ROAD TRAFFIC NOISE: GIS TOOLS FOR NOISE MAPPING AND A CASE STUDY FOR SKÅNE REGION

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ABSTRACT:

Traffic noise pollution is a growing problem that highly affects the health of people. To cope with this problem one has to regulate traffic or construct noise barriers. In order to implement effective measures against traffic noise the information about its distribution – noise maps - is imperative. This paper presents our work in creating a noise calculator software package implementation that can create noise maps. The noise calculator is based on the noise model described in Nordic prediction method for road traffic noise.
As a case study, the noise calculator was used to build both large noise maps for Skåne region in south of Sweden and detailed noise maps for smaller areas in the city of Lund.

1. INTRODUCTION

Traffic noise is often perceived as one of the biggest environmental problem. Many studies illustrate a link between exposure to noise and negative effects on public health. Noise may severely impair quality of life (disrupt sleep, interfere with speech intelligibility), or possibly giving rise to both social and psychological problems [8]. Such type of disturbances can also create risk of cardiovascular conditions [9].

Knowledge about noise levels on roads is necessary in order to develop and plan remedial actions. Calculators for noise traffic levels exist but they are commercial (cost aspect) or they cannot calculate noise maps for large regions. In this paper we presented our noise mapping tools and their application on a case study for the Skåne region in southern Sweden.

There are several dedicated commercial software packages available to calculate noise maps such as SoundPlan [3], etc, but these are expensive and not very flexible. Such tools usually, also have limitations i.e., just a small region of the city can be calculated by SoundPlan. LimA [4] is a commercial GIS noise simulator based on ArcMap similar to the one presented in this paper. The Municipality and the region wanted to explore how it was possible to implement the functions and algorithms for noise diffusion with full control of the system and its parameters in a standard GIS environment where most of the necessary data were already available.

The tools in this paper are based on the Nordic Prediction Method published by the Nordic Council of Ministers [1]. This method is valid up to 300m along the normal to the road in neutral or moderate (0-3 m/s) downwind and moderate temperature.

The noise prediction model calculates L_{Aeq} (level of noise) in decibels (dB). The L_{Aeq} is calculated over a period of time (normally 24 hours). The following input parameters are required for the calculation (after the parameters we also give the correction in which they are used):

- traffic flow for light and heavy vehicles (L_1);
- real speed;
- distance to road centre line (from the receiver point) (ΔL_2);
- height of road surface relative to the surrounding ground;
- position and height of barriers (ΔL_3);
- thickness of barriers (ΔL_4);
- location of the receiver relative to the surrounding ground surface, road surface or barriers (ΔL_4);
- location of the receiver relative to reflecting vertical surfaces (ΔL_5);
- type of ground i.e. soft and hard (ΔL_3).

According to the Nordic Prediction Method the L_{Aeq} is calculated in several steps for each road or section of the road: $L_{Aeq} = L_1 + \Delta L_2 + \Delta L_3 + \Delta L_4 + \Delta L_5$. After the calculation of L_{Aeq} for each section of the road, these values are integrated to calculate the entire contribution:

$$L_{Aeq} = 10\lg(\sum_{i=1}^{n} 10^{L_{Aeqi}/10})$$

For more information about the Nordic Prediction Method please consult [1] or [2].

The tools described in this paper are developed as an extension to ArcMap GIS package. The noise calculations were performed on a personal notebook (2Ghz AMD, 2GB RAM) which is the minimum hardware requirement for the noise tools.

1.1 ArcGIS Desktop

ArcGIS Desktop [6] (Figure 1) is a state-of-the art GIS software package developed by ESRI. The software can be used in a wide area of general as well as specific GIS applications and can be extended easily via its Application Interface (API). The API gives fine grain access to data stored as well in general data base formats as topologically indexed vector data in the industry standard "shape" format as well as different GRID and geo-referenced raster formats.

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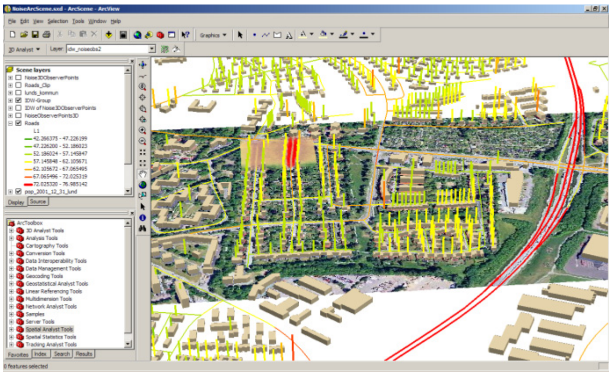


Figure 1. ArcMap and ArcScene - a GIS tool for 2D/3D

The software further has all necessary functionality to manage the different data formats and geographical datum and adjust them into suitable components in applications and models. Noise prediction models rely heavily on geometry calculations and without such fine grain access to the geometries of objects involved (roads, buildings, population, etc) it would have been impossible to accurately model noise levels.

2. THE NOISE MAPPING TOOLS

The noise prediction method was implemented as one of several extensions of ArcGIS Desktop. The implementation has been coded in Visual Basic and uses the ArcGIS Desktop API for data query and manipulation.

2.1 The Input data

Lund University and the Region of Skåne provided the GIS data, including road maps, vehicles count, population, buildings, etc. As data was not originally captured for use in GIS they were to some extent incomplete and contained some inaccuracies which we will describe in this section.

2.1.1 The Roads shape

A variety of shape files containing road data was provided. They contain all type of roads, highways and city roads but not private roads. The provided data about the speed limits for roads was just partial. Because of this, the first step was to integrate the available road data to obtain the missing speed limits.

For noise calculation, according to the noise prediction method, some calculations should be carried out using the real speed, not the speed limit. In this paper the speed limits are used.

2.1.2 The Buildings shape

Buildings outlines were provided on a single map. The map with buildings covers just the Lund Municipality (Kommun). The map contains the shape of the building and its location. Because the height is an important factor in noise calculation (but our available building data did not contain the height) we had to estimate it for each building depending on the building area and the number of persons living in the building.
For the buildings where the number of persons is unknown the supposition was that the given height is 9m. This height was chosen because most of buildings in Sweden do not exceed 2 floors (besides ground floor), and each floor standard it is under 3m high. If the data about buildings height can be provided in the future (this data is often available in municipal GIS databases), it will be an easy process to adjust the calculation; just by introducing the actual height in the table associated with the building and the new calculation can be carried out. In this way it is also possible to simulate the noise aspect of tearing down or building a new house in the city planning process.

