DELIVERABLE D1.2

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PROJECT N°	FP6-516420
ACRONYM	QCITY
TITLE	Quiet City Transport
Subproject 1	Noise mapping & modelling – identification of noise hot-spots
Work Package 1.1	Noise maps: Initial situations Detailed diagnostic of specific hot spots related to the particular attention areas of each site and related to people complaints
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This deliverable has been quality checked and approved by QCITY Coordinator
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TABLE OF CONTENTS

0 EXECUTIVE SUMMARY

0.1 Objective of the deliverable

This deliverable presents detailed diagnostic of specific hot-spots related to the particular attention areas of each site, the noise maps and analyses of existing situations for the selected European cities. This deliverable contains also parts from Deliverable D1.1 to cover the input information that the hot-spot Analysis is based on.

The objective of QCITY is to propose measures that can realistically be integrated in actions plans that the cities will have to produce as a consequence of the EC Noise directive 2002/49/EC. This means that the project needs initial situation noise maps and digital information for cities to:

1. Evaluate hotspot analysis techniques
2. Identify possible hot-spots for further analysis in the QCITY-project
3. Validate different noise mitigation measures and there effect on noise maps
4. Link outcome from the mitigation studies to noise maps

In this deliverable the **Initial situations** and the **identification of hot-spots** for the selected cities are presented.

Totally 7 cities or parts there of are handled, these are **Brussels, Ostend, Ghent, Göteborg, Stockholm, Augsburg and Stuttgart**. For 4 of these cities the mapping areas are between 75 and 680 km^2; Stockholm, Göteborg, Augsburg and Stuttgart.

0.2 Description of methods used

0.2.1 Calculation methods

Three partners have been working on the initial situations. The national computation methods are adopted and used according to EC directive.

ACC, Germany – Augsburg & Stuttgart
Used Calculation methods: Road - RLS-90
Rail – Schall03
Aircraft - AzB

ACL, Sweden – Göteborg & Stockholm
Used Calculation methods: Road - Nordic prediction method, rev 1996
Rail - Nordic prediction method, rev 1998

ACR, Belgium - Brussels Ghent, &Ostend
Used Calculation methods: Road – NMPB
Rail – Nordic
Industry - ISO 9613

0.2.2 Software

Two environmental noise mapping software have been used within the project. ACC and ACL have used CadnaA, developed by DataKustik GmbH, Greifenberg, Germany and ACR have used IMMI, developed by Wölfel, Würzburg, Germany.

Both software use digital 3D-maps, including buildings, screens and foliage for the calculations. Effects due to propagation, ground absorption, screening, reflections etc. are automatically included in the calculations according to the used calculation method.

0.3 Partners involved and their contribution

Three partners have primarily been working on the initial situations; ACC, ACL and AKR. Apart from these TRAF and SEA have been contributing with data for Göteborg and Stockholm.

0.4 Conclusions

Noise maps for cities were calculated according to the European Directive within the time schedule of the project. Based on this maps hotspot analysis will be possible, so that different noise mitigation measures can be proofed in other subprojects.

1 NOISE RANKING AND SCORING METHODOLOGY

1.1 The Noise Scoring technique in the frame of action planning

In the frame of the QCity project the following scheme was proposed to develop effective and optimized action plans.

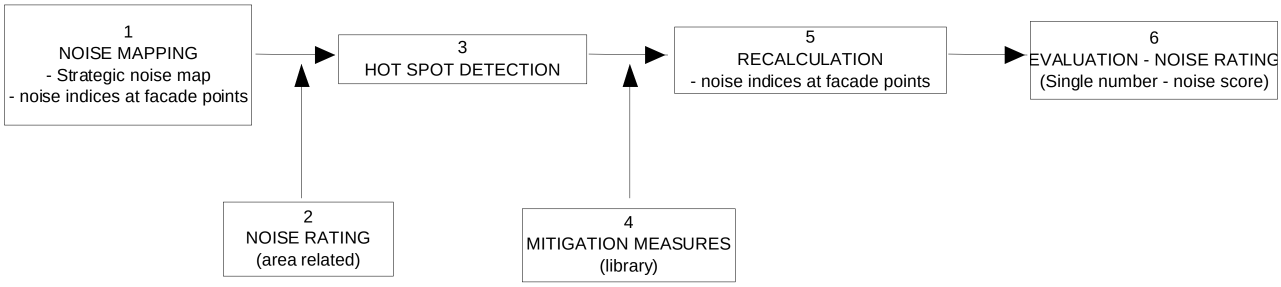


Figure 1.1.1: The basic methodology to develop an action plan based on strategic noise maps

Step 1

Basis of each noise evaluation of larger areas and agglomerations is the noise map, that includes the relevant noise indicators L_{den} and L_{night} for each building or dwelling.

Step 2

A ranking methodology and an additive noise score NS is needed to characterize an area with any number of dwellings by a single number depending on the noise exposure and the number of people exposed.

Step 3

The Hot Spots are areas where the area related NS is larger than 90% of all values occurring. These Hot Spots are a strong and valuable indication in what areas mitigation measures should be planned.

Step 4

A catalogue of mitigation measures is provided containing data sheets with the description, a valuable estimation of the achievable noise reduction and the cost, the limitations of the method and – if possible - reference applications.

Step 5

After implementing the measures according to an action plan in the 3D-model the noise map is recalculated. This is done separately for all scenarios alternatively discussed.

Step 6

By calculation of the NS value and summing it up in the relevant area for all regarded scenarios each can be characterized by the total NS. This allows to rank the different solutions and to decide about the best solution.

The described procedure is based on the existence of an accepted method of evaluating and scoring noise exposures.

1.2 Proposal of a Noise Scoring Methodology

Most publications in the past about this issue used the concept of highly annoyed (HA), where the number of persons that will be highly annoyed from a statistical point of view are summed up for the relevant area.

It has been shown that this approach is methodically wrong and therefore misleading if action plans shall be derived. The method does not take into account the increasing annoyance with increasing level – the increase of HA is only a measure of the distribution of sensitivity with respect to noise in a population.

The principle of the proposed scoring system is shown in figure 1.1.2

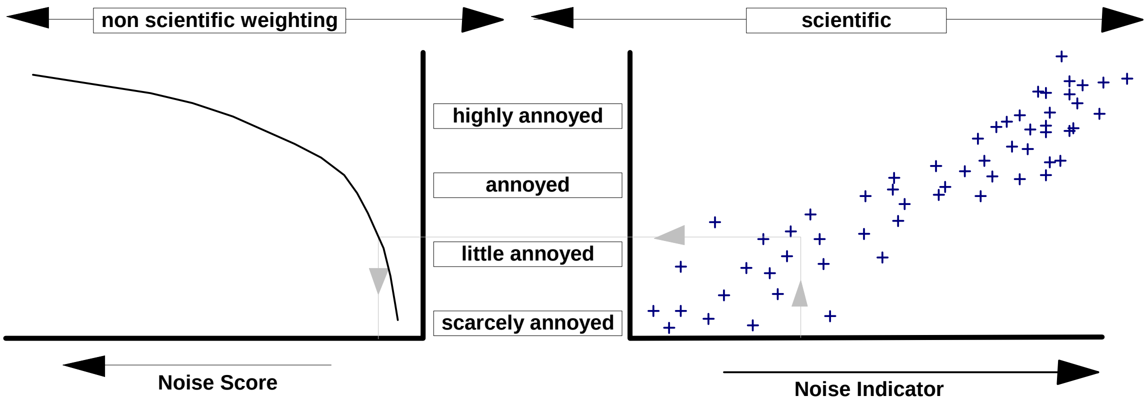


Figure 1.1.2: The Noise Score developed in two steps on the basis of noise exposures

The diagram at the right side presents the relation between noise exposure and grade of annoyance, where annoyance is used as a very rough and general description of many effects together. This relation can be determined interviewing people with known noise exposure in front of their dwelling. Many questionnaires in different countries have been undertaken and therefore this relation is well known.

