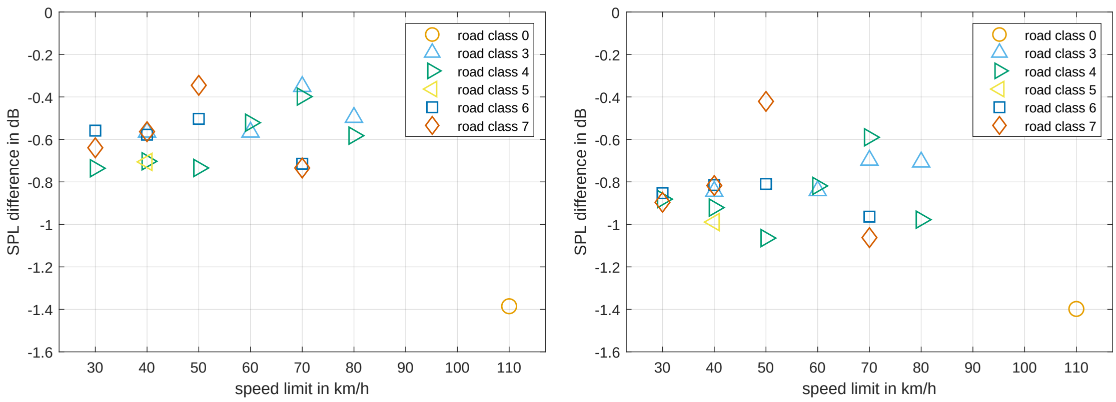
(c)

Figure 4.7: Percentage of SPL difference for streets with the road class 7 for representative speed limits for day (a), evening (b) and night hours (c).

tive. This could be because there is a miss-match of the road class and speed limit. These cases are more significant, because the difference can be noticed by humans (more than 3 dB difference). There are several rare cases where the distribution for the difference was clear and the most common pattern was focused around the 0 dB. The behaviour of the curves for the 30 km/h speed limit can not be taken as completely accurate since that is the limit of the Nord96 calculation model. The SPL calculation for the speed limit of 110 km/h is modeled with Nord96 as is for the speed of 90 km/h in this case, for the purpose of comparison.

The SPL difference calculated with the Nord2000 model for the road classes 6 and 7 are presented in the figures A.1 and A.2 and show the same behaviour as for the previous road classes. The accuracy of the calculation model adds to the ambiguous distribution of the SPL difference and a need for the further and detailed analysis, which is made in Subsection 4.3.

4.2.1 Analysis of difference in the 24h equivalent SPLs



(a) **(b)**

Figure 4.8: Difference in SPL for equivalent 24h levels for mixed vehicles, calculated average for all data points according to different road classes and speed limits. Nord96(a), Nord2000(b)

The average difference in equivalent 24h SPL for all data points is shown in Fig. 4.8 divided according to the speed limits and road classes. This was done in order to investigate the possibility of assigning a correction for the calculation of the noise maps in the future. The speed limits for each road class, which do not have enough sample numbers are excluded from Figures. The Nord96 calculation shows that the difference for all road classes for the speed limits from 30 km/h to 80 km/h is in the range of -0.4 dB to -0.8 dB. The road class 0 which has only the speed limit of 110 km/h is the only one with the more extreme SPL difference of -1.4 dB. The Nord2000 calculations show a general shift in the speed limits from 30 km/h to 80 km/h to the range of -0.6 dB to -1.2 dB. The differences for the different road classes exist and get more noticeable with the increase of the speed limit.

The more significant SPL differences between the signposted and real speeds, as well as the calculating models, arise when the spatial distribution is taken into account. For example, the differences for the roundabouts which are presented in Fig. 4.9, along with the segments of the street near and including the crossroads, as well as the instances of steep or curved streets. In Fig. 4.9 the differences for speed limits and calculation models can be seen. The roundabouts with the speed limits of 60 km/h to 75 km/h have the biggest SPL difference always in the range of -3 dB to -4 dB. The Nord2000 model shows bigger SPL difference for the lower speed limits of 40 km/h and 45 km/h oscillating around -2 dB. This shows the importance of analysing data with regards to the spatial distribution.

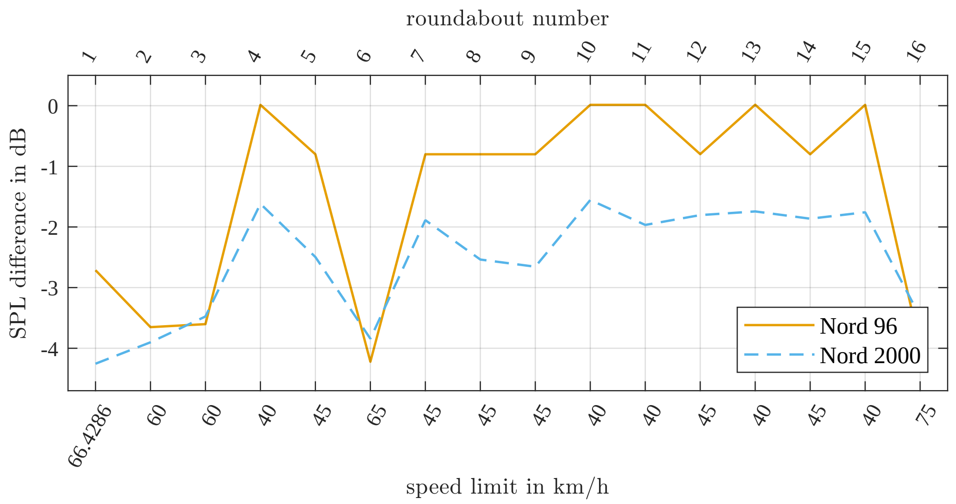


Figure 4.9: Average SPL difference for the equivalent 24h levels for mixed vehicles for all roundabouts in the studied area.

4.3 Analysis of the noise maps and streets of the Kävlinge area

The noise maps calculated with the signposted and GPS aquired speeds are shown in Fig. 4.10 and Fig. 4.11 respectively. These noise maps are calculated for the Kävlinge area which was chosen for the detailed analysis in this Section. Fig. 4.12 shows the difference of SPLs for the previous two noise maps. In these maps, the difference in SPL can be seen mostly for the specific spatial forms like roundabouts and crossings, but also for some segments of the streets. The streets Högsvägen, Tornvägen and Harjagersvägen will be analysed closely in following Sections, while the streets Västra Långgatan and Kvarngatan are shown in Appendix A.

For the calculation of the noise maps, the following was defined:

1. Height data resolution is 5m per height point
2. Only roads with actual traffic data (year average traffic, ÅDT) were taken into the calculation
3. Only average speeds for 24 hours for GPS data was taken into account, for both light and heavy vehicles
4. Only road traffic noise (the railway was not taken into the calculations)
5. Hard surfaces are defined according to the standard and based on the in data in Kävlinge
6. Corrections for roads were implemented (cobblestone) with 3 dB
7. Only equivalent noise levels for 24 h have been calculated
8. Calculation settings: reflection order 1, search radius 200m, reflection distance receiver 100m, reflection distance source 25m, 0,1 dB tolerance.

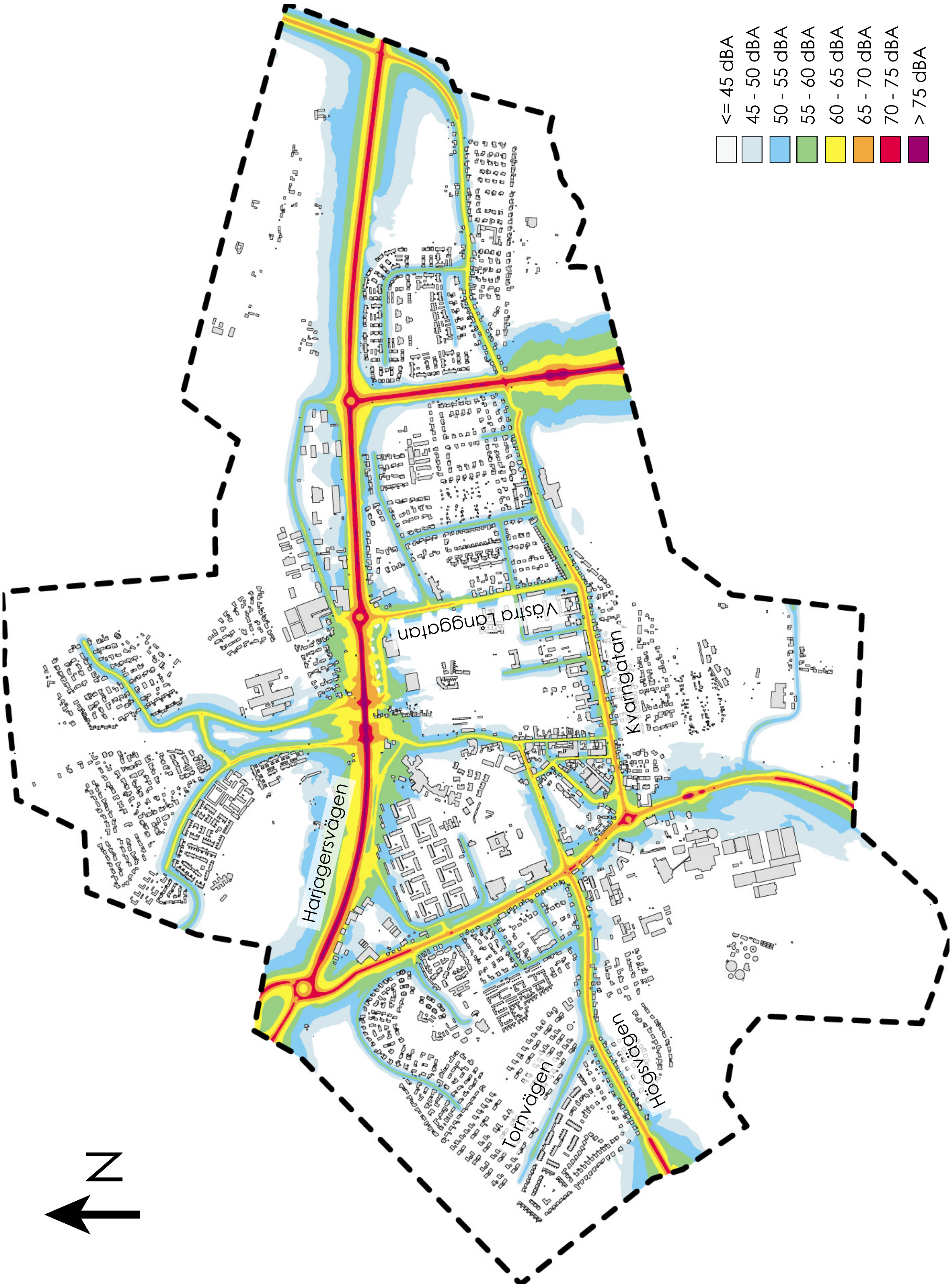


Figure 4.10: Noise map of the Kävlinge area calculated with the Nord96 model for the signposted speeds