Where the population information for a building was available we assumed there are 2 rooms per inhabitant and the average living area per person is almost 47 m² in order to calculate the height of the building (see section 2.2.1 and [7]).

2.1.3 The Population shape

The population data is a sensitive subject because of the privacy issues involved. In the noise calculation, only the location of the population is used. In Sweden, the location of population is managed by the city departments according both building location but also in specific key code statistical areas related to blocks. Due to inaccurate position the number of residents for some of the buildings was unknown. Because incomplete building data it was not possible to link population data to the building - a problem which arise in regard of data quality on overlapping maps. If more data on buildings (and number of persons) would be available it would give further possibilities for detailed calculations of possible noise disturbance risks.

2.2 Data quality

In this section we describe the necessity being aware of the needs for resolution, completeness and quality in data while introducing more detailed planning and simulation tools in the city planning and management. All such problems must be considered when one starts an integrated GIS project.

In GIS we also have to consider the problems with maps in different scale, with different geographic datum or with different generalisation. Example on this is Figure 3 where road maps are collected with less spatial accuracy and not suitable for analysis together with the buildings that are digitized with higher resolution. Another challenge arose in the point of harmonisation of roads (some were missing) and the population database which had a different (lower) resolution.

The missing road data were easy to acquire because there are a multitude of existing online maps for roads in Sweden.
The problem regarding population location was resolved by assigning the population located outside buildings to the nearest building.

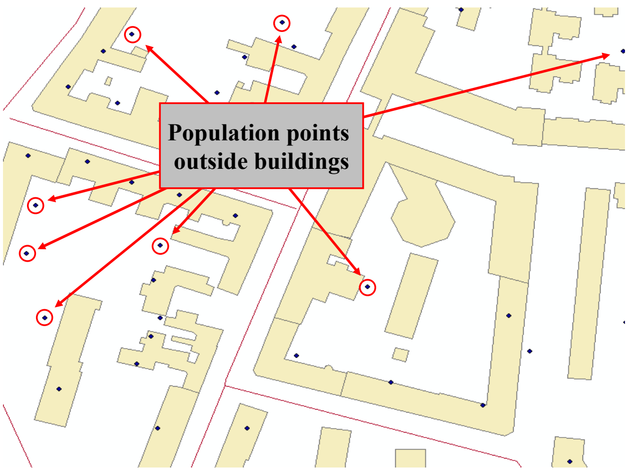


Figure 2. Data quality issues for population

In the case of roads intersecting buildings the problem was solved during the calculation, when the program checks the distance from the roads to the building. In the case of intersection, the distance is considered 2 m.

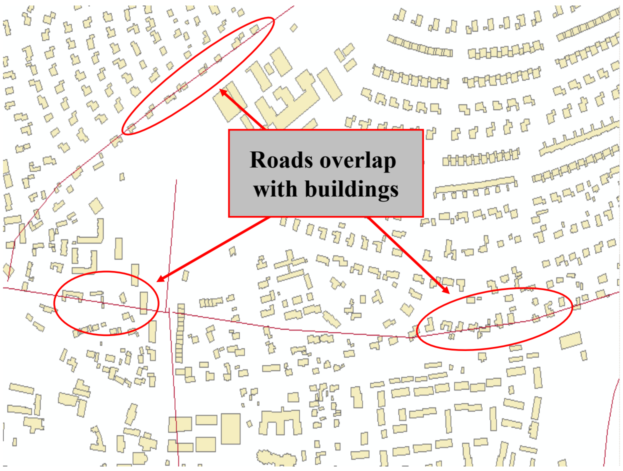


Figure 3. Data quality issues for buildings

The figures above show some examples of problems regarding data quality that had to be handled during the project.

2.2.1 Assumptions for the missing information (data)

Because the noise calculation needs more data than we received, we made the following assumptions during the calculation:

Building heights data – was calculated from building area and population count using this formula (of course if the building heights are provided, this formula is not needed):If the population in the building is unknown then consider the building height equal to 9m, else the height is ((number_of_residents * 47m^2) / building_area)*3m.
We assume here that a person has 47m^2 (including corridors, etc) for living. We multiply the area for living with the number of persons in the building and divide it by the building area to find out the number of floors. The number of floors is then multiplied by 3m to find the height of the building.

Road traffic flow – on some roads there was no information about the number of vehicles for a 24 hour period. We estimated the number of vehicles for these roads by averaging the number of vehicles for the roads where this number is available filtered by the same specific speed.

Terrain elevation and road gradients were ignored as the corrections due to these are small. The terrain and the roads are considered to be flat.

Ground type data – approximated from road speed using this formula:

- For roads with speed limit 50km/h we consider hard ground from the road to the buildings and soft ground after the building
- For roads with speed limit >= 70km/h we consider soft ground from the road to the building and after the building.

2.3 The Development of Noise Mapping Tools

In this section we present the tools we developed in this project. Because of the complexity of noise calculation and the time required to perform them, the tools were constructed to be applicable for specific analyses.

The tools we developed are general and they can be applied to entire regions if run on a computer with a fast CPU. Tools are presented in the order of their complexity and their inputs and outputs are graphically explained. The results obtained by the tools are presented and explained in the case study section.

2.3.1 Tool 1 – Noise Calculation for Roads

Tool 1 calculates **basic noise level** levels for roads, easiest and the fastest tool we implemented. This is straightforward:

1. for each road segment calculate L_{Aeq} as a function of speed and the number of heavy and light vehicles
2. save the L_{Aeq} in the Roads table as field L_1

Because we only had available data for the number of light/heavy vehicles over 24h, we needed to develop a method for approximation of these data for the other roads. We applied the following approximation:

1. Calculate the basic noise levels for the roads that have data
2. Calculate the average basic noise level for the speed classes (30, 50, 70, 90, 110 km/h) from the step 1.
3. Apply the average to the rest of the roads for which we do not have light/heavy vehicle numbers over 24h data. We do have the speed limits for all the roads

After the tool is applied for displaying the results, one can convert the Road shape vector file into a raster map according to the noise level L_1.