The second step is shown at the left diagram – there is no evidence based procedure how to weight these different grades of annoyance. It is a social decision at how many dwellings of little annoyed persons the level must be reduced by x decibels to compensate an increase of the level by x decibels at the dwelling of one just highly annoyed person.

One more or less “axiomatic” property of any noise ranking function is indicated in the left diagram figure 1.1.2 – a level increase of x decibels in a situation where the noise exposure is just high is worse and should produce a larger increase of the NS value as it is the case at lower levels. Levels of 50 dB(A) are comfortable, 60 dB(A) are quite annoying but typical in agglomerations, 70 dB(A) are extremely annoying and unacceptable (nevertheless typical for many main roads in cities) and nobody should be forced to live with levels of 80 dB(A). It is obvious that a ranking system should not recommend to increase the level of 70 dB(A) at dwellings if the level at some other dwellings with an existing exposure of 55 dB(A) is reduced the same amount.

This means that the slope of the function level – score should increase with increasing level. This requirement is fulfilled using an exponential function of the type

$$NS = \sum_i n_i \cdot 10^{K \cdot (L_i - L_R)} \quad (1)$$

with

NS Noise Score

n_i number of persons in group i

L_i level L_{den} at the dwelling of the group i

L_R reference level

K constant defining the steepness of the function

It can be shown that the reference level L_R has no influence on the decisions recommended by the minimization of the NS value. The parameter K determines the behaviour of the system – it should be adjusted carefully taking into account our opinion how the unwanted exposures should be distributed if they cannot be avoided.

The situation shown in figure 1.1.3 can be used to support this decision. If the traffic N cars/h of one road is split up into two other roads with traffic N1 and N2 and n1 resp. n2 persons live at those two roads, the optimal traffic distribution recommended by a scoring system is defined by the minimum of the resulting NS value.

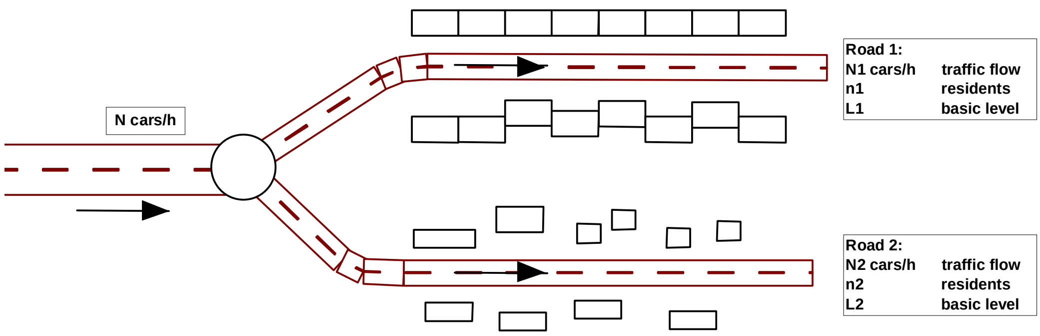


Figure 1.1.3: Distribution of a traffic flow N on two roads with flows N1 and N2

On certain conditions the Noise Score function (1) for this situation can be determined in dependence of the ratio N1/N2 where the sum of these two flows is constant (=N).

This investigation shows that with parameters

K < 0.1

the resulting Noise Score is smallest if the traffic is completely bundled on the road with fewer residents, even if these numbers of residents differ only by 1 person. If the number of residents, n1 and n2 are equal, bundling produces the same minimal noise score independent through which road the complete traffic N is channelled. Complete channelling is the recommended distribution even in cases where the level at the dwellings exceeds 80 dB(A) or any other value and even if no mitigation measures are taken into account.

It is obvious that this is not conforming to the public opinion about a fair distribution of unwanted hazards. Bundling of traffic on main roads may in fact be a good solution, but this should only be possible if unacceptable high noise exposures are avoided by a simultaneous planning of mitigation measures.

This is the case if a parameter

K > 0.1

is used in the Noise Score Function (1). In that case bundling is also recommended by minimizing the NS value, but only if additionally mitigation measures are applied at the road with high noise levels. If no additional measures are possible the traffic is distributed in a way that higher levels are produced at the road with fewer residents, but total channelling through one road is not possible.

Based on these findings the following Noise Score function was developed:

$$NS = \sum_i \begin{cases} n_i \cdot 10^{0.15 \cdot \left(L^*_{den,i} - 50 - dI + dL_{source}\right)} & with\ L^*_{den,i} \leq 65\ dB(A) \\ n_i \cdot 10^{0.30 \cdot \left(L^*_{den,i} - 57.5 - dI + dL_{source}\right)} & with\ L^*_{den,i} > 65\ dB(A) \end{cases} \quad (2)$$

with

NS Noise Score

n_i number of persons exposed with level $L_{den,I}$

$L^*_{den,j}$ Effective noise indicator at the relevant façade at dwelling i

dI deviation of mean sound insulation of dwelling i from the mean insulation of all dwellings

dL_{source} correction that accounts for different reaction versus noise from roads, railways, aircraft and industry

In our city models Stuttgart and Augsburg dl and dL_{Source} is not used, because only noise from road traffic was taken into account and no detailed information about the building structures was available.

In equation (2) the L^*_{den} is used to characterize the noise exposure. This is a combined indicator with malus corrections for evening and night. In an overall ranking system it is problematic to use additionally the L_{night} noise indicator – e.g. to take into account sleep disturbance – because this means to use the night exposure twice and to weight it to much.

If measures are planned that influence the L_{den} differently at different times the reduction of the effective L^*_{den} should be calculated before this is used in (2).

Example: Installation of sound insulated ventilation:

In noise exposed dwellings around airports or very noisy main roads some communities give financial support to owners to improve the windows and to install sound insulating ventilation. This allows to keep the window closed all the time, while without this system the window must be tilted with a level increase of about 15 dB.

If such a ventilation system is installed, the window can be closed at night and the level reduction is 15 dB.

The equation to calculate the effective noise indicator reduction is

$$\Delta L^*_{den} = 10\lg\left\{\frac{1}{24}\left(\begin{aligned}&T_d(1-k_d)+T_d k_d\cdot 10^{-0.1\cdot dL}+T_e(1-k_e)\cdot 10^{0.1\cdot(5-dL_{de})}+\\&T_e k_e\cdot 10^{0.1\cdot(5-dL_{de}-dL)}+T_n(1-k_n)\cdot 10^{0.1\cdot(10-dL_{dn})}+T_n k_n\cdot 10^{0.1\cdot(10-dL_{dn}-dL)}\end{aligned}\right)\right\} \quad (3)$$

With abbreviations (typical values in brackets)

T_d Hours day (12)

T_e Hours evening (4)

T_n Hours night (8)

k_d portion of time with an effective improvement by the closed window day (0)

k_e portion of time with an effective improvement by the closed window evening (1)

k_n portion of time with an effective improvement by the closed window night (1)

dL_{de} difference L_d – L_e in decibels (0)

dL_{dn} difference L_d – L_n in decibels (10)

dL level difference inside window closed – window tilted in decibel (15)

The reduction of the L_{den} by installing such a ventilation system calculated with (3) using the indicated values in brackets is about 3 dB – although the level inside is decreased by 15 dB if the window can be closed. But in fact the improvement does not influence the noise exposure at daytime and therefore the overall effect is by far lower.