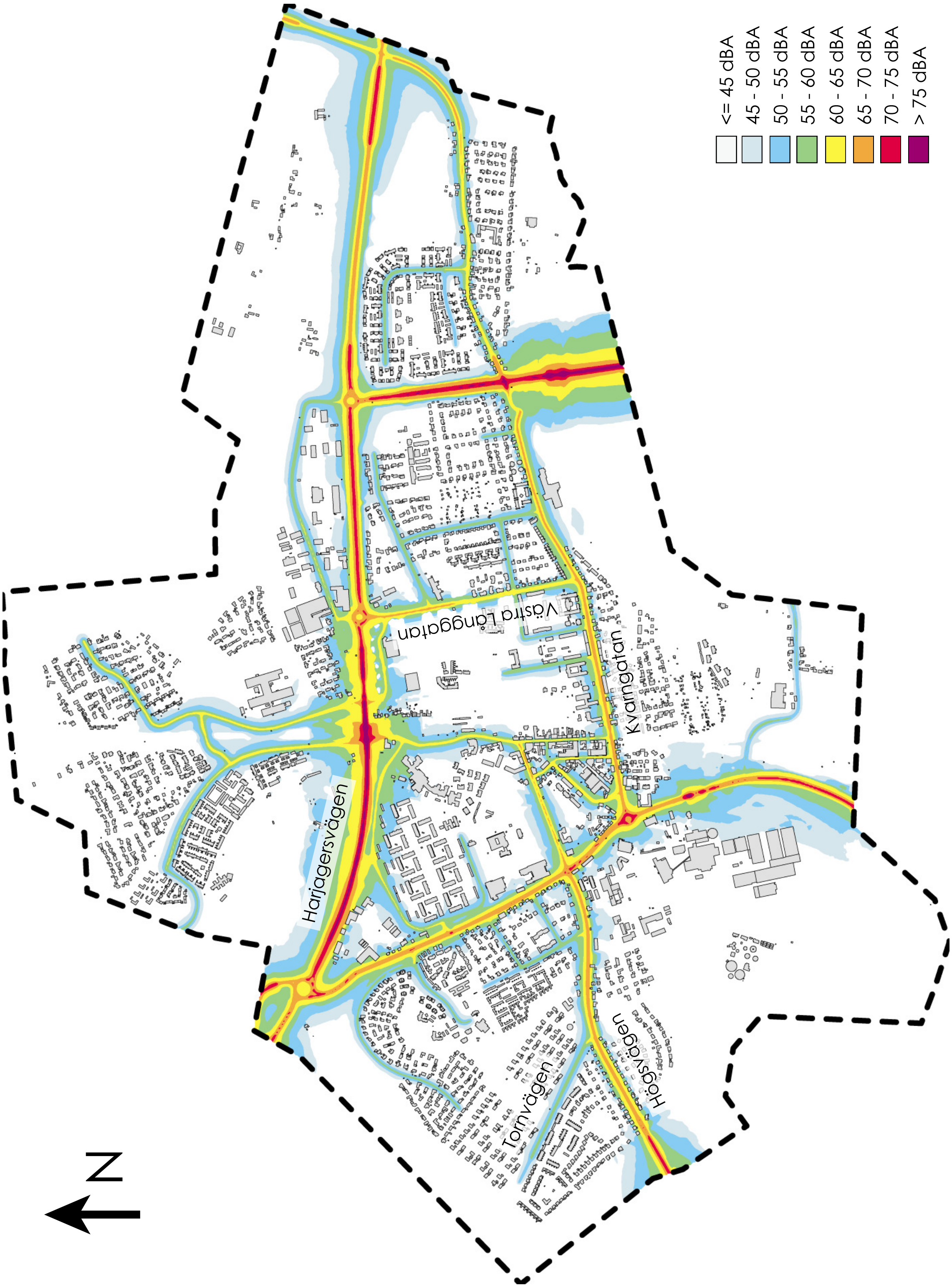


Figure 4.11: Noise map of the Kävlinge area calculated with the Nord96 model for the GPS acquired speeds.

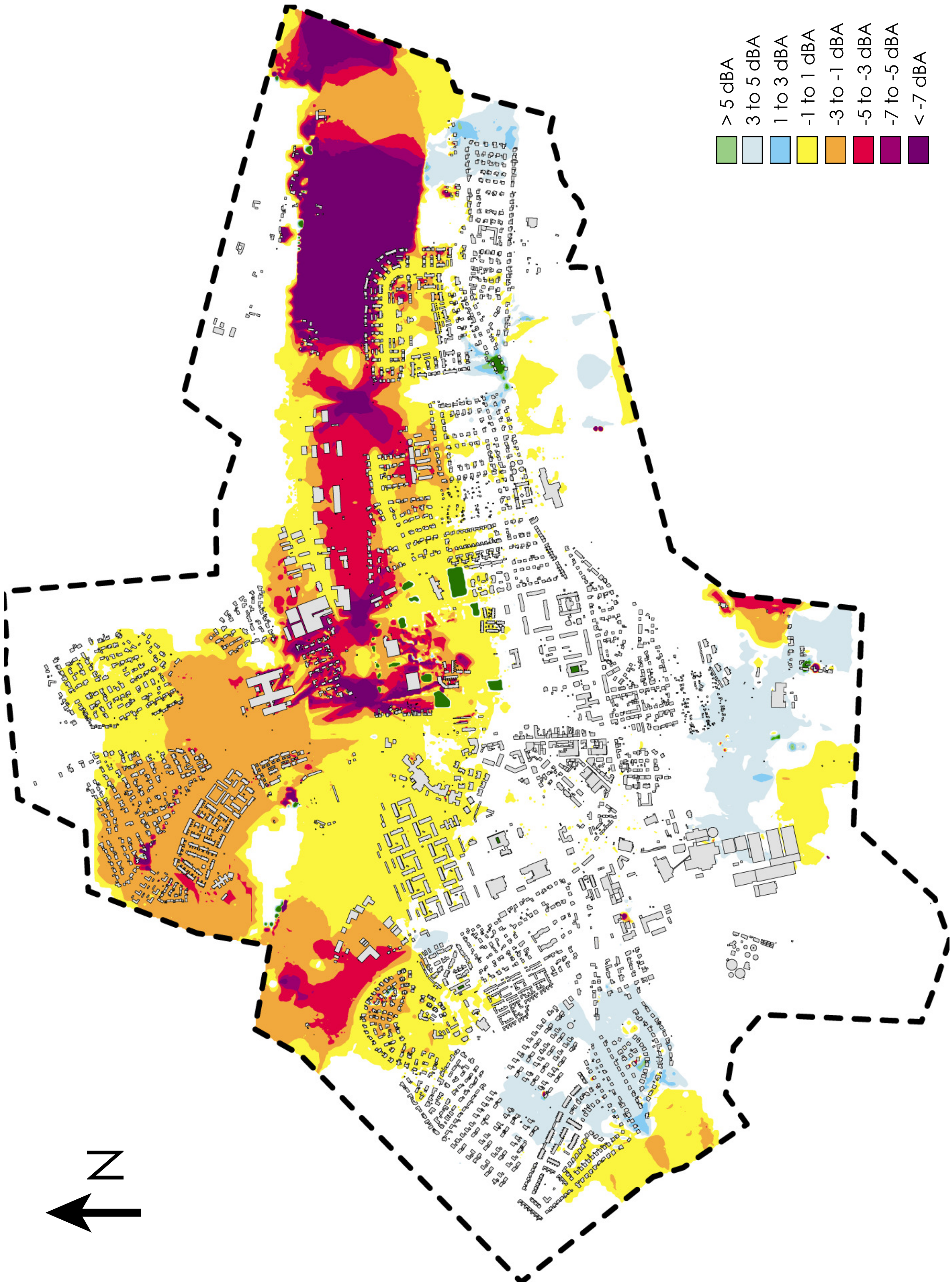
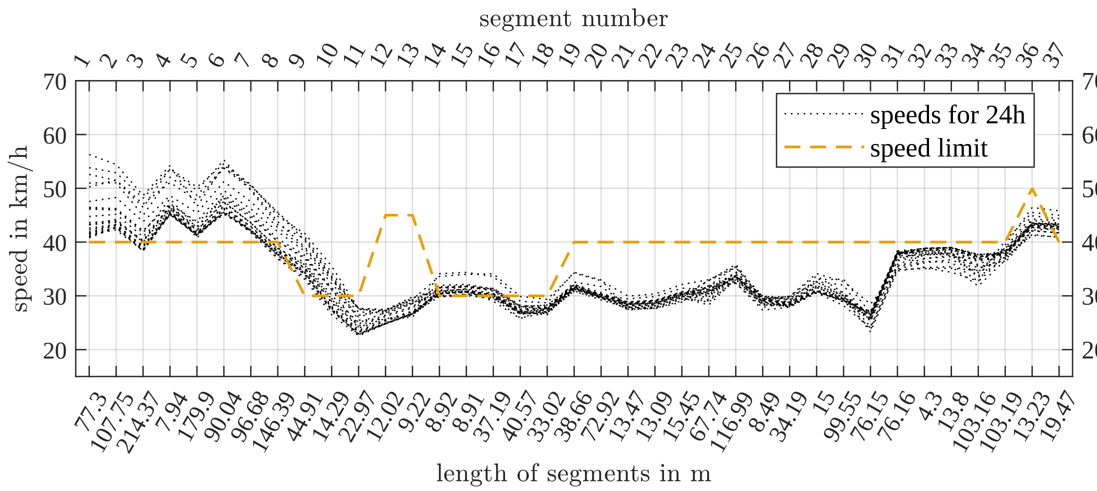


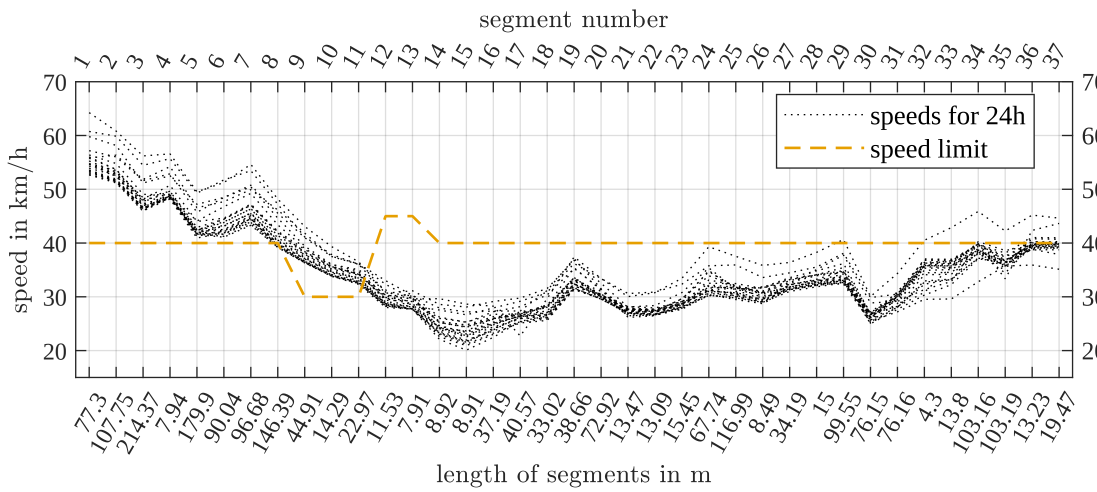
Figure 4.12: Noise map of the Kävlinge area calculated with the Nord96 model for the difference between the levels calculated with signposted and GPS acquired speeds.