2.3.2 Tool 2 – Noise Calculation for Roads and Buildings

This tool calculates: **Distance correction.** In the second tool we considered the position of the buildings and their distance from the roads. The tool then applies the formula for noise attenuation with distance to find the noise level at the building positions. The buildings are considered to be points in this case. The calculated noise level is saved in a new table as a NoiseLevel field, together with the id of the corresponding building. Tool steps:

1. for each road segment and each building position, calculate the distance between them
2. if the distance is less than 300 m apply the distance correction
3. save the result noise level in the BuildingNoise.dbf table

To display the results one has to join the buildings shape with the BuildingNoise table and generate a raster according to NoiseLevel. The raster can be merged with the roads raster to display them together.

2.3.3 Tool 3 – Noise Calculation at generated receiver points

This tool calculates the **noise level with all the corrections** that we could apply with the provided data:

- Distance correction
- Angle of view correction
- Screen and screen ground correction
- Thick barrier correction
- Integration of noise levels from multiple road segments

The calculations performed with this tool are very heavy. Starting from the map view extend, this tool generates receiver points (the x and y coordinate where the noise level is calculated) as show in Figure 4 at configurable distance from one another on X (stepX=2m) and Y (stepY=2m). The receiver height is also configurable. For efficiency, the receiver points are generated only if they are outside buildings and within 300m from any existing road in the map view extend. For each point the tool performs the following steps:

1. select the next road segment
2. construct the angle of view triangle given by the point and the road segment
3. if the angle of view triangle contains any buildings (obstruction) break the road segment into 2 classes: a) Obstructed segments and b) Unobstructed segments.
3. for unobstructed segments compute the noise level with the distance correction and the angle of view correction (Figure 5)
4. for each obstructed segment calculate the new angle of view and construct the angle of view bisector (Figure 6)
5. intersect the angle of view bisector with the buildings exiting on the its path and construct points at the intersection
6. fetch each building height from the building table and construct the thick barrier
7. apply the distance correction, the thick barrier correction the screen correction, the screen ground correction and the angle of view correction to the basic noise level.
8. integrate all the resulted noise levels for obstructed and unobstructed segments into the final noise level for that road segment.
9. save the noise level together with the receiver point in NoiseReceiverPoints shape.
10. generate the next receiver point and go to step 1.

Some of the steps performed by the tool are presented below.

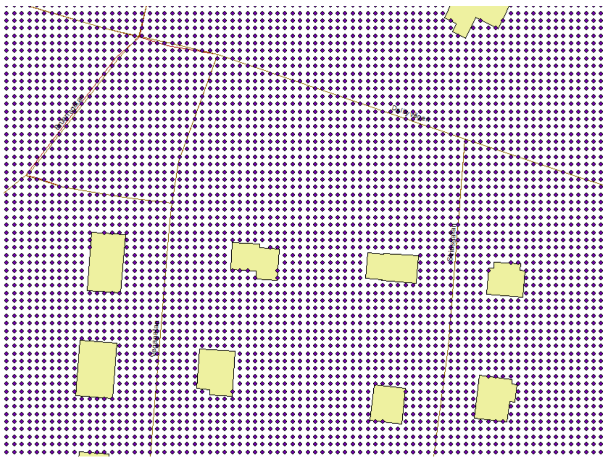


Figure 4. Generated receiver points each 2m (step) on X and Y

The tool displays messages in the ArcGIS console to let the user know how long the current execution is going to last. The execution can be interrupted at any time.

pt: 000435/4816.8: AvrgTimeOnePt:0.38sec,timeToEnd:00.4661h, x:1336726.3, y:6177580.8, L_Aeq:69.6

pt: 000436/4816.8: AvrgTimeOnePt:0.39sec, timeToEnd:00.4703h, x:1336728.3, y:6177580.8, L_Aeq:68.7

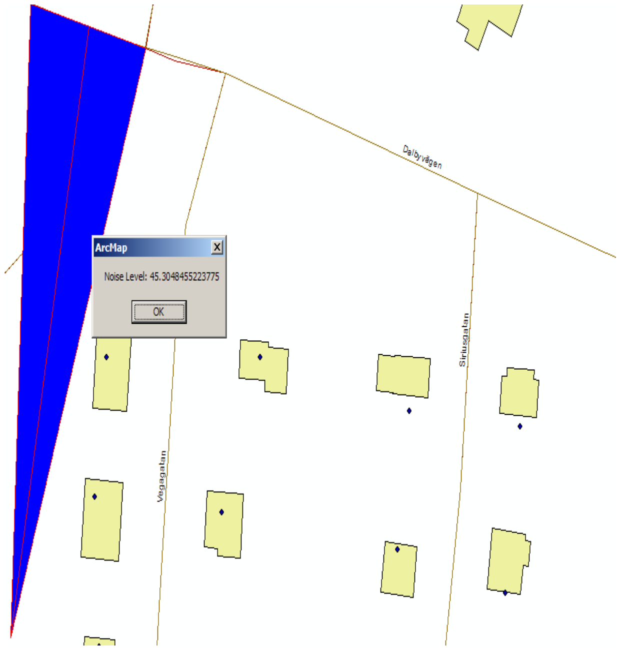


Figure 5. Unobstructed angle of view and its bisector

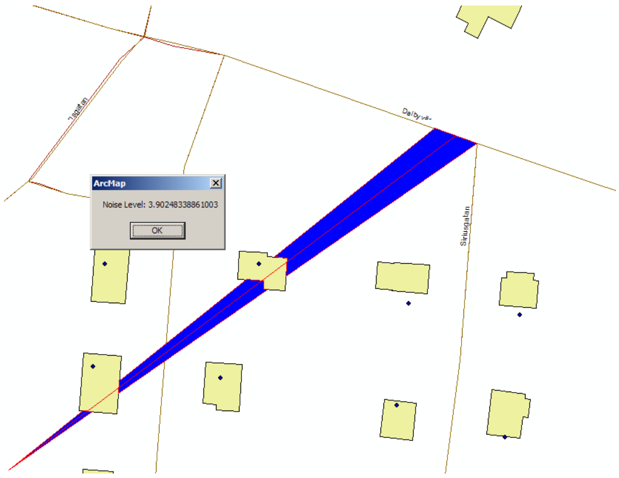


Figure 6. Obstructed angle of view and its bisector

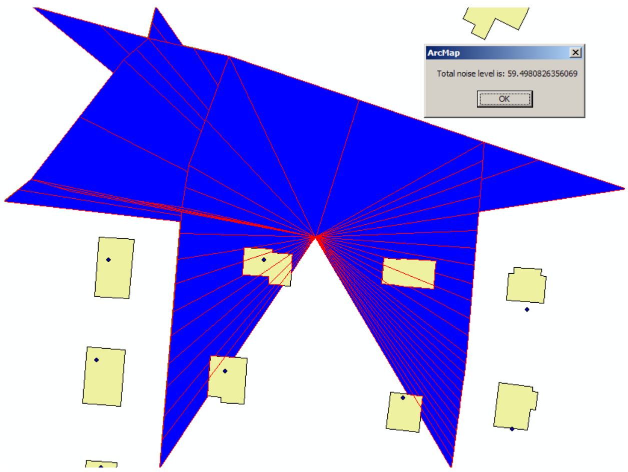


Figure 7. All angles of view for all roads segments

One way to display the results of the tool is to change the colors of the receiver points according to the noise level. (Figure 8)