1.3 Hot Spot Detection

In the first step (noise map calculation) for each dwelling the level L_{den} at the most exposed façade is determined. Further the number of residents in each dwelling must be known. With these two numbers equation (2) can be used to get the Noise Score for each building.

To find the Hot Spots a map of the area related Noise Score is produced. The procedure is shown in figure 1.1.4.

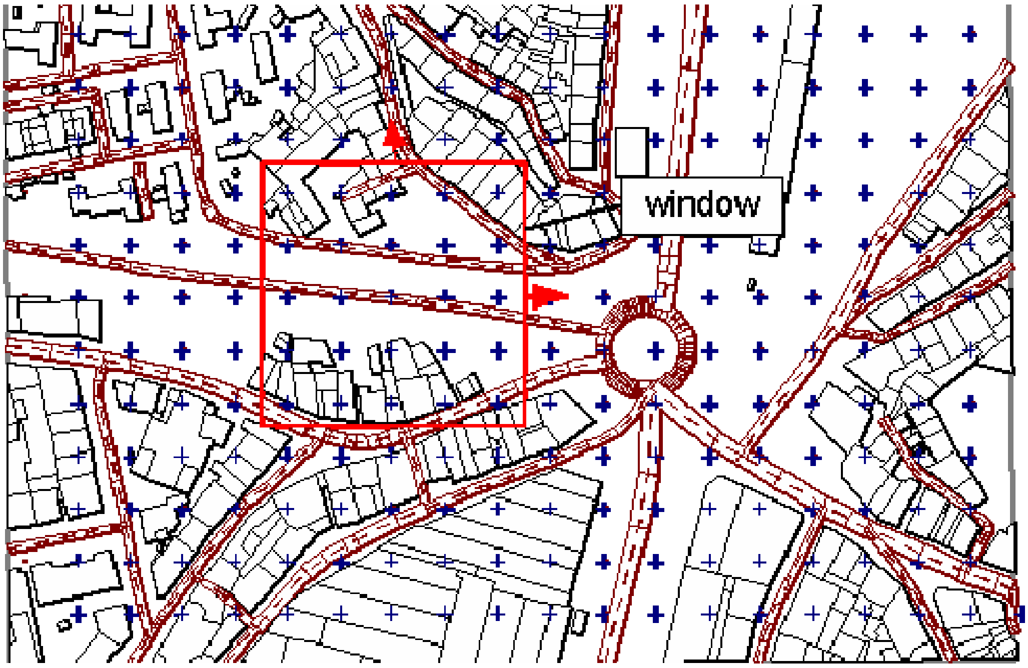


Figure 1.1.4: Gliding window to calculate the area related noise score for the center grid point

To calculate the area related noise score for a grid point, the NS values of all buildings inside the window are summed up. Buildings that are intersected by an edge of the window are taken into account proportional to their area inside and outside the window. The resulting sum is divided by the window area and multiplied by a reference area (= 1000 m²). Then the window is centred above the next grid point and the procedure is repeated. At the end the grid shows the distribution of the noise score related to 1000 m².

This area specific NS covers values from 0 up to NS_{max}. To get a coloured map presenting the Hot Spots in red colour, a three colour presentation can be used.

$0 < NS < 0.5\ NS_{max}$ → green

$0.5\ NS_{max} < NS < 0.9\ NS_{max}$ → yellow

$0.9\ NS_{max} < NS < NS_{max}$ → red

The resulting presentation shows the areas where people are most exposed and where actions shall be planned to reduce the noise.

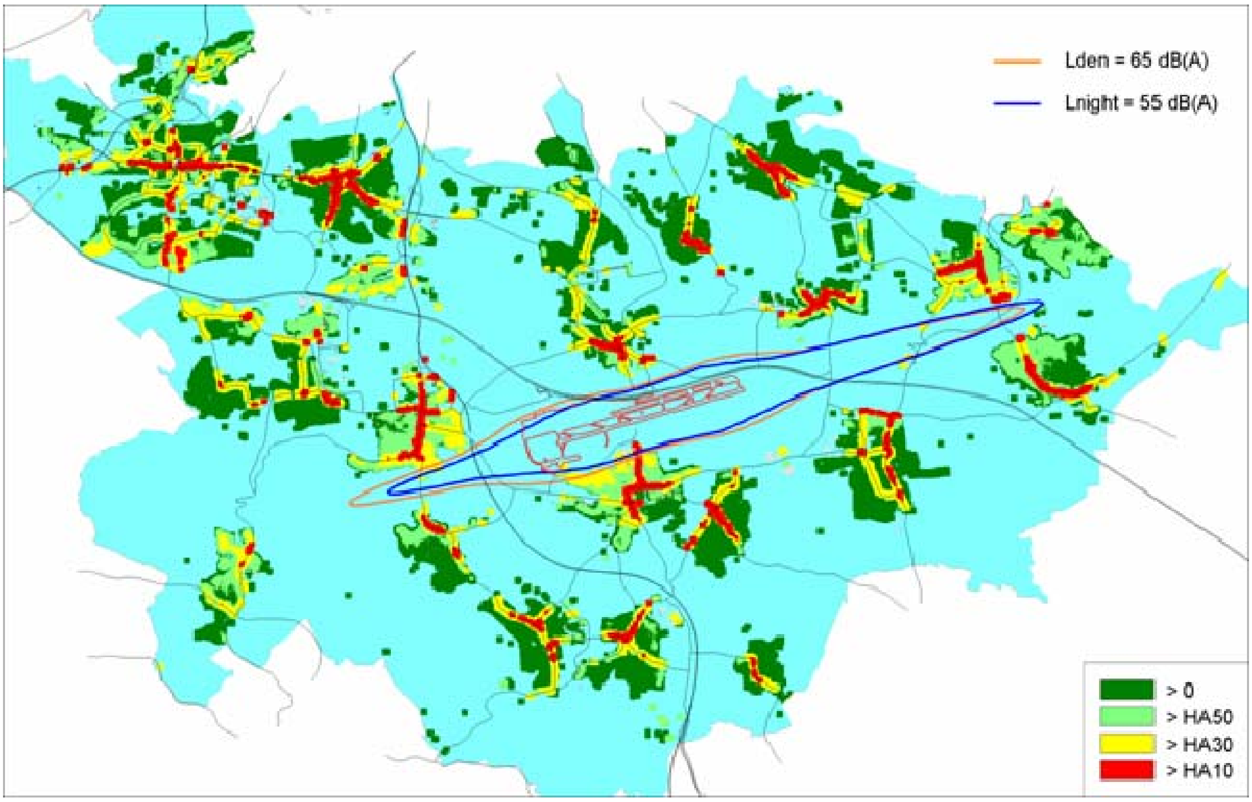


Figure 1.1.5: Presentation of hot spots in 3D-View

For further information see Annex 4.1: Probst W.: "Zur Bewertung von Umgebungslärm", Zeitschrift für Lärmbekämpfung Nr. 4 2006, pp 105-114, with English translation.

2 PARTS OF CITY AREAS

Difference has been made between global mitigation measures and local complaint handling. Both problems are important in urban noise. In this part, attention is paid to local complaint handling.

Parts of three cities have been partly modelled for evaluation of urban track; **Brussels, Ostend and Ghent**. The size of the models are 0.5 to 2 km² and that is sufficiently large to validate all types of mitigation measures on track and sufficiently small to have acceptable calculation times and possibilities to evaluate multiple cases. The work carried out within QCity is an actualization of existing noise maps and noise map information to the Interim Calculation Methods imposed by the EC Directive. Used calculation methods are according to EC Directive:

- NMPB: road;
- SRM II: rail;
- ISO: industry (if applicable).