4.3.1 Street Högsvägen

The speed behaviour for the street Högsvägen is presented in Fig. 4.13. The speed limit changes along the street, being 40 km/h for most of the segments and road class assigned to the segments is 4 and 6. The speed limit of 30 km/h, 45 km/h and 50 km/h also occurs for some segments. The two lanes do not have the same speed limits for all of the segments. This presents one of the factors that influences the difference for the SPL for the two lanes. The GPS acquired speeds are presented for each segment and for all 24 h in order to see what is the distribution of speeds for each segment. Regarding this, different regions can be noticed in Fig. 4.13. The segments from 1 to 9 are representing the part of the street that is leading out or in of the populated area (depending on the direction). The driving speed for these segments is bigger and has a bigger distribution for the 24 h.



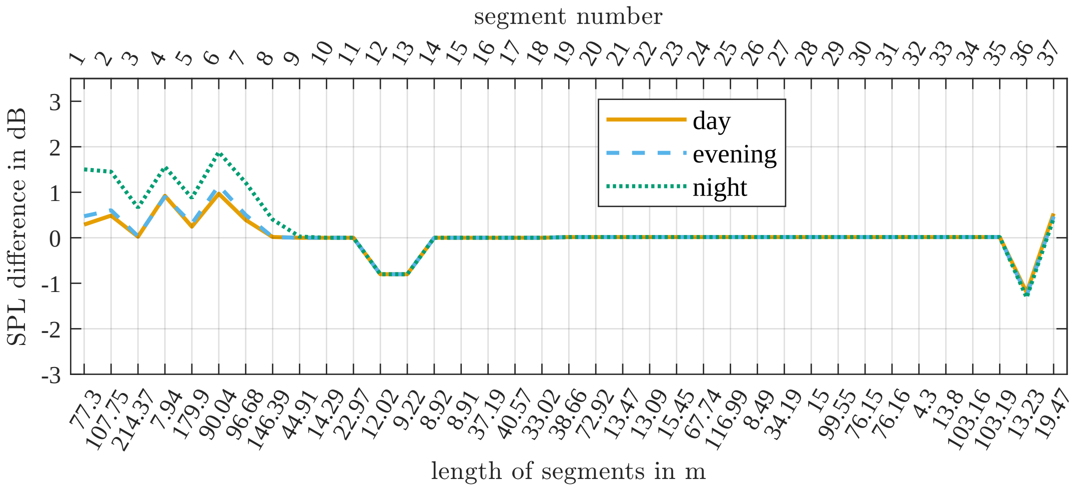
(a) Direction 1



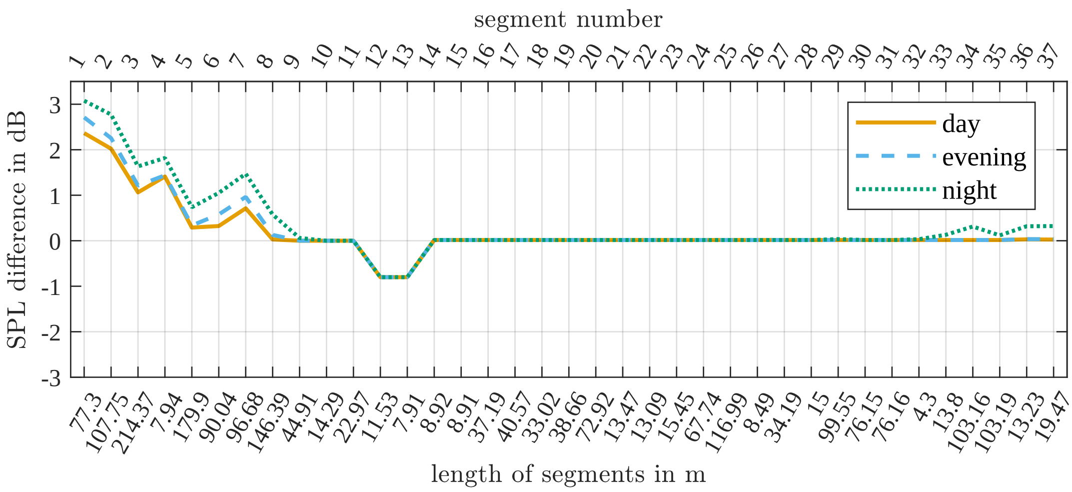
(b) Direction 2

Figure 4.13: Distribution of driving speeds for the street Högsvägen compared to the speed limit for all 24 h and all street segments.

Additionally, the speeds are above the speed limit, spanning from 40 km/h to 65 km/h for both directions. The speed behaviour is very similar for both lanes for the rest of the segments with some peaks and dips which do not show up at the exact same segments. This could have an influence on the summed SPL for the two lanes. This kind of behaviour could stem from streets flowing into this street at different places. The speeds for the segments 9 to 37 are usually below the speed limit.



(a) Direction 1



(b) Direction 2

Figure 4.14: Difference in SPL for the street Högsvägen for all street segments calculated for day, evening and night hours.

Fig. 4.14 shows the difference in SPL for the street Högsvägen along the street segments calculated with the Nord96 model for day, evening and night hours. The biggest difference is seen for the segments 1 to 8 and segments 12,13 and 36. The difference for the segments 1 to 8 spans from 0 dB to 3 dB. For these segments, the

SPL difference follows the behaviour of the speeds seen in the Fig. 4.13. In addition, SPL difference for direction 2 (Fig. 4.14)is bigger. The difference is also biggest for the night hours, while the day and evening hours are similar. The 1.5 dB difference for direction 1 for the first segment and 3 dB for the direction 2 will produce a different number when combining the SPL of the two lanes. In this case, this will not make a significant difference. The segments from 9 to 37 do not show any significant differences between the day, evening and night hours. The driving speed for these segments is usually lower than the speed limit and the difference is almost always 0 dB with the exception of 12,13 and 36 segment where the difference between the real and signposted speed is bigger than for the rest of these segments.

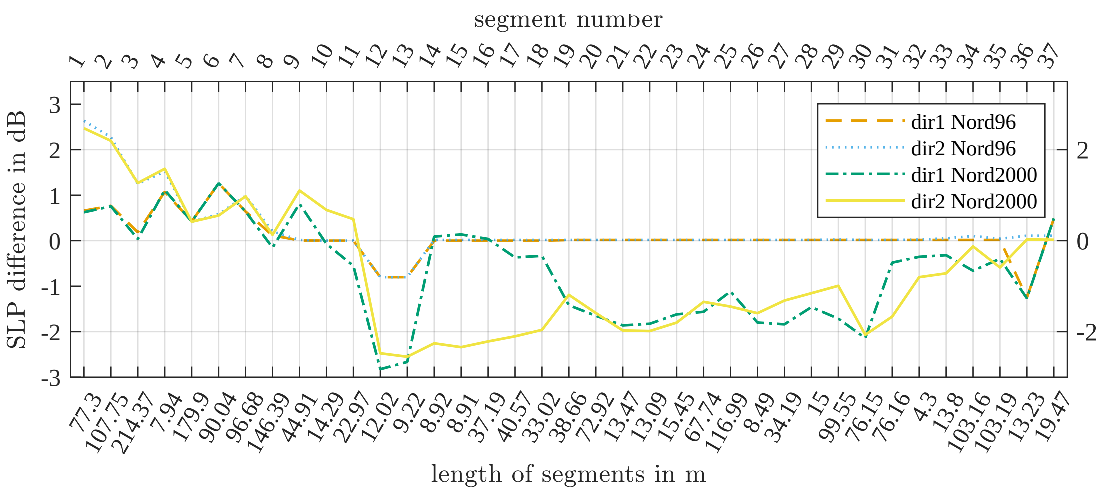
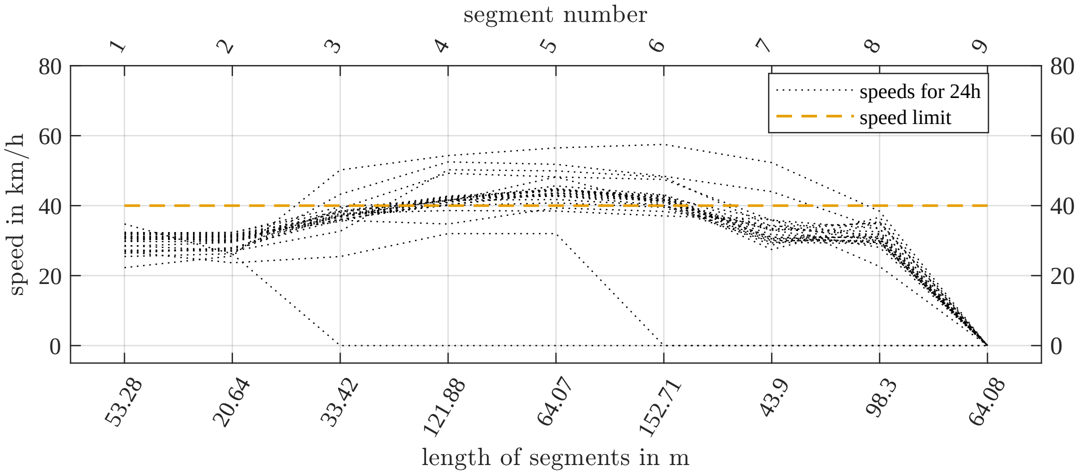


Figure 4.15: Difference in SPL for the street Högsvägen for all street segments calculated for 24 hours with both models and for both directions.

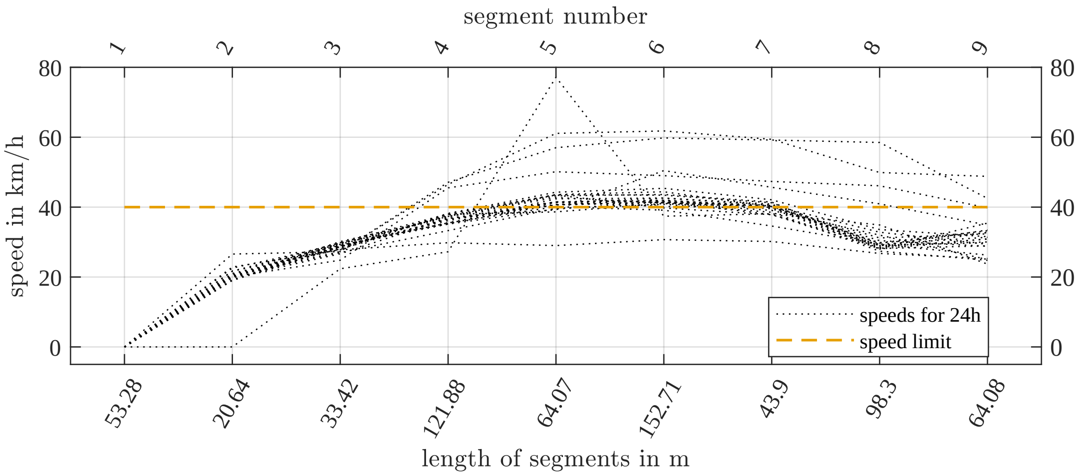
The comparison of the two calculation models is shown in Fig. 4.15 for the two directions of the street and equivalent SPL for 24 h. There is an obvious difference for the segments 9 to 37. The Nord2000 model shows more difference in SPL for these segments, which spans from 0 dB to -3 dB. The two lanes also show difference in behaviour, mostly for the segments where the speed limit is also different. For segments 14 to 18, the difference of two directions will also cause more significant difference in the summed levels. For these segments the summed levels for two directions, calculated for the signposted speeds would give a +3 dB levels. On the other hand, the summed levels calculated with the Nord2000 model will give a negative difference for the segments 14 to 18 which will than make even bigger deviation.