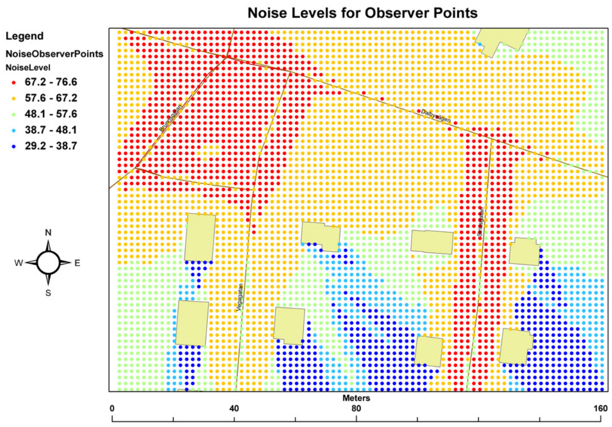


Figure 8. Receiver points coloured by noise level

A better way to display the results of the tool is to integrate the NoiseObserverPoints shape using interpolation (for example the IDW interpolation) and generate a raster (Figure 9).

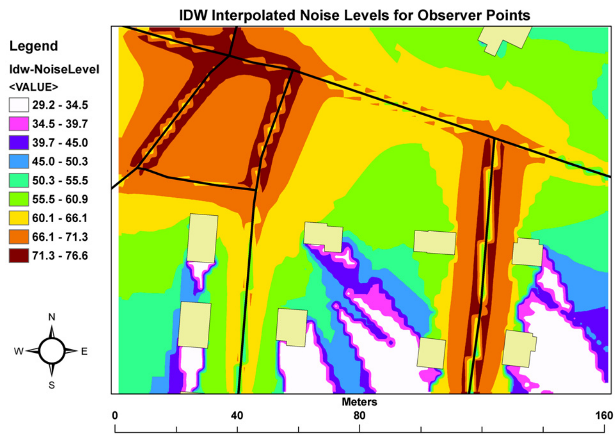


Figure 9. IDW Interpolated noise level for observer points

To calculate the noise for the 4800 receiver points (each 2m on X and Y) in the area it takes about 40 minutes. As one can see, there are a lot of calculations performed by this tool. The main time spent by the tool for one point is to calculate the intersection of the angle of view with the buildings for the application of the thick/thin barrier correction. On our notebook computer (2Ghz AMD and 2GB RAM) the calculation of the noise level for one point it takes between 0.30 to 2 seconds, heavily depending on the complexity of the geometrical sub-problem for calculation of thick/thin screen correction.

As a remark we can mention that this tool could be used to calculate noise levels in 3D by invoking it with various receiver heights. It is actually invoked from Tool 6 to calculate 3D noise levels.

2.3.4 Tool 4 – Noise calculation with population as receiver points

This tool performs the same calculations as Tool 3, but considers the population as receiver points (Figure 10 and Figure 11). There are additional steps to handle the fact that the population is inside the buildings and the angle of view bisector, when intersected with the buildings would generate more points than needed.

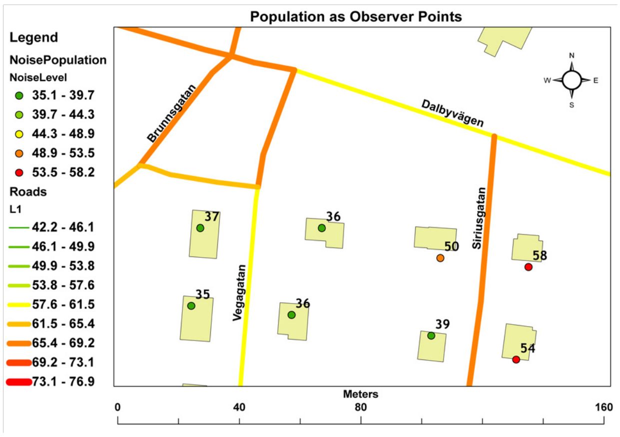


Figure 10. Noise levels on roads and on receiver points for existing population

Some of the population data is placed outside the buildings, and because of that those points are exposed to higher noise levels.

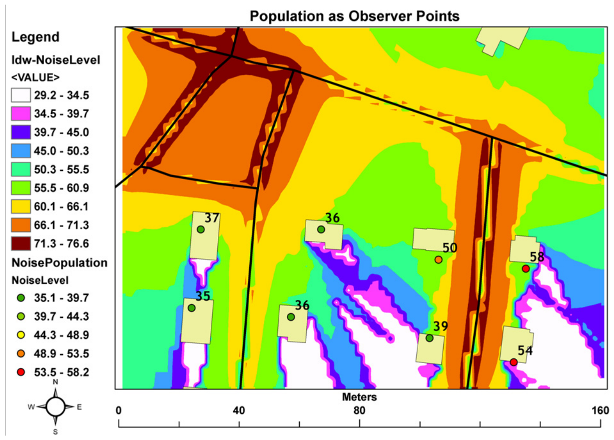


Figure 11. Noise map with buildings and population

2.3.5 Tool 5 – Noise calculation at building façades

Using this tool one can calculate the **noise level at the building facades**. The same calculations as in Tool 3 are performed. This tool buffer each building by a given distance, then generates observer points on each segment of the buffer polygon. The density of the generated observer points on each segment is configurable. Also, receiver points are not generated if they are contained by any other building.
The noise at building facades can be presented as in the following figure.