The software used was the commercial available software program IMMI, an environmental noise mapping software (developed by company Wölfel, Würzburg, Germany).

During the first year, the studies included the calculation of the basic situation: selection of information and evaluation of nuisance by calculation of L_{den}, L_{night} and number of annoyed.

In a second stage, (second year), further detailed analysis of these maps has been carried out:

- exploration of sensitivity of results in noise maps to uncertainties in input data;
- evaluation of the effects of local mitigation measures.

2.1 Brussels

2.1.1 Noise map

Area

Densely populated area of Brussels: 1 km².

- work area: 725 m x 656 m = 0,48 km²
- ±1104 houses
- ±6400 civilians
- 14 streets (total length = 4.3 km)

Tram:

- tracks in 2 streets (total length = 1500 m);
- 1 depot (18.530 m²) + tracks for access to depot.

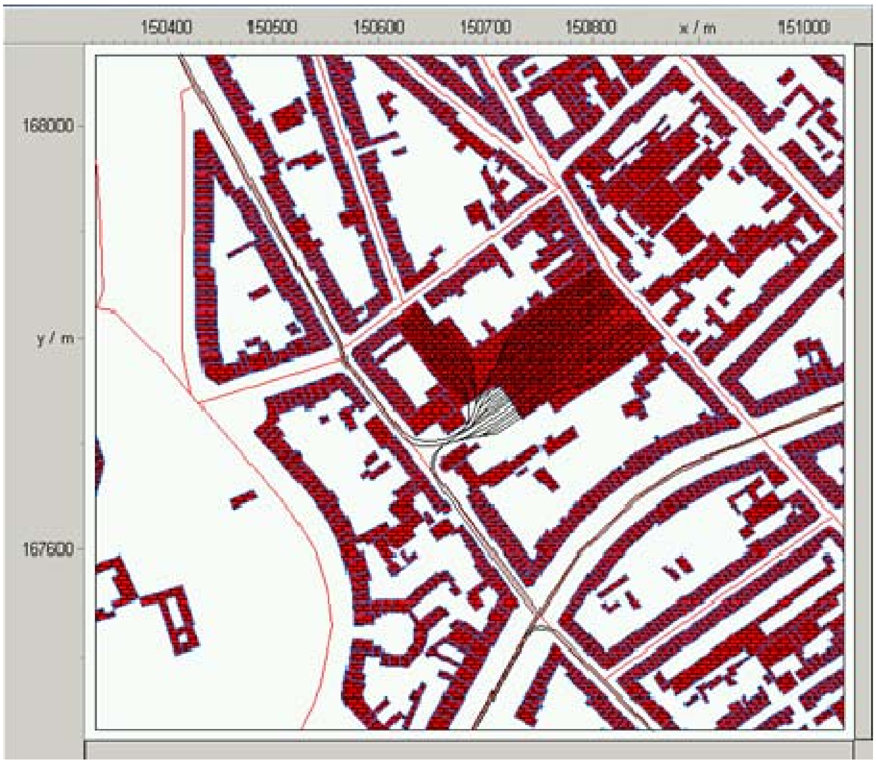


Figure 2.1.1: Partial model out of overall city model

Aim

- study of area around tram depot;
- combined effect of road, bus, tramways;
- linking of outcome of detailed mitigation studies to global noise maps.

Origin

This map has been retrieved from the general noise map of the city of Brussels.