4.3.2 Street Tornvägen

Speed behaviour for the street Tornvägen is shown in Fig. 4.16. The speed limit is constant for all of the segments and both directions. For some of the segments there is no speed data, depending on the hour. The speed behaviour differs for the two directions. Direction 1 shows decrease in speed for the segments 8 and 9, while the same happens for the direction 2 for the segments 1, 2 and 3. This is probably because this street has a dead end and this would explain the behaviour for one direction, while for the other it would be the connection to the roundabout. This street has a road class of 7, which despite the similar speed limit, makes a difference, not only for the amount of heavy vehicles, but the traffic flow for this class. The speed distribution seems to be more sparse than for the street Högsvägen, spanning from 30 km/h to 60 km/h for the middle segments (3 to 8) in both directions. The beginning and end of the street are the only places where the speed is mostly under the speed limit.



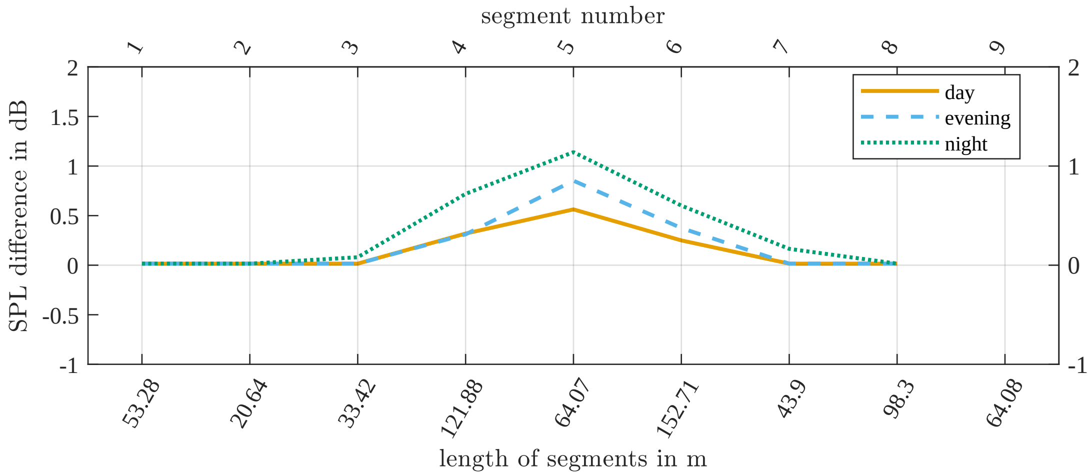
(a) Direction 1



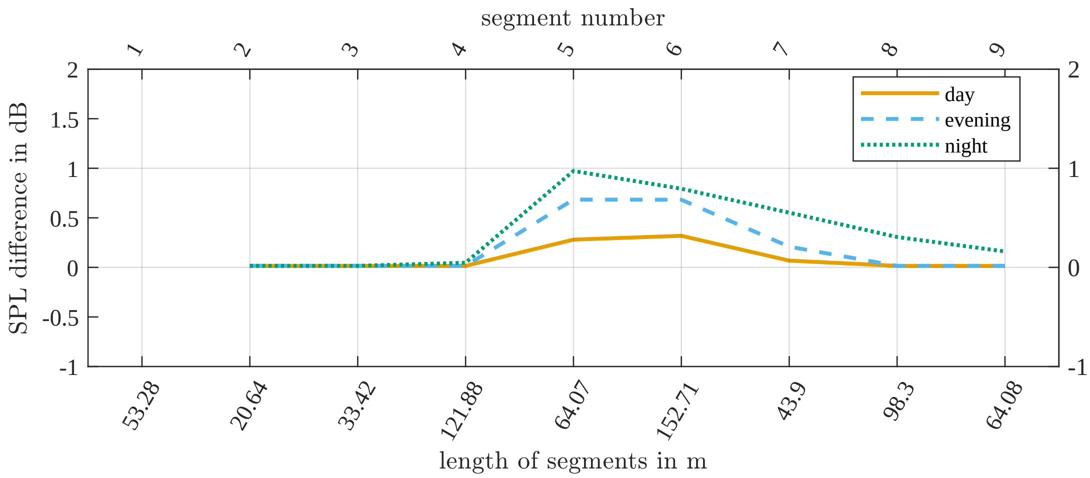
(b) Direction 2

Figure 4.16: Distribution of driving speeds for the street Tornvägen compared to the speed limit for all 24 h and all street segments.

Fig. 4.17 shows the difference in SPL calculated with the Nord96 model. The segment 1 for the direction 1, as well as the segment 9 for the direction 2 does not have any speed data and accordingly no data for the SPL difference. If the complete



(a) Direction 1



(b) Direction 2

Figure 4.17: Difference in SPL for the street Tornvägen for all street segments calculated for day, evening and night hours.

stop of the traffic flow at these instances is assumed, than the noise map made with only signposted speeds would not show the accurate behaviour of the traffic. As for the street Högsvägen, the biggest difference in the levels is for the night hours, than evening and day. The SPL difference is biggest for the middle section of the street, where the two lanes do not match the behaviour for each segment and it spans from 0.3 dB to 1 dB which is not of big significance. When the Nord96 calculation is compared to the 24 h equivalent levels calculated with the Nord2000 model in Fig. 4.18, bigger difference can be seen for the segments where the Nord96 model showed 0 dB difference. For beginning and ending segments of the street the difference goes from -1.5 dB to -2.5 dB, for both directions. The SPL difference is not the same for most of the segments of the street when looking at the two directions, which will cause bigger difference when the levels of the two lanes are summed and as for the street Högsvägen, it will deviate from the value predicted with the signposted speeds.

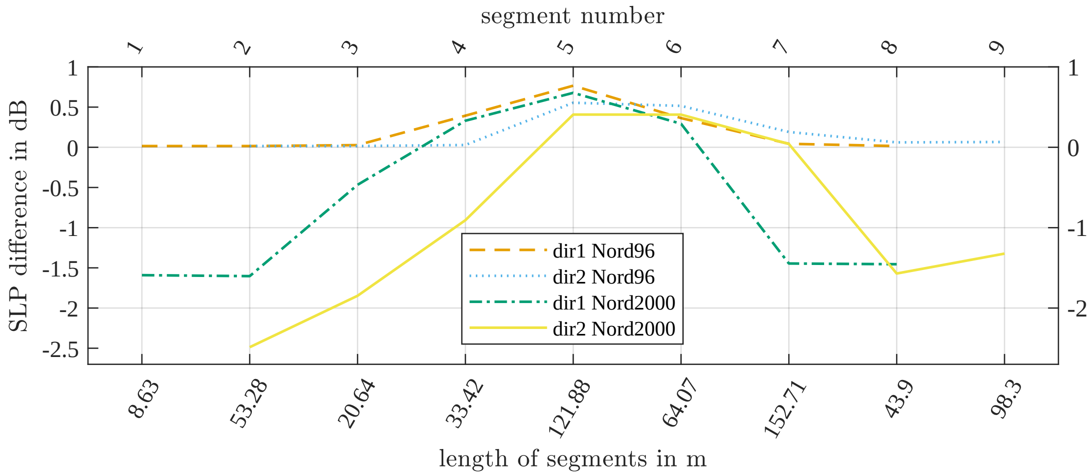
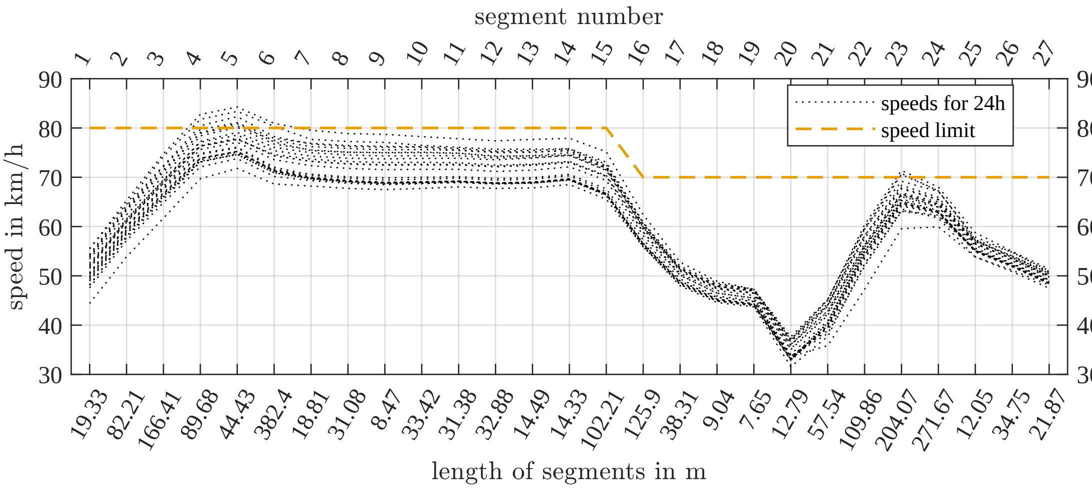


Figure 4.18: Difference in SPL for the street Tornvägen for all street segments calculated for 24 hours with both models and for both directions.

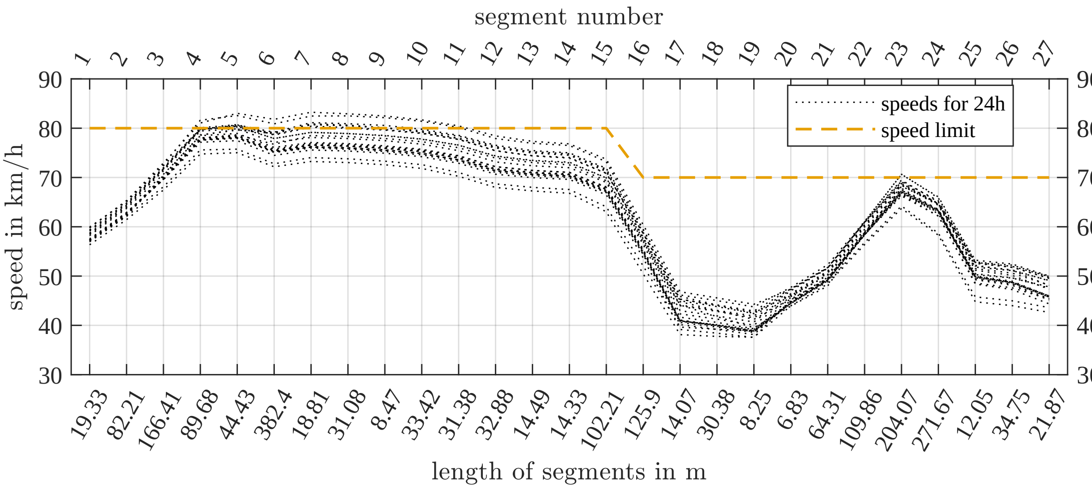
4.3.3 Street Harjagersvägen

Behaviour of the driving speeds for the street Harjagersvägen is shown in Fig. 4.19. With the speed limit of 80 km/h and 70 km/h the real speeds are almost always below the speed limit. Segments from 1 to 4, as well as 15 to 23, show drastic changes in speed for both driving directions. The segments 1, 20 and 27 are where the roundabouts are connected to the street. The speed distribution for 24 h is narrow, showing the behaviour of the vehicles for this street is well established. Compared to the previously analysed streets, the cause for this can be the higher speed limit, as well as Harjagersvägen street being longer.