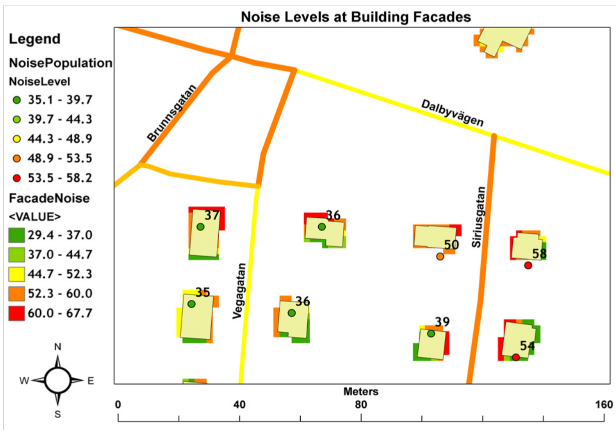


Figure 12. Noise Levels at Building Façade

2.3.6 Tool 6 – Noise calculation for different receiver heights

This tool calculates the noise in 3D. The user provides an interval for the receiver height and a stepZ to sample the interval. The tool then invokes Tool 3 with receiver height within the given interval and a shape Noise3DObserverPoints is generated, where besides the noise level, the height of the observer is saved (Figure 13).

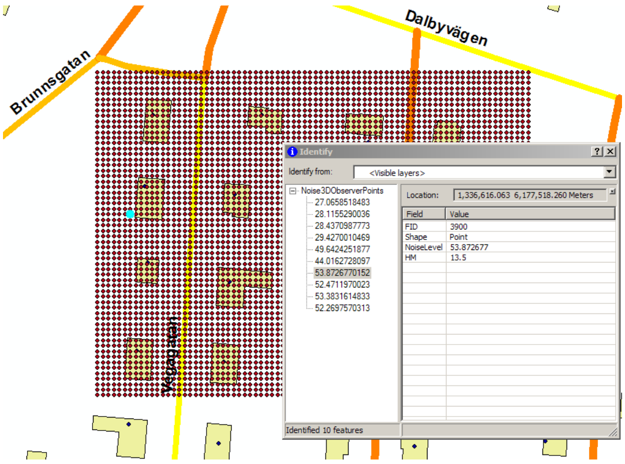


Figure 13. Noise level at different observer heights

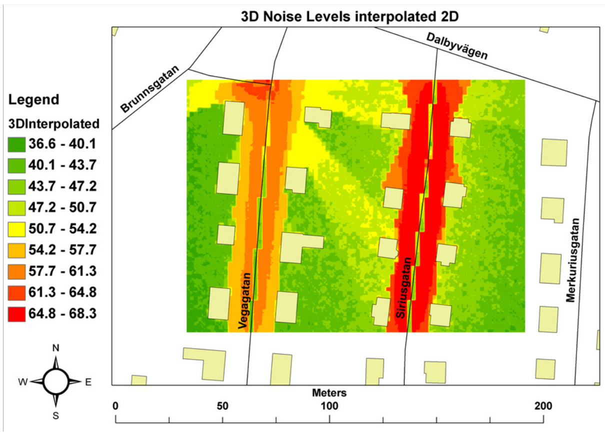


Figure 14. Calculated 3D noise levels projected in 2D

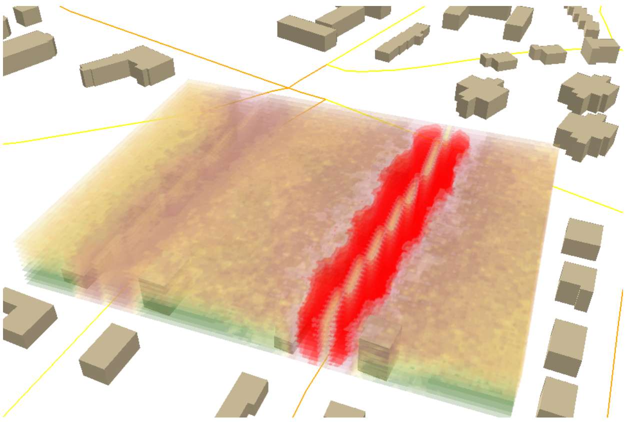


Figure 15. 3D Noise IDW interpolated at each height

The 3D noise levels cannot be directly displayed in ArcMap, which is only 2D, but they can be displayed very well in ArcScene. One way to display the 3D noise levels is to interpolate (project) them in 2D (Figure 14). In the case study section we will show other ways to display the 3D noise levels using ArcScene which is a 3D GIS component of ArcGIS.

Another way to display the 3D Noise Levels is to interpolate the noise at each height and then display the interpolated surfaces at their height using transparency. The result of such operation is displayed in Figure 15.

2.3.7 Tool 7 – Population exposure to noise

This tool gathers the results obtained by Tool 4 and generates a table with **population exposure to noise**. The classification of the population exposure to noise by sex, age and count within given dB(A) intervals can be obtained using SQL queries.

There are several ways to display such data. We imported the noise levels in an SQL database and wrote SQL queries to import the data in MS Excel. The queries to classify the population exposure to noise into noise level classes look like:

```
select count(*) from pop where NoiseLevel<30;
select count(*) from pop where NoiseLevel>=30
                         and NoiseLevel < 40;
select count(*) from pop where NoiseLevel>=40
                         and NoiseLevel < 50;
select count(*) from pop where NoiseLevel>=50
                         and NoiseLevel < 60;
select count(*) from pop where NoiseLevel>=60
                         and NoiseLevel < 70;
select count(*) from pop where NoiseLevel>=70
                         and NoiseLevel < 80;
```

Of course, one could write queries for classification of population with regards to age, sex, etc, which is what we did to obtain various result data. The result data is presented in the case study section.

2.4 Noise prediction

Noise prediction is supported by any of the presented tools as only the input shapes are modified adding additional possible barrier. One could generate the noise map before and after a barrier or road is added to the input shapes and then compare them to predict the future noise levels. Using map algebra the before noise raster could be subtracted from the after noise raster, given the exact impact of the planned constructions.

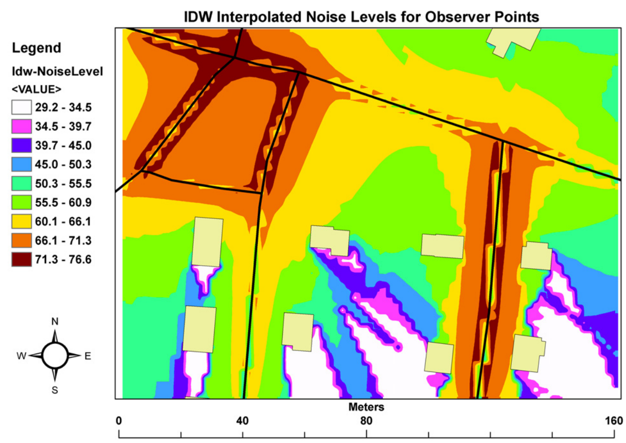


Figure 16. Noise levels before applying barrier

As an example, study the noise level given before (Figure 16) and after (Figure 17) the application of noise barriers to see the decrease in noise exposure.