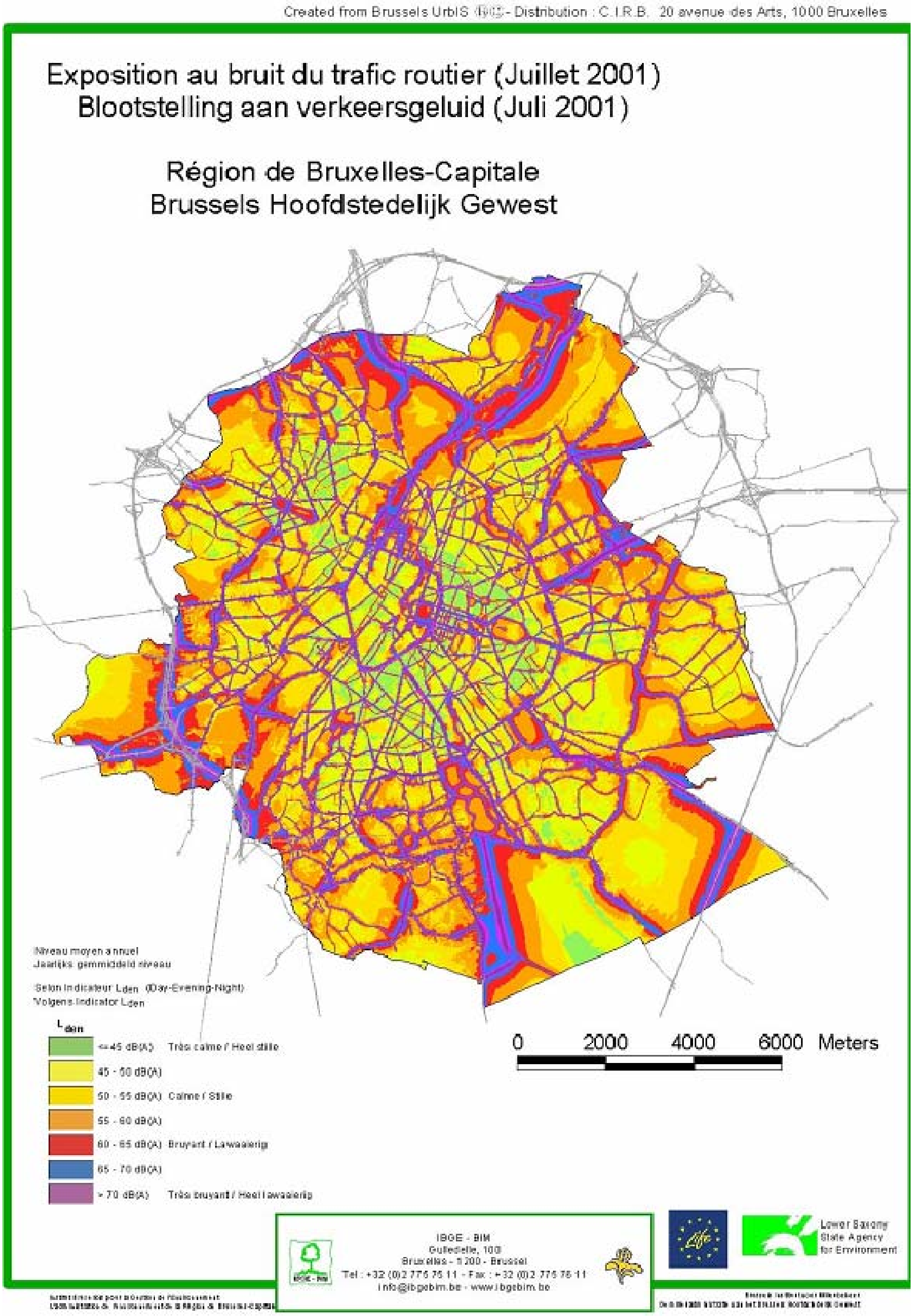


Figure 2.1.2: Global model

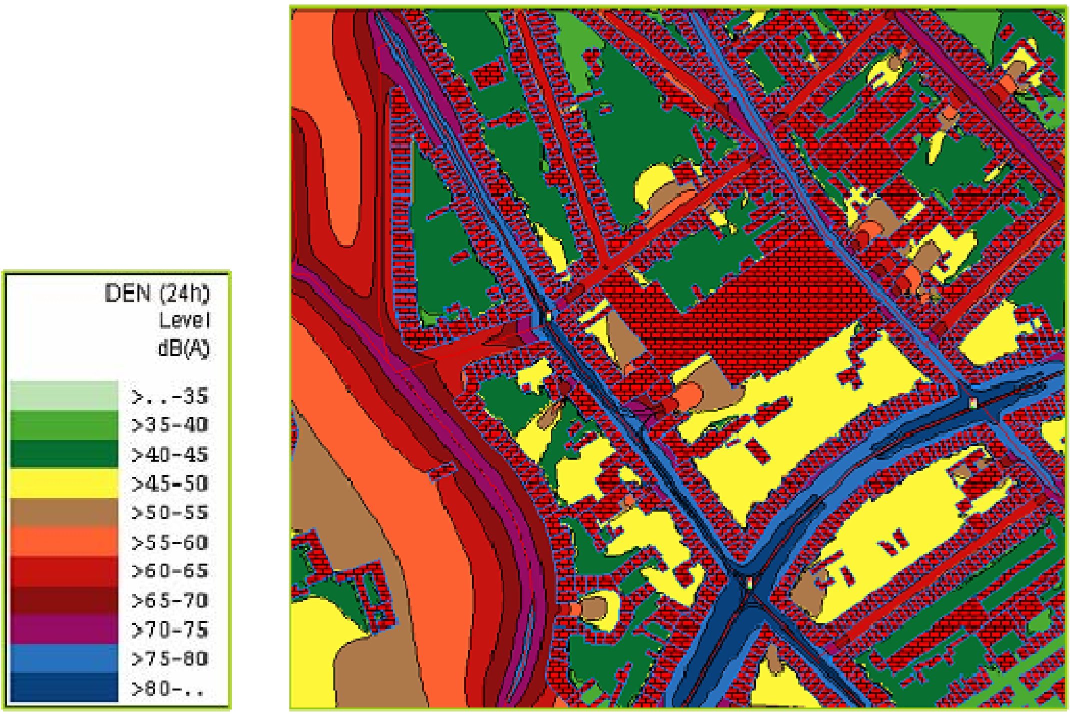


Figure 2.1.3: L_{den}

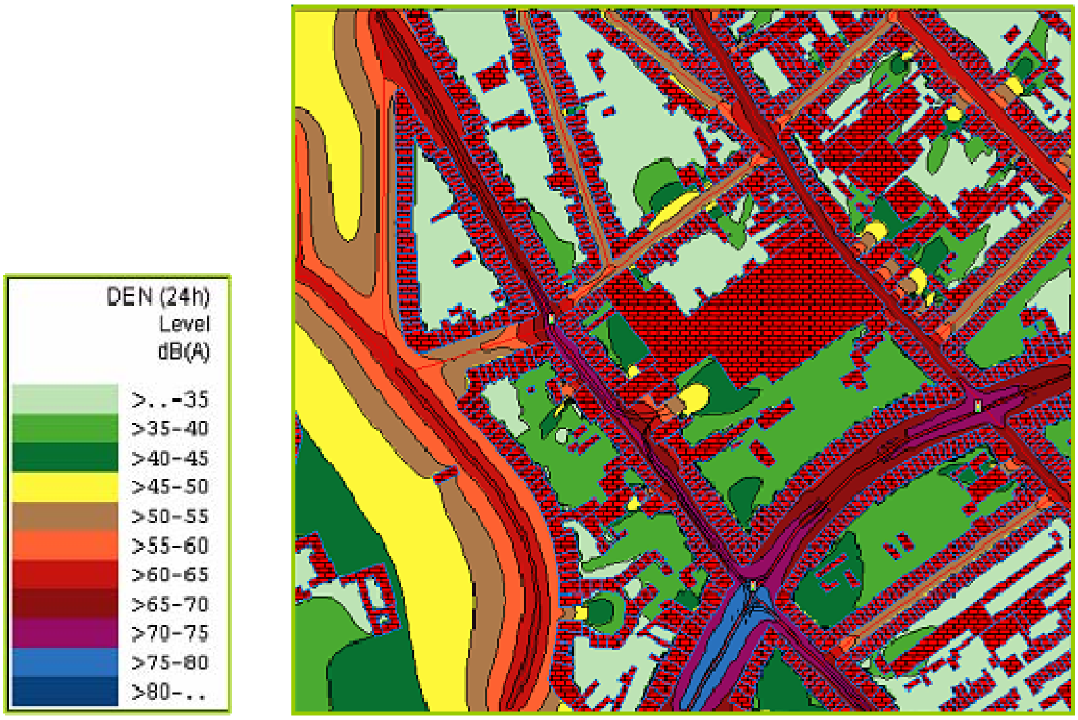


Figure 2.1.4: L_{night}

Noise index	Range /dB	P1A *)	P1B *)	P2A *)	P2B *)
Day	... < Lden < 55 dB	1150	3487	30	1723
	55 <= Lden < 60 dB	1321	724	489	9
	60 <= Lden < 65 dB	704	430	491	0
	65 <= Lden < 70 dB	808	424	737	0
	70 <= Lden < 75 dB	1187	651	880	0
	75 <= Lden <... dB	1214	658	990	0
	Sum	6384	6373	3617	1726
Night	... < Ln < 45 dB	1085	3441	0	1766
	45 <= Ln < 50 dB	100	84	0	9
	50 <= Ln < 55 dB	1688	955	851	0
	55 <= Ln < 60 dB	631	338	525	0
	60 <= Ln < 65 dB	751	422	607	0
	65 <= Ln < 70 dB	1673	867	1369	0
	70 <= Ln <... dB	456	267	342	0
	Sum	6384	6373	3694	1767
Evening	... < Ln < 45 dB	838	3124	0	1774
	45 <= Ln < 50 dB	184	295	0	106
	50 <= Ln < 55 dB	158	113	54	9
	55 <= Ln < 60 dB	1517	863	895	4
	60 <= Ln < 65 dB	884	418	740	0
	65 <= Ln < 70 dB	797	485	615	0
	70 <= Ln <... dB	2006	1075	1634	0
	Sum	6384	6373	3938	1892
P1A *): Inhabitants of a building with a value at the most exposed façade inside the specified range					
P1B *): People assigned to a partial façade with the façade pollution					
P2A *): Number of people from the set P1 living in a building with a quiet façade					
P2B *): Number of people from the set P1 living in a building with a quiet façade					

Table 2.1.1

2.1.2 Sensitivity analysis and mitigation measures

Relation with other subprojects

- expects input from WP3.1 – 3.2 (this information is summarised in D6.2);
- is required as input for WP5.3.

Mitigation measures

Out of D6.2, following mitigation measures seem to be potentially interesting:

- GM-RAIL6 - Embedded rail;
- GM-RAIL9 - Rail grinding;
- LC-RAIL7 - Laterally resilient rail fastener ;
- LC-RAIL8 - Friction modifier/lubricants.

2.1.1.2 Rail grinding

The actual calculation method for rail transportation noise in the AR-Interim Method proposed by the CE (SRM II, 1996) does not include a method for including rail grinding.

A methodology has been proposed in more recent version of SRM II (2202, 2004), but has not been accepted by the CE.

This will be one of the topics subject to future study in WP1.2.

In the meanwhile, this aspect has been studied arbitrary by: 10 dB improvement of Roughness → 7 dB(A) reduction of noise.