The difference in SPL for the street Harjagersvägen is shown in the Fig. 4.20. The difference is always below the 0 dB and always biggest for the day hours. The difference spans from -6 dB to 0 dB. The behaviour of the curves follows the behaviour of the speeds more accurately than for the streets Högsvägen and Tornvägen. The two directions differ in behaviour, but not significantly. However, when addressing the differences that arise when the levels of the two lanes are summed, the biggest differences will occur for this street. For the signposted speeds, summing the SPL of different lanes will show the increase in level by 3 dB. On the other hand, because of the negative values in SPL for the GPS aquired speeds, the summed level will still be negative. This will cause an even bigger difference in SPL prediciton. The segments 1 to 4, 15 to 17 and 24 to 25 have the steepest inclines/declines in speed, as well as in SPL, which can indicate the places of acceleration and deceleration. In this case, with the application of the penalty for acceleration/deceleration from the Table 2.2, the difference in SPL would change for these segments.



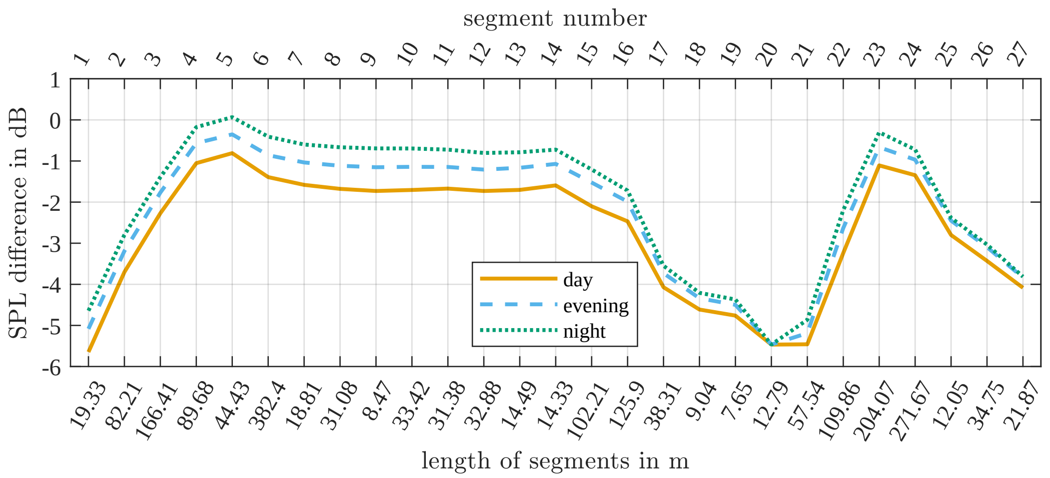
(a) Direction 1



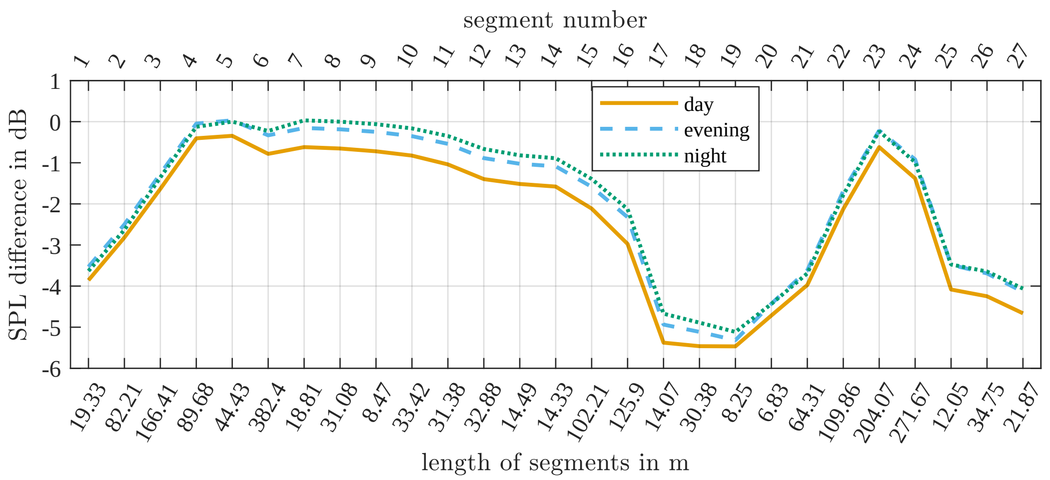
(b) Direction 2

Figure 4.19: Distribution of driving speeds for the street Harjagersvägen compared to the speed limit for all 24 h and all street segments.

In Fig. 4.21 the comparison of the two calculation models for the street Harjagersvägen is presented. In this case, the two calculation models predict the sound pressure levels very similarly. This shows that the limitation of the Nord96 model is low precision for the lower speeds. This can also be seen in Fig. 4.21 where for the segments 1 to 4, 15 to 23 and 24 to 27 the deviation of Nord96 model from the Nord2000 for the difference in SPL becomes bigger as the speed goes down, while for the segments 4 to 15, the models calculate almost the same.



(a) Direction 1



(b) Direction 2

Figure 4.20: Difference in SPL for the street Harjagersvägen for all street segments calculated for day, evening and night hours.

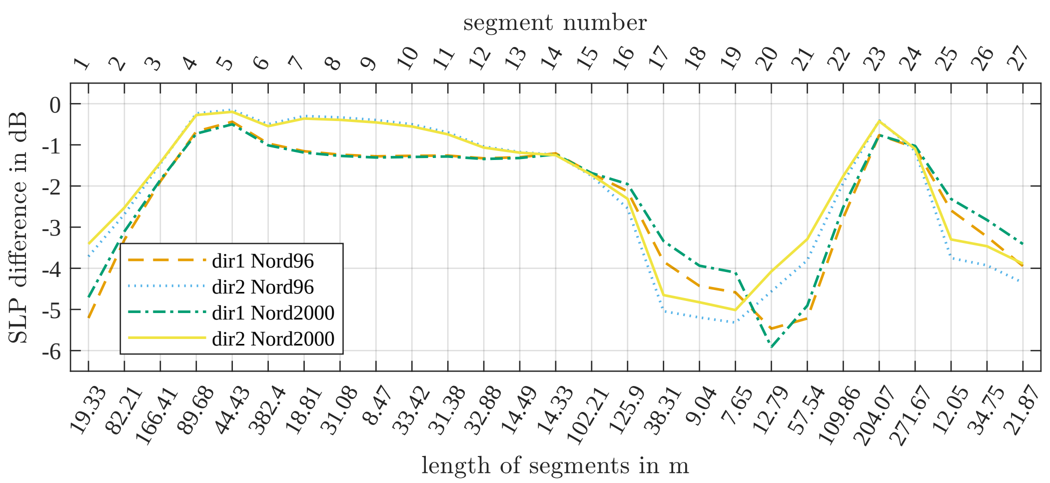


Figure 4.21: Difference in SPL for the street Harjagersvägen for all street segments calculated for 24 hours with both models and for both directions.

4.3.4 Roundabout in the street Harjagersvägen

Roundabout in the Harjagersvägen street is assigned the speed limit of 60 km/h. Fig. 4.22 shows the speed behaviour and SPL difference for the roundabout positioned between segments 19 and 20 of the street in Secion 4.3.3. The vehicles speed is always drastically below the speed limit, oscillating in the range 30 km/h to 45 km/h. This causes constant SPL difference for 24 h of around -3.5 dB along all of the segments of the roundabout, for Nord96 calculated SPL as can be seen in Fig. 4.23. With the Nord2000, predicted difference in SPL shows even bigger changes for segments 2, 3, 4 and 7,indicating lower speeds. Because of this behaviour, the difference in levels for the roundabouts is usually -3 dB to -4 dB and they were taken out from the analysis of the full data set.

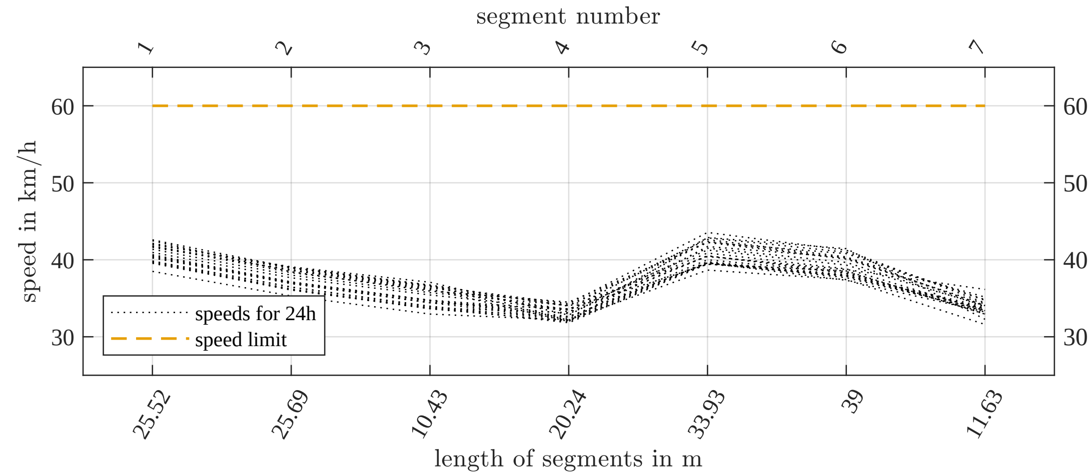


Figure 4.22: Distribution of driving speeds for the roundabout in the street Harjagersvägen compared to the speed limit for all 24 h and all segments.