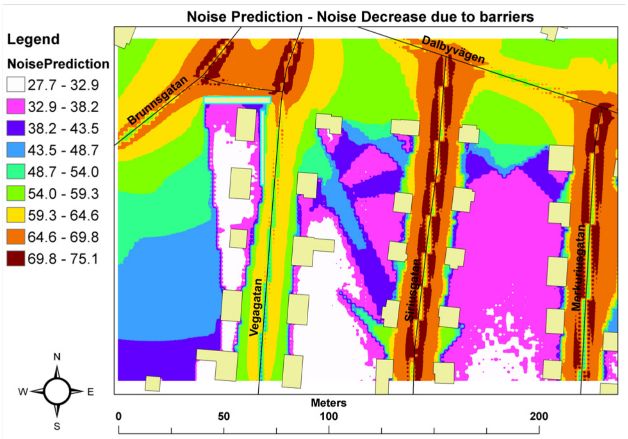


Figure 17. Noise levels after applying barrier

One can clearly see that before the application of noise barriers, the top left building has a sound pressure level of 66 dB(A). After the application of 2m high noise barriers (selected in the picture above), the noise levels were decreased to 43 dB(A).

3. CASE STUDY

In this section we present the results of applying our tools for a case study of the whole Skåne region. The results are presented, analyzed and explained. We show different views of calculated noise levels for roads, population, areas and so on. Our results are quite comparable with [11].

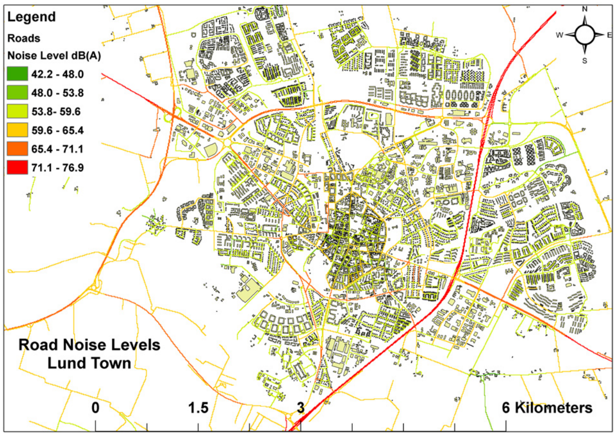


Figure 18. Basic noise level for roads in Lund City

3.1 Noise Maps

Lund is a compact town with narrow streets as one can see in Figure 18. The buildings usually are not very high which means that they are not a very effective barrier against traffic noise. The high noise levels are passing the first row of houses and are reaching the second row. Because the streets are mostly narrow in the city centre, sound barriers are hard to apply.

3.1.1 Noise levels on Roads

The results of Tool 1 are discussed in this section. The tool calculates the basic noise levels for each road section. We display basic noise levels for roads using different colours that classify intervals. The result for Skåne region is shown in Figure 19. The noise map for region Skåne shows the potential of the tools to calculate the noise for a big area. See also Figure 18 for a detailed visualization.

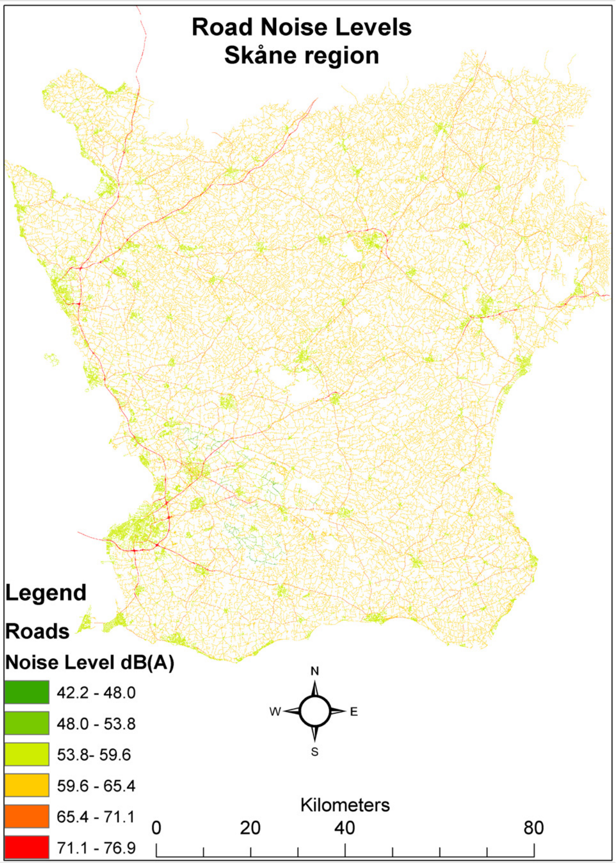


Figure 19. Basic noise levels for roads in Skåne

In the following we go to a smaller detail, to Lund Municipality. The basic noise levels calculated using the roads speed limits and volume traffic in the Lund Municipality is presented (Figure 20).

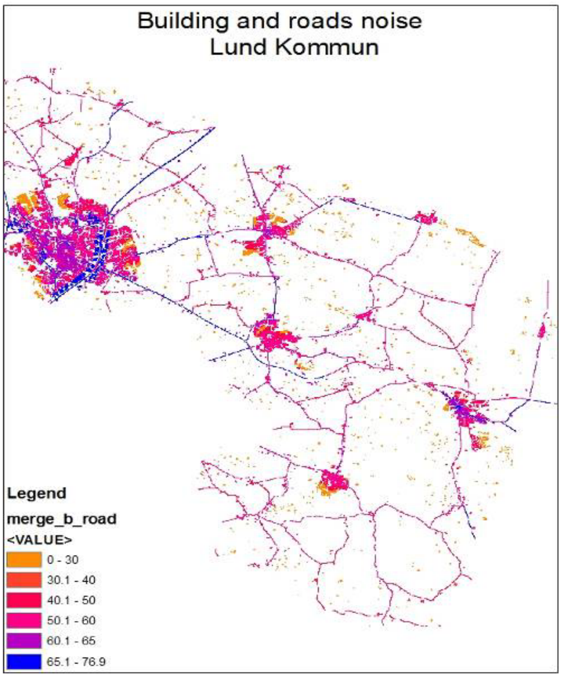


Figure 20. Noise levels for buildings and roads in Lund County

Another way to display the basic noise level for the Lund County is to display it in 3D Figure 21.