The influence on L_{den} is visualised in figure 2.1.5.

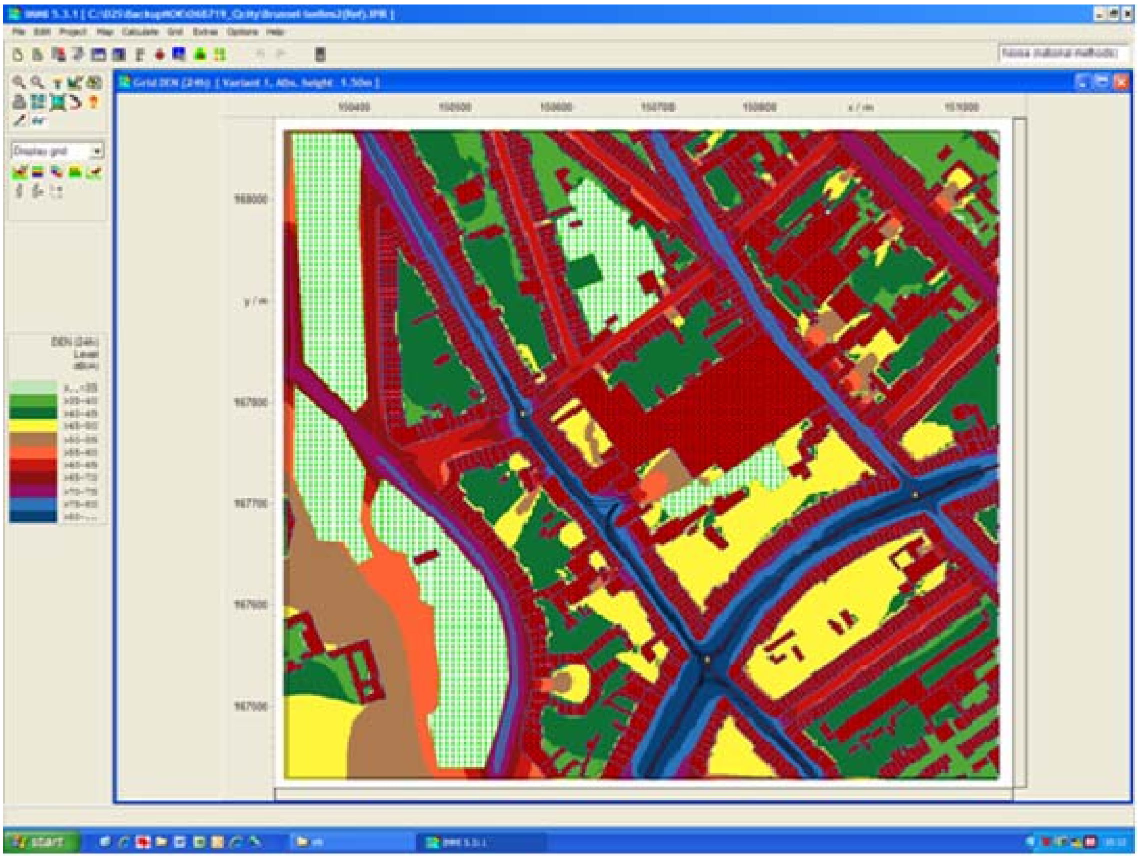


Figure 2.1.5: Original situation L_{den}

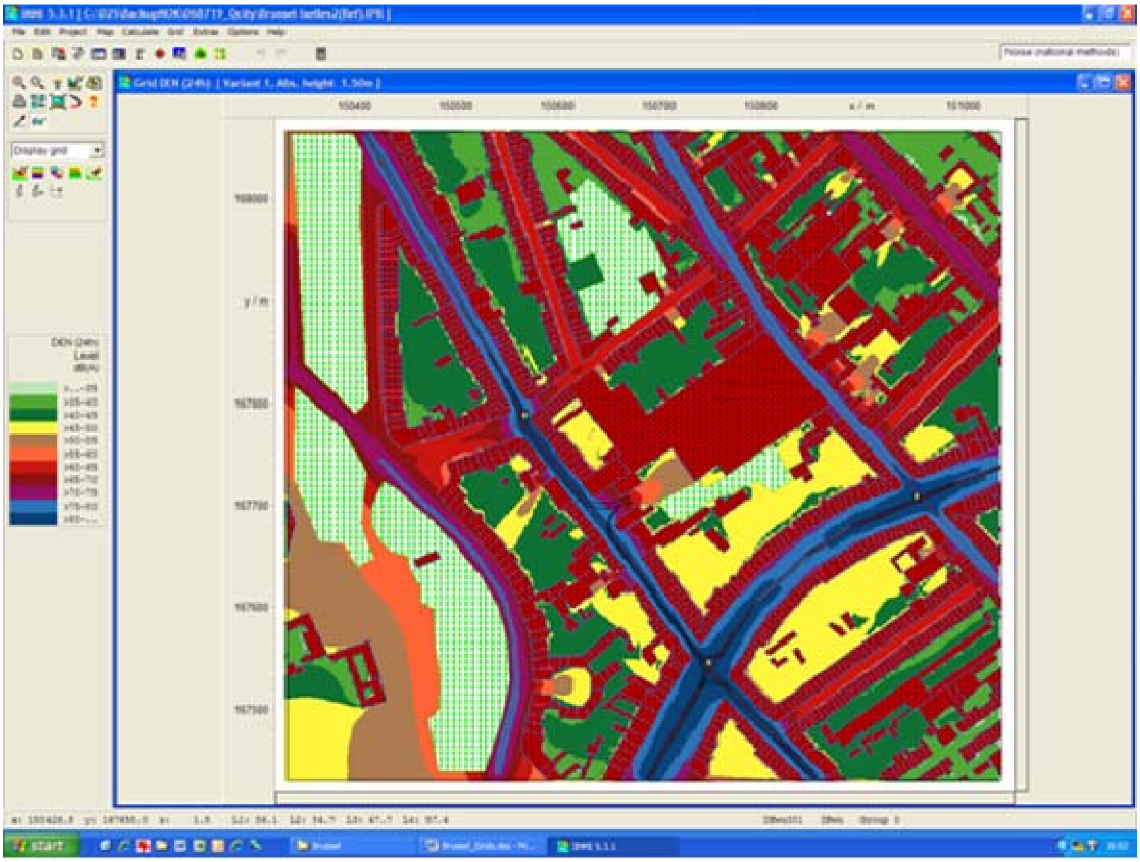


Figure 2.1.6: Rail grinding L_{den}

More precise information can be found in figure 2.1.7 and table 2.1.2.