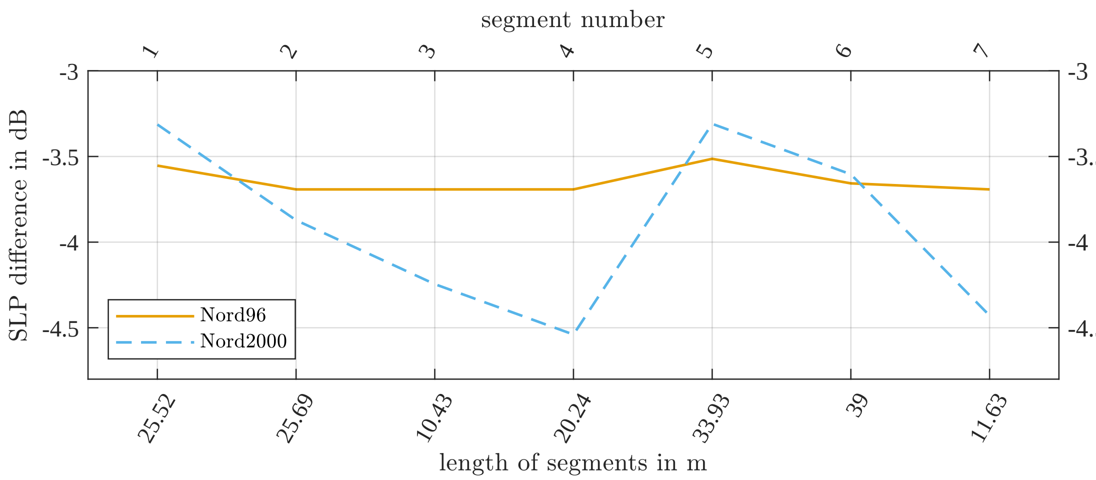


Figure 4.23: Difference in SPL for the roundabout in the street Harjagersvägen for all segments calculated for 24 hours with both models.

4.4 Facade SPLs

The calculation of equivalent SPLs at the surface of the facades of the buildings in the Kävlinge area, using the Nord96 model, were conducted for the signposted and GPS acquired speeds. Fig. 4.24 shows the percentage of SPL difference in the range of -0.5 dB to 0.5 dB and in the range -1 dB to 1 dB for each floor. The lowest percentage for the range of -0.5 dB to 0.5 dB is for the ground floor (GF) with 40 %. The same stands for the range of -1 dB to 1 dB with 70 %. The floor 7 and 8 are showing no difference between the signposted ad real speeds. It is important to notice that the biggest percentage of the data point belongs to the ground floors (70 %) and very low for the floors 4 to 8, which render those unreliable. The small percentage of data points that show difference bigger than 1 dB or smaller than -1 dB can be attributed to the calculation mistakes, or distance to the source.

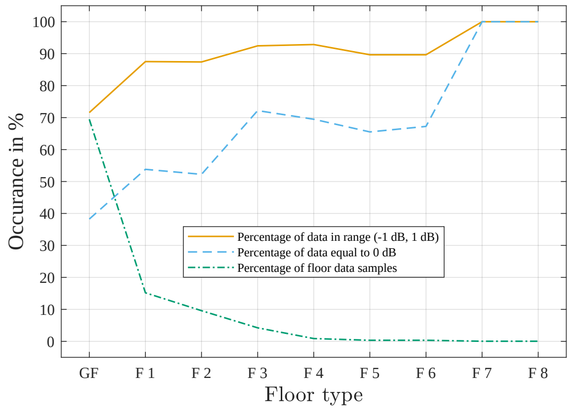


Figure 4.24: Percentage of 0 dB SPL difference for each floor from.

5
Conclusion

The effect on the equivalent sound pressure levels of using the GPS acquired speeds instead of the signposted speeds for the purpose of noise mapping has been investigated. The initial aim for this project was to determine if the difference in SPL can be somehow quantified in the form of a penalty that can be applied to the current method of calculation (using the signposted speeds). This could not be clearly defined.

The results show that there are differences of +3 dB and -6 dB when investigating specific locations in the street network, which is a significant result and can be noticed by human ears. This shows that GPS data does provide better accuracy and can help in determination of what kinds of measures, if any, should be implemented to mitigate the traffic noise. On the other hand, the average difference in equivalent SPLs calculated for each road class and speed limit shows results in the range of -1.4 dB to 0 dB, with majority being in the range of -0.2 dB to -0.8 dB. This shows that a penalty could not be defined with only parameters for classification being the speed limit and road class of the street. Additional parameters should be of the spatial and functional nature, identifying roundabouts, crossings, segments of the streets leading to the roundabouts and crossings and other obstacles like speed bumps which have an influence on the vehicle speed.

Another matter that should be taken into account for the purpose of producing more exact noise maps is the calculation model used. The limitation of the currently used calculation model, Nord96, is the undefined case for the speeds lower than 30 km/h as well as low precision for the speeds lower than 40 km/h. The best solution for improvement of the accuracy of the noise maps would be the introduction of the more detailed calculation model like Nord2000. The higher sensitivity of the Nord2000 model to speed differences provides the means for showing the impact of GPS acquired speeds on equivalent SPLs, which has been shown in this investigation.

Additional problem that needs to be addressed is the variety of speed limits that each road class has. The expectation of certain speed behaviour is not fulfilled for all speed limits and road classes and for some are drastically different. This brings the question: should the penalty for such cases be introduced or if the speed limit should be corrected to fit the speed behaviour? In the case of the GPS acquired speeds being lower than the signposted, it should be sufficient to lower the speed limit in order to match the vehicle behaviour. In the opposite case, the possibility of penalty should be further investigated.

6
Future work

At the beginning of this project, there were already initial limitations because of the lack of data. The data that could not be included in the analysis is: acceleration/deceleration hourly data for each vehicle and identification of different categories of vehicles for the speeds provided. By including this, investigation in this report could be improved and more detailed results could be provided.

In the future work, the exact frequency content of different vehicle categories could be investigated. As it was presented in Section 2.1.1, the frequency content of light and heavy vehicles changes with the change of speed, with lower frequencies having more power for lower speeds. In the setting of the city, this would present a disturbance. The acoustical energy of speech is in the frequency range of 100 Hz to 6000 Hz, while the most important cue-bearing energy is in the range of 300 Hz to 3000 Hz.[1] The heavy vehicles would contribute in the process of masking signals in these frequency ranges causing speech interference, but also masking other important signals like door bells, alarm clocks, fire alarms, etc.[1] This shows the importance of the frequency content investigation.

As it was concluded in Section 5, spatial and functional identification of street segments and obstacles in the street network is of importance for the further investigation. A more detailed study could be done, including these as parameters for determination of penalty of SPLs. Gathering more data points for the different spatial formations (roundabouts, crossroads, street segments leading to crossroads and roundabouts, curved and/or steep roads, speed bumps,etc.) in the street network and seeing if there is any pattern in SPL difference can be done in the future. This is where including the information about acceleration/deceleration for different street network segments can be helpful, since these spatial formations influence the change in speed. For determination of SPL penalty, calculation of maximum SPLs could also be done.

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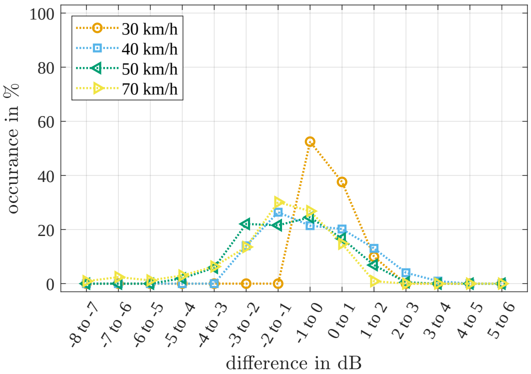
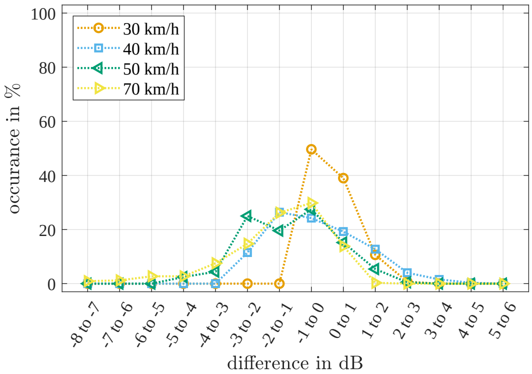
A

Appendix 1

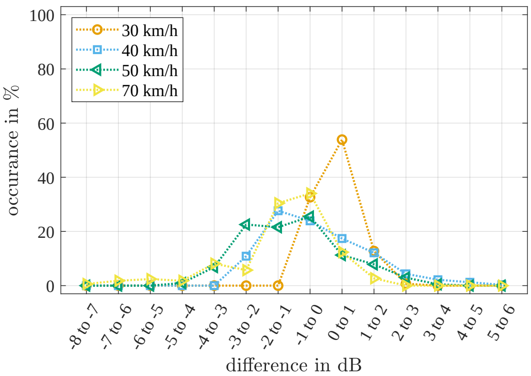
A.0.1 Difference of equivalent sound pressure levels for road class 6 and 7 calculated with the Nord200 calculation model



(a)

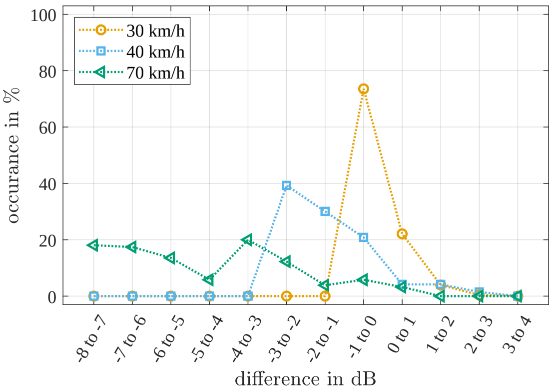


(b)

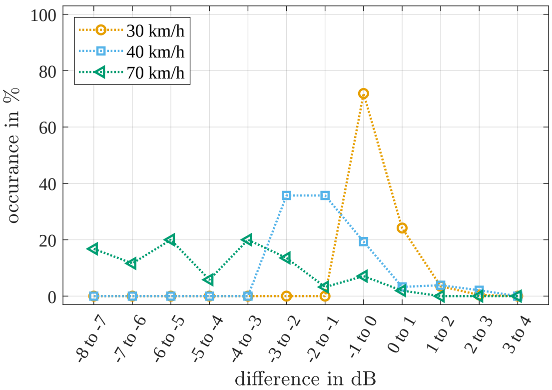


(c)

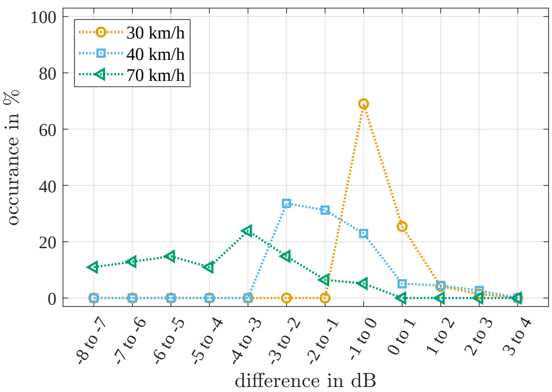
Figure A.1: Percentage of SPL difference for streets with the road class 6 for representative speed limits for day (a), evening (b) and night hours (c) calculated with the Nord 2000 model.