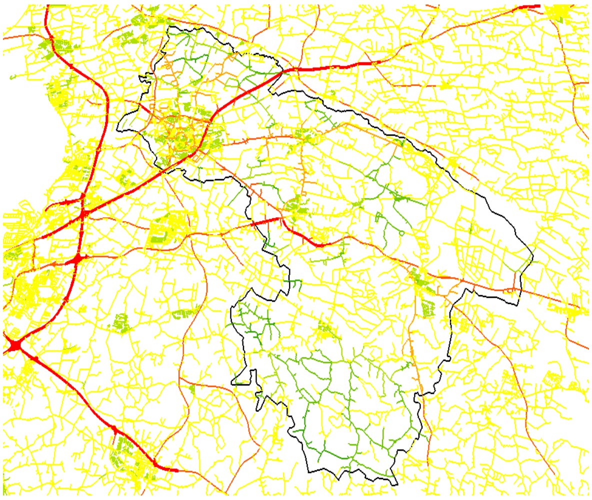


Figure 21. 3D view of basic noise level for Lund Municipality

One can go to even further detail, and display the basic noise level for roads in Lund City (Figure 18 and Figure 22).
With GIS software is easy to go to even more detailed zoom. The Lund City detailed zone is presented below. A fly picture (courtesy of Eniro) was projected on the Lund map to achieve a better view. Aligning a picture with GIS data is not easy, we needed about 30 steps of shifting, rotating and scaling of picture to be able to align it with our GIS data.

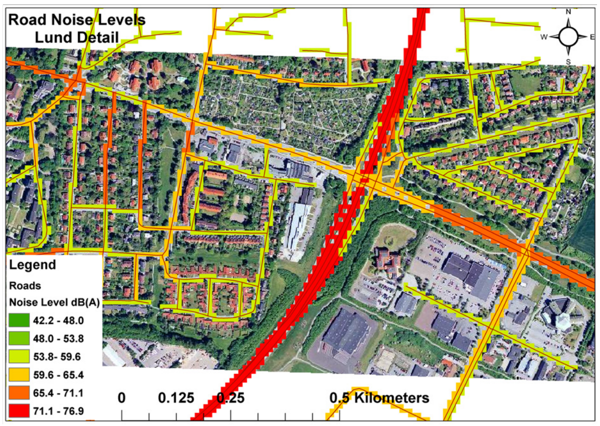
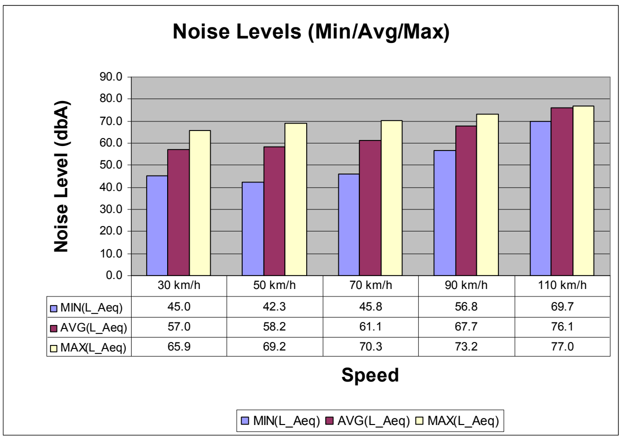


Figure 22. Detail of Basic noise level

The minimum, average and maximum of basic noise levels for the roads that have all the necessary data is presented below in Figure 23.



	30 km/h	50 km/h	70 km/h	90 km/h	110 km/h
MIN(L_Aeq)	45.0	42.3	45.8	56.8	69.7
AVG(L_Aeq)	57.0	58.2	61.1	67.7	76.1
MAX(L_Aeq)	65.9	69.2	70.3	73.2	77.0

Figure 23. Road Basic Noise Levels as a function of speed and light/heavy vehicles

3.1.2 Noise levels with population as receiver points

Tool 4 was applied to calculate the noise levels at the population location. We only had population data from 2002 for Lund Municipality, and because of that we cannot present the results for all Skåne.

Figure 24. 3D Detail View of Noise Levels for Lund Population

Figure 24 and Figure 25 and presents the 3D view of basic noise level for roads in a part of Lund City and also the noise level calculated at the population points. The noise at the population points is displayed on height proportional with the noise.

Figure 25. Details of noise level for roads and population

The reader can consult [2] for more information.

3.1.3 Noise levels for building facades

There are no general results for the building facades as this is a local noise analysis. In the figure below we present a detail of building façade noise calculation.

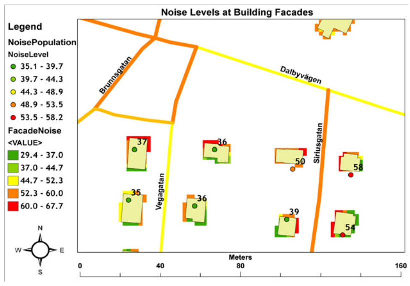


Figure 26. Detail of Noise Levels at Building Façades

3.1.4 Noise levels at different receiver heights

We applied Tool 6 for a local analysis of noise levels. The results we obtained are presented below using various displaying modes.