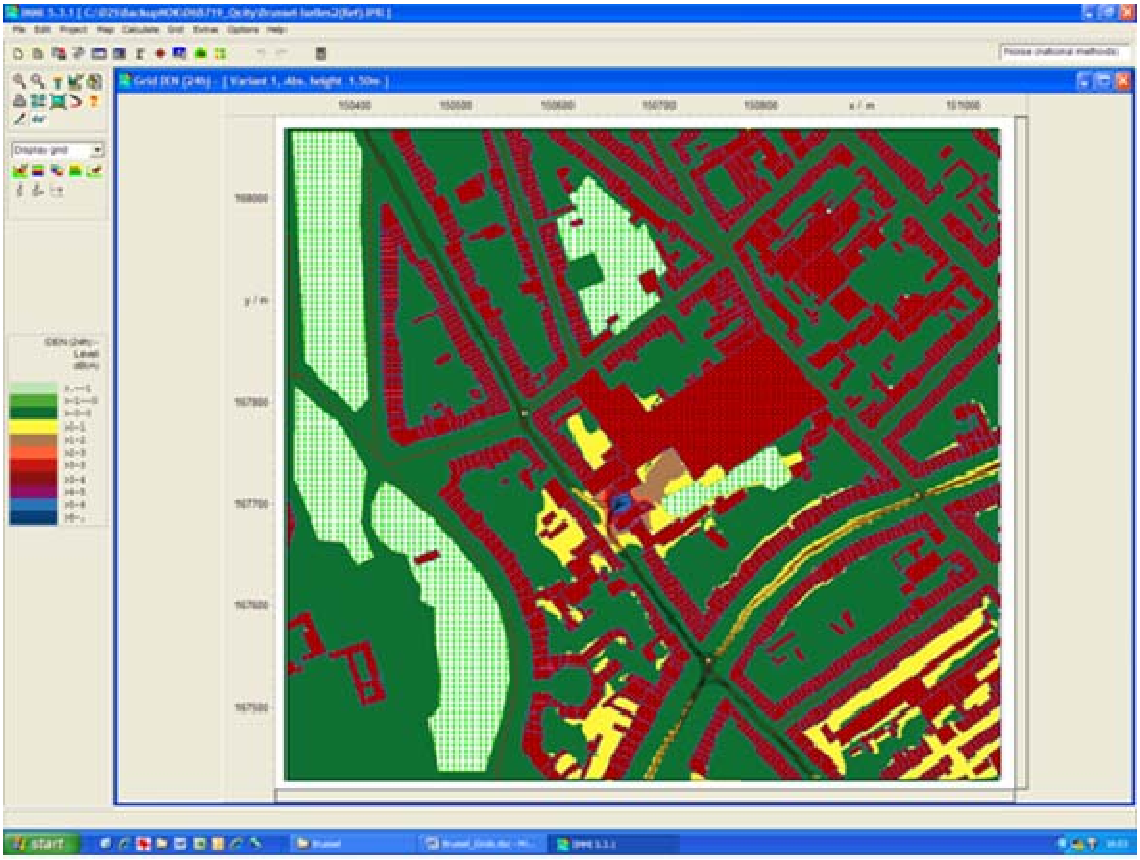


Figure 2.1.7: Difference map

	Inhabitants of a dwelling with a value at the most exposed façades inside the specified range Original	Rail Grinding
Road & Rail		
$\ldots < L_{den} < 55$ dB	1092	0
$55 \leq L_{den} < 60$ dB	233	0
$60 \leq L_{den} < 65$ dB	1572	0
$65 \leq L_{den} < 70$ dB	885	0
$70 \leq L_{den} < 75$ dB	425	32
$75 \leq L_{den} < \ldots$	1977	-11
sum	6381	-21
Rail only		
$\ldots < L_{den} < 55$ dB	4337	686
$55 \leq L_{den} < 60$ dB	574	542
$60 \leq L_{den} < 65$ dB	526	-342
$65 \leq L_{den} < 70$ dB	887	-843
$70 \leq L_{den} < 75$ dB	39	-39
$75 \leq L_{den} < \ldots$	21	-21
sum	6384	0

Table 2.1.2

Further, both calculations are carried out for both:

- global noise: road & rail traffic;
- rail transport: only rail traffic.

One can observe that the global effect on the number of annoyed is minimal (±50 persons change one class).

2.1.2.2 Squeal noise

A major complaint in this city area, is a complaint of squeal noise of tram cars driving in an out the depot.

When regarding the SRM II calculation method, a factor for track bed correction is available, but does not include "squeal".

In this preliminary evaluation, an arbitrary value (see WP3.3) has been chosen, limited to the emission of the curvature only. (Also this aspect will be studied further in WP1.2.)

Calculation of L_{den}, L_{night} and number of annoyed was carried out. Again sensibility towards a global (or a local) approach is looked for, figure 2.1.8, table 2.1.3.

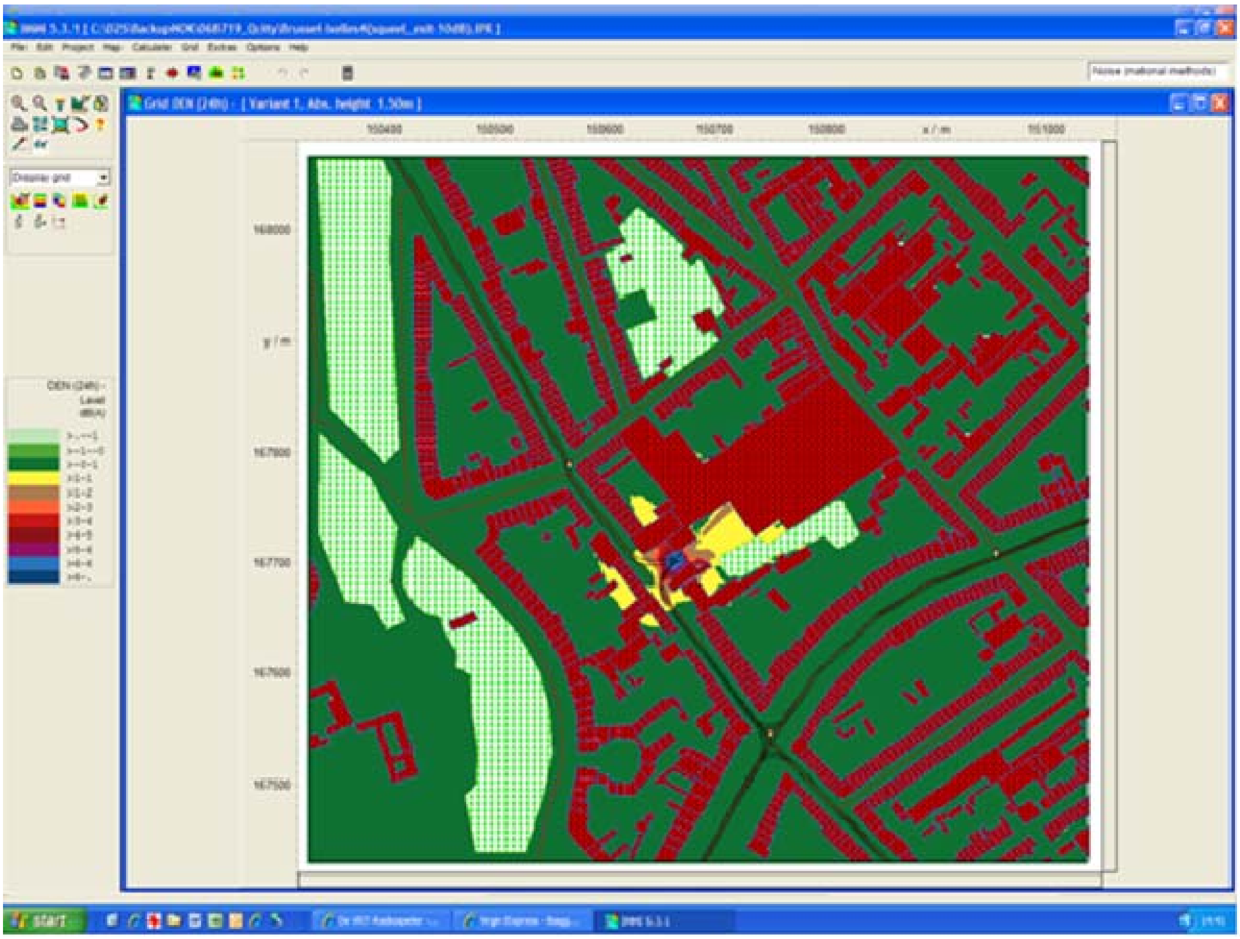


Figure 2.1.8: Difference map

	Inhabitants of a builing with a value at the most exposed façades inside the specified range Original	Squeal noise
Road & Rail		
… < L_{den} < 55 dB	1092	0
55 ≤ L_{den} < 60 dB	288	0
60 ≤ L_{den} < 65 dB	1572	0
65 ≤ L_{den} < 70 dB	885	0
70 ≤ L_{den} < 75 dB	425	0
75 ≤ L_{den} < …	1977	0
sum	6381	0
Rail only		
… < L_{den} < 55 dB	4337	0
55 ≤ L_{den} < 60 dB	574	81
60 ≤ L_{den} < 65 dB	326	76
65 ≤ L_{den} < 70 dB	887	-97
70 ≤ L_{den} < 75 dB	39	-39
75 ≤ L_{den} < …	21	21
sum	6384	0

Table 2.1.3

There it can be observed that inside a global map, the information is completely lost, no influence on L_{den} or L_{night}. On a local scale, rail transport, a few hundred people are considered.