(a)



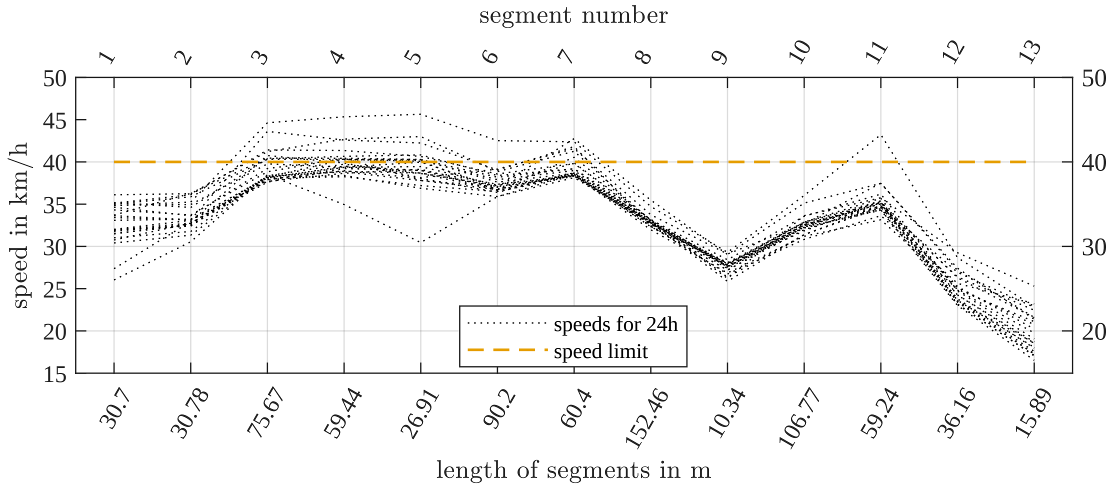
(b)



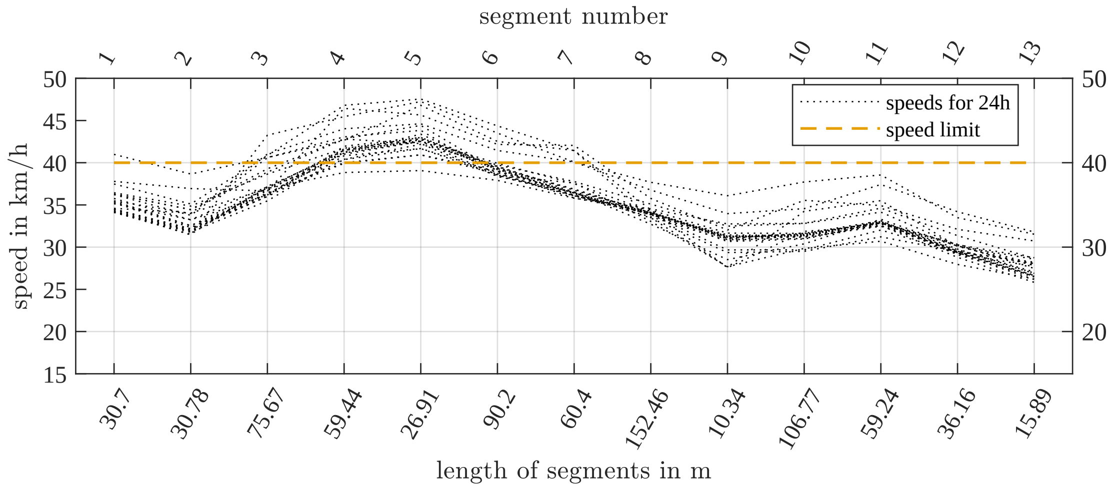
(c)

Figure A.2: Percentage of SPL difference for streets with the road class 7 for representative speed limits for day (a), evening (b) and night hours (c) calculated with the Nord 2000 model.

A.0.2 Analysis of the street Västra Långgatan

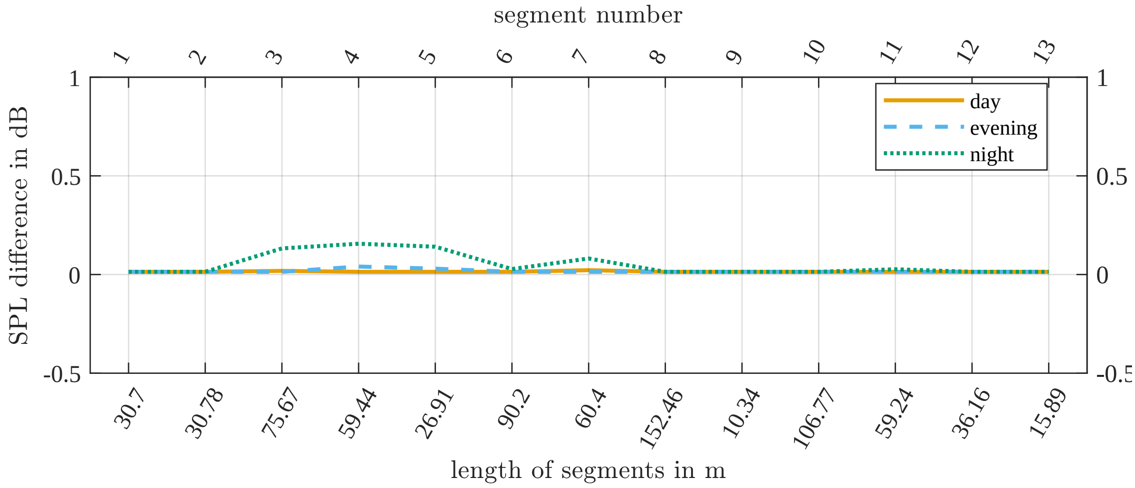


(a) Direction 1

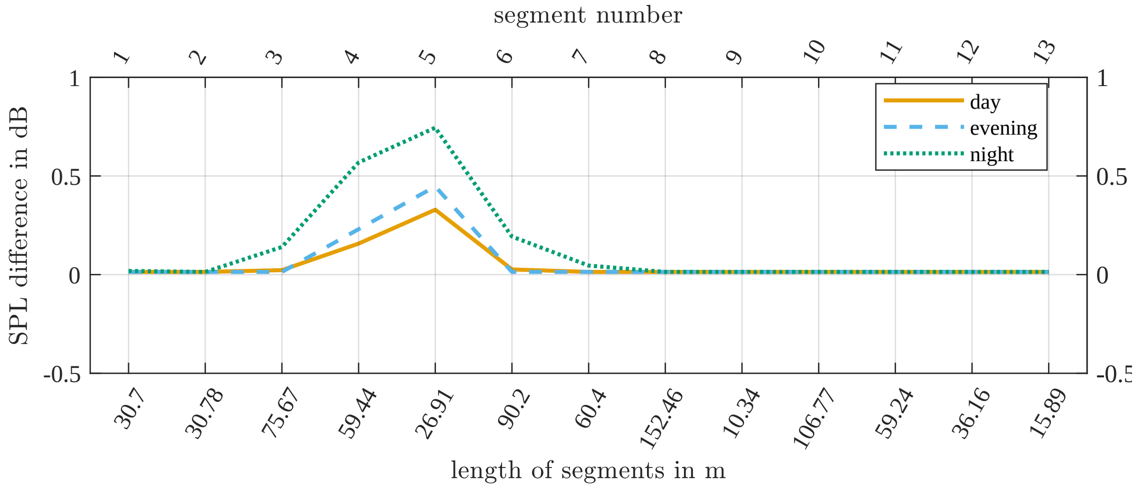


(b) Direction 2

Figure A.3: Distribution of driving speeds for the street Västra Långgatan compared to the speed limit for all 24 h and all street segments.



(a) Direction 1



(b) Direction 2

Figure A.4: Difference of SPL for the street Västra Långgatan for all street segments calculated for day, evening and night hours.

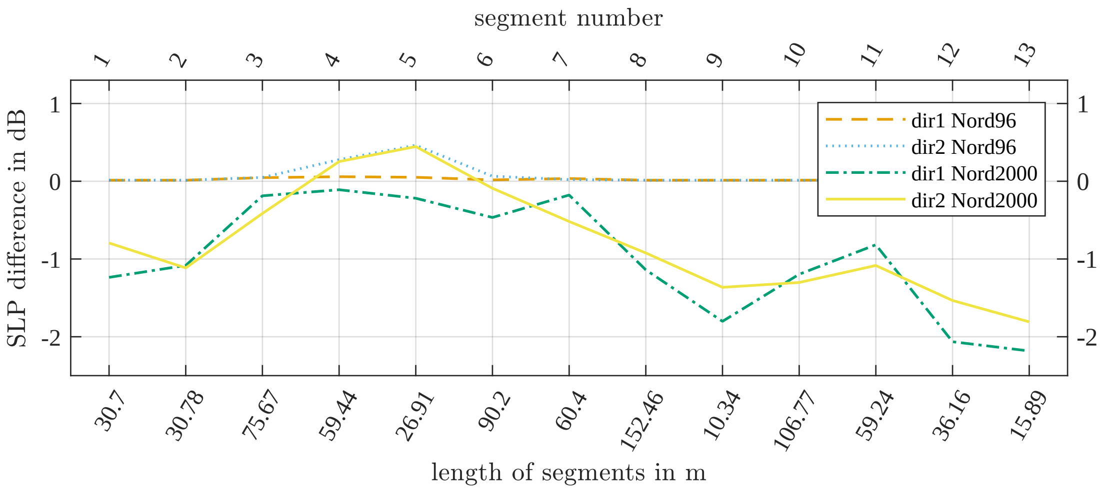
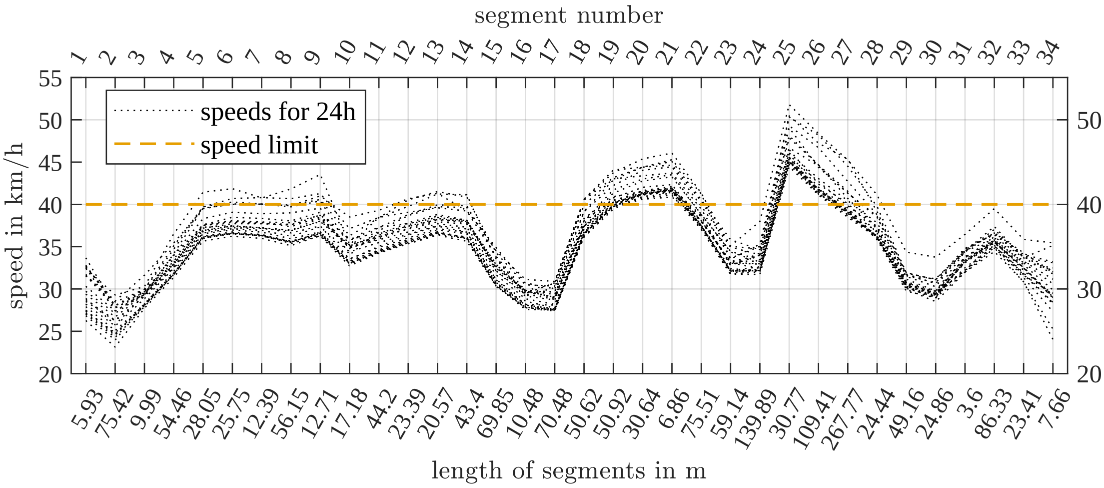
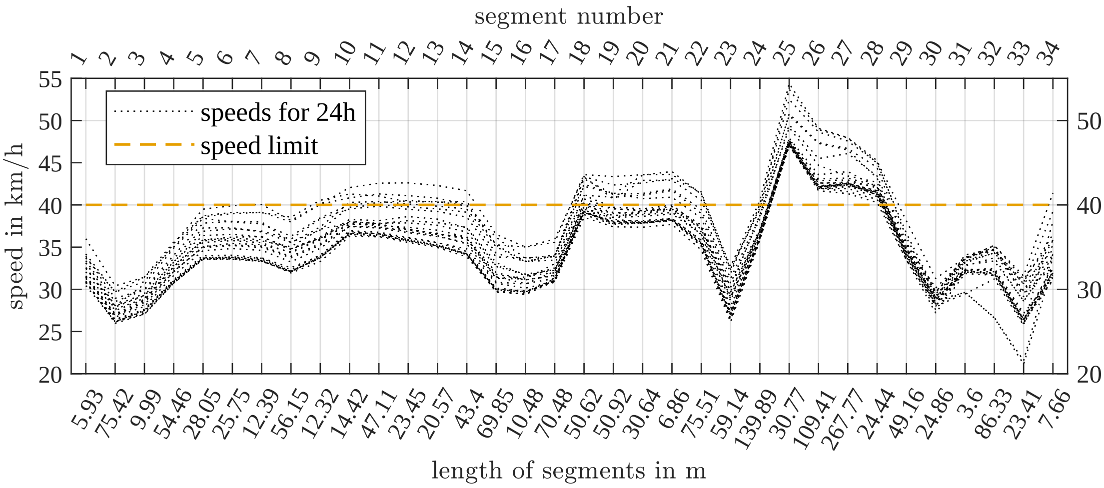