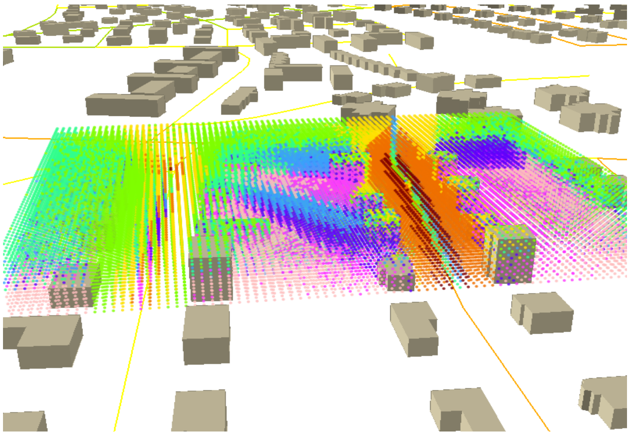


Figure 27. Observer each 2x2x2 - 160mX116mX20m - 20% transparency

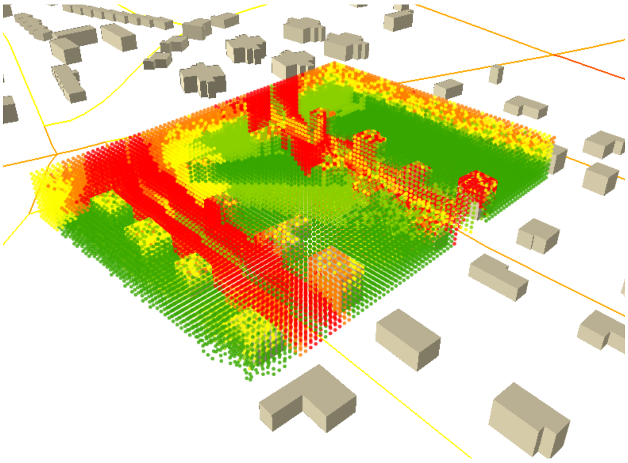


Figure 28. 3D noise levels on Building Façades

3.2 Noise impact on population

In this section we present the noise impact on Lund Municipality population. The population data we had was from 2002 and contained ~99000 persons.

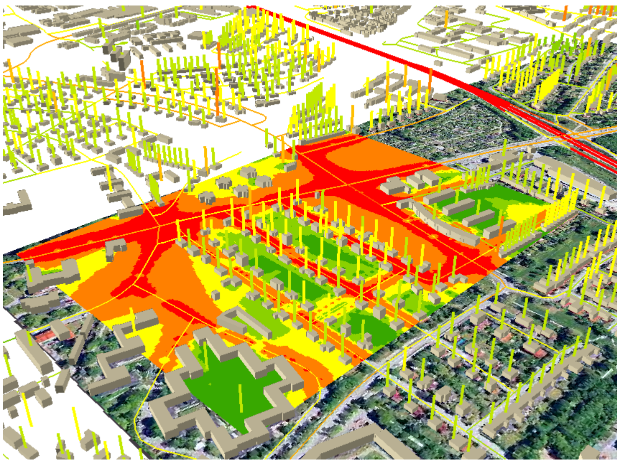


Figure 29. 3D Detailed View of Population Exposure to Noise

3.2.1 Affected population

The following table contains the noise levels for all the population points: 99,000. We presented the noise levels data classified in noise level intervals. The population is also classified according to sex and age. The results are detailed below.

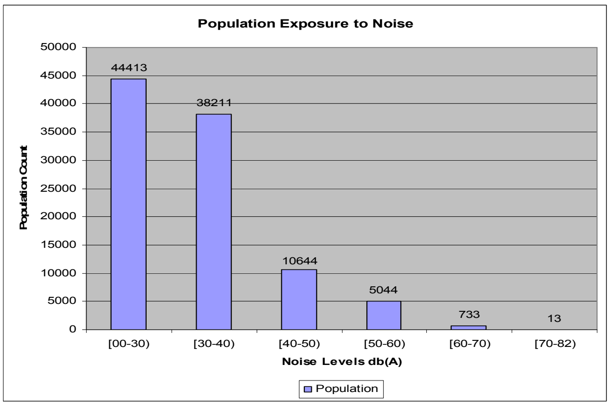


Figure 30. Population Exposure to Noise

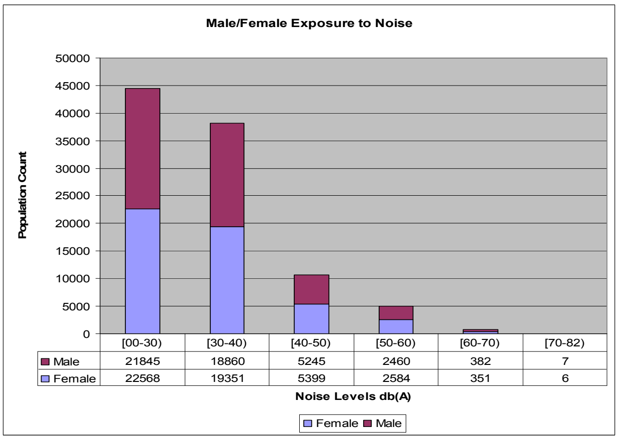


Figure 31. Population (Male/Female) exposure to Noise

As one can see, the population that suffers from a noise exposure of more than 55 db(A) - that the legislation enforces - is more than ~5600 people (~5.65%), which is rather high. This percentage is supported by [14].

4. CONCLUSION AND FUTURE WORK

In this paper we present tools that generate noise maps based on the available mathematical equations from Nordic Prediction Method for Road Noise calculation.

Other software systems (like SoundPlan), are commercial tools developed to calculate traffic noise levels, but usually, they can manage just small regions of a city.

Our aim was to develop a software system that can calculate the noise levels for big regions, such as Skåne. As far as we know the system we developed is the only one available for noise calculation implemented as an ArcMap non-commercial extension.

Seven tools were implemented to analyze noise levels varying from entire regions like Skåne to several streets in detail. We have also shown that our tools can be applied in noise prediction and can calculate the noise levels before and after the application of noise barriers. Noise prediction also depends on the noise barrier technology which was not investigated in this paper. For a traffic sound pressure of 66dB and a 2m high noise barrier, the noise level will decrease to 43dB. Having a building of 9m height as a barrier would decrease the sound level by 15dB; this means that a 78dB noise level on a road (which is the maximum noise level calculated in the project) would generate an acceptable noise level of ~55dB after the first building.

The implemented tools are general and if they are provided with additional data they can accurately calculate noise levels for new areas.

Regarding accuracy questions: none of the software tools to calculate noise levels are accurate; they are based on predictions and mathematical models created by measuring the real noise levels in different situations. However, the calculations performed by the tools were verified using the Nordic Prediction Noise graphs which give the results for a range of parameters. According to the Swedish Environmental Protection Agency, the maximum level of noise is 75dB(A) [10] which is also what we considered in this paper.
A 100% accurate noise calculation can be made just via measurements - perhaps guided by a statistical model to choose with what frequency during different hours and periods (seasons). Even with this problem of accuracy, and the missing data for all corrections, the tools can be used for an overview of traffic noise problems.

We have also shown that ~5.65% of the entire population in Lund Municipality is affected by higher level of noise than the 55 dB(A) which legislation enforces. These results can be used for planning medical studies, traffic shaping or noise barrier construction.

As future work we plan to upgrade the Nordic Prediction Method (that was used from 1996) to the newest prediction methods. We also plan to optimize our noise calculation tools so that they can be applied to entire regions using normal computing power.

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