Figure A.5: Difference of SPL for the street Västra Långgatan for all street segments calculated for 24 hours with both models and for both directions.

A.0.3 Analysis of the street Kvarngatan

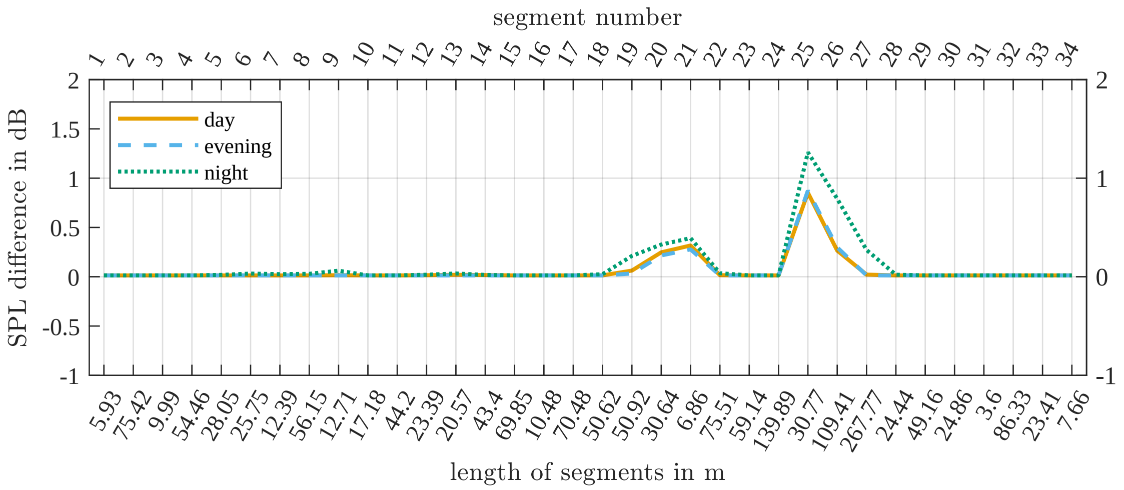


(a) Direction 1

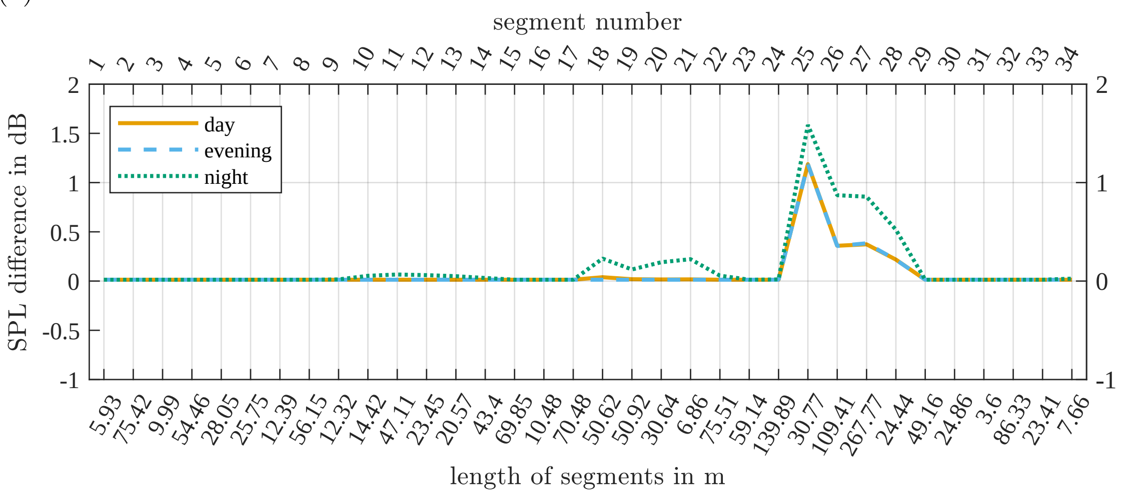


(b) Direction 2

Figure A.6: Distribution of driving speeds for the street Kvarngatan compared to the speed limit for all 24 h and all street segments.



(a) Direction 1



(b) Direction 2

Figure A.7: Difference of SPL for the street Kvarngatan for all street segments calculated for day, evening and night hours.

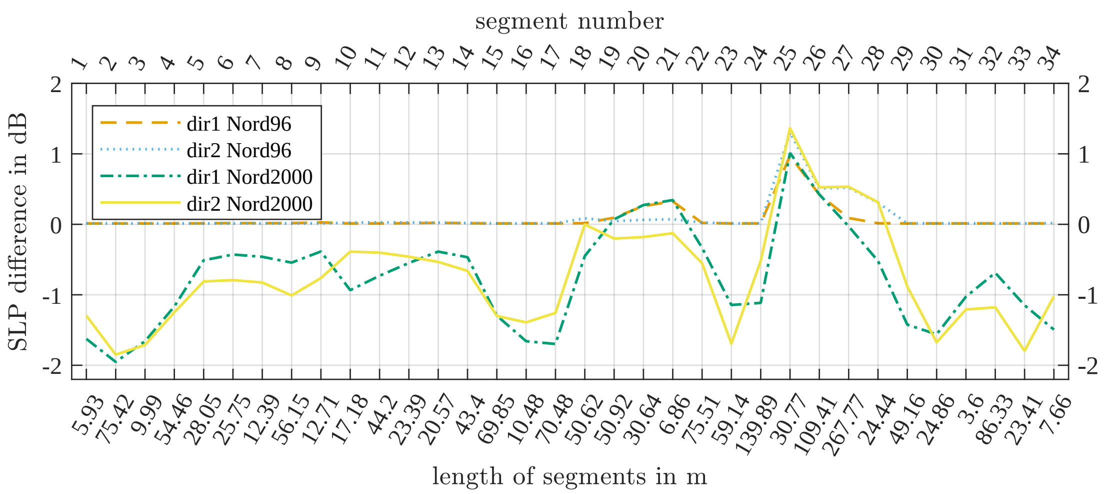


Figure A.8: Difference of SPL for the street Kvarngatan for all street segments calculated for 24 hours with both models and for both directions.

B

Appendix 2

Table B.1: Coefficients for sound power determination according to the Nord2000 calculation model.[3]

f	Rolling						Propulsion					
	cat 1		cat 2		cat 3		cat 1		cat 2		cat 3	
	a_R	b_R	a_R	b_R	a_R	b_R	a_P	b_P	a_P	b_P	a_P	b_P
25	69,9	33	76,5	33,0	79,5	33,0	89,8	2	97	0	97,7	0
31,5	69,9	33	76,5	33,0	79,5	33,0	91,6	2	97,7	0	97,3	0
40	69,9	33	76,5	33,0	79,5	33,0	91,5	0	98,5	0	98,2	0
50	74,9	30	78,5	30,0	81,5	30,0	92,5	0	98,5	0	103,3	0
63	74,9	30	79,5	30,0	82,5	30,0	96,6	2	101,5	0	107,9	0
80	74,9	30	79,5	30,0	82,5	30,0	94,2	2	101,4	0	105,4	0
100	79,3	41	82,5	41,0	85,5	41,0	92	4	97	0	101	0
125	82,5	41,2	84,3	41,2	87,3	41,2	87,4	2	96,5	0	101	0
160	81,3	42,3	84,3	42,3	87,3	42,3	86,1	2	95,2	0	101,3	0
200	80,9	41,8	84,3	41,8	87,3	41,8	86,1	6	99,6	0	101,3	0
250	78,9	38,6	87,4	38,6	90,4	38,6	87,2	8,2	100,7	8,5	102,5	8,5
315	78,8	35,5	88,2	35,5	91,2	35,5	86,5	8,2	101	8,5	103	8,5
400	80,5	31,7	92	31,7	95,0	31,7	85,6	8,2	98,3	8,5	102	8,5
500	87,0	25,9	94,1	25,9	97,1	25,9	80,6	8,2	94,2	8,5	101,4	8,5
630	88,7	26,5	96,5	26,5	99,5	26,5	80,7	8,2	92,4	8,5	99,4	8,5
800	90,8	32,5	96,8	32,5	99,8	32,5	78,8	8,2	93,4	12,5	95,1	8,5
1000	93,3	37,7	95,6	37,7	98,6	37,7	79,3	8,2	95,5	12,5	95,8	8,5
1250	92,5	41,4	93	41,4	96,0	41,4	82,4	8,2	96	12,5	95,3	8,5
1600	92,8	41,6	93,9	41,6	96,9	41,6	83,7	8,2	93,8	12,5	92,2	8,5
2000	90,4	42,3	91,5	42,3	94,5	42,3	83,4	9,5	93,4	12,5	93,2	8,5
2500	88,4	38,9	88,1	38,9	91,1	38,9	81,3	9,5	92,1	12,5	90,7	8,5
3150	85,6	39,5	86,1	39,5	89,1	39,5	81,8	9,5	90,1	12,5	88,8	8,5
4000	82,7	39,6	84,2	39,6	87,2	39,6	79,9	9,5	87,9	12,5	87,5	8,5
5000	79,7	39,8	80,3	39,8	83,3	39,8	77,9	9,5	85,6	12,5	85,9	8,5
6300	75,6	40,2	77,3	40,2	80,3	40,2	75,1	9,5	85,7	8,5	86,9	8,5
8000	72,0	40,8	77,3	40,8	80,3	40,8	73,1	9,5	82,6	8,5	83,8	8,5
10000	67,5	41,0	77,3	41,0	80,3	41,0	69,5	9,5	79,5	8,5	80,3	8,5

DEPARTMENT OF APPLIED ACOUSTICS
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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