This study has been retained to be the start of WP5.3.

2.2 Ostend

This area has specifically been selected because it consists of a typical situation of a regional harbour where maritime traffic (freight train) coincides with other traffic noise (road, tramways, ...) in an urban environment.

Specific complaints were uttered towards freight train noise when passing over a steel bridge.

2.2.1 Noise map

Area

- Work area: 1200 m x 1500 m = 1.80 km²
- ±300 houses (some of the industry included)
- ±2400 civilians
- 14 streets (total length = 6.3 km)
- Tram: 2 tracks (total length = 3 km)
- Freight train: 1 track (total length = 1.8 km)

Aim

- validation of new train concepts in a regional harbour;
- linking of outcome detailed mitigation studies to global noise maps in marine.

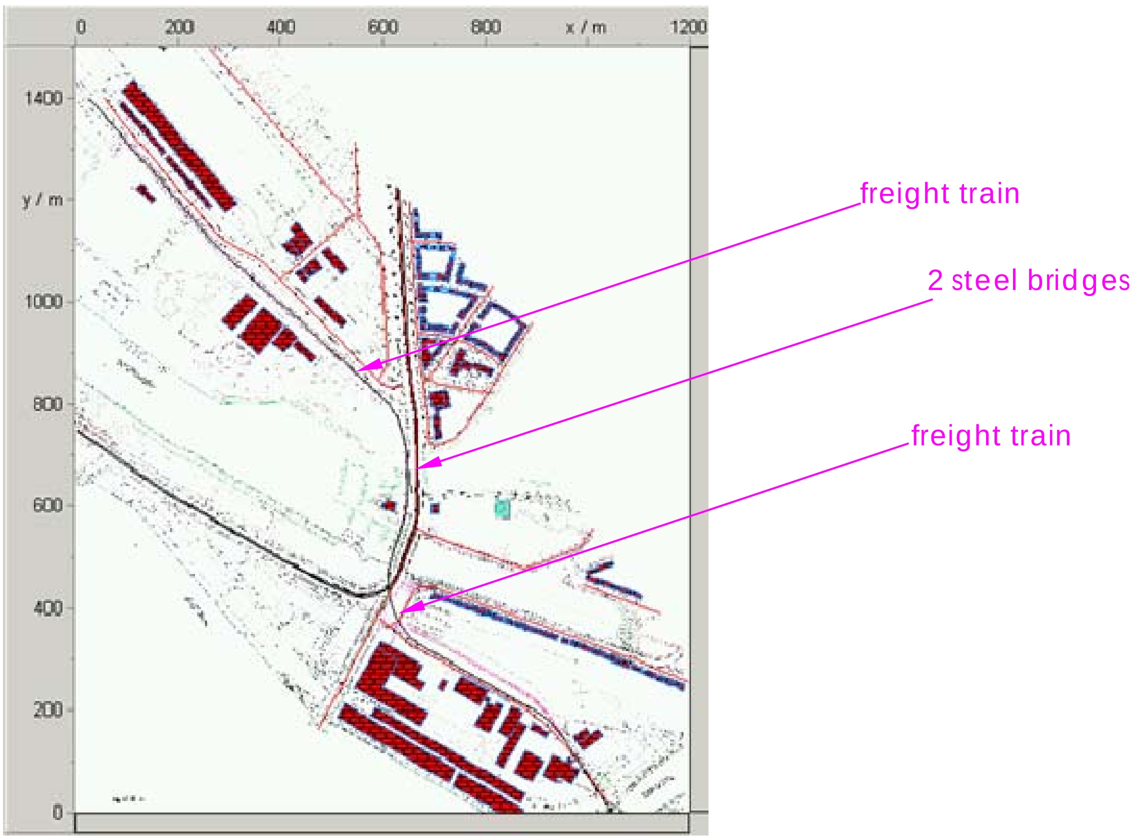


Figure 2.2.1: Noise map – detailed model

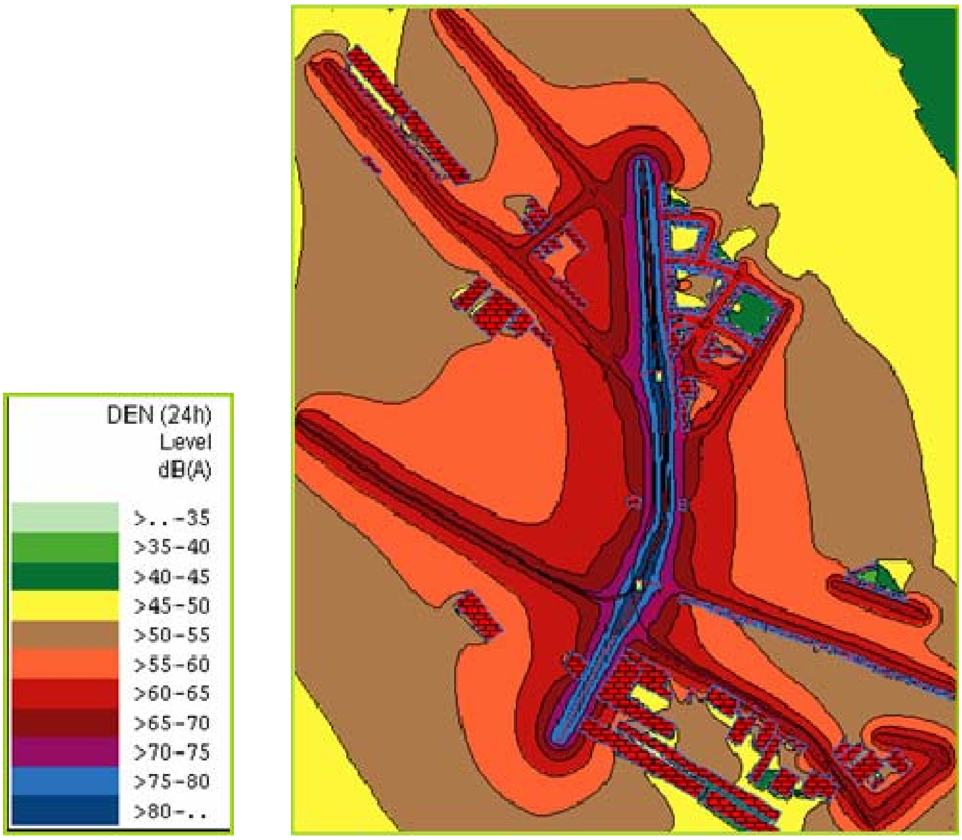


Figure 2.2.2: Calculation of L_{den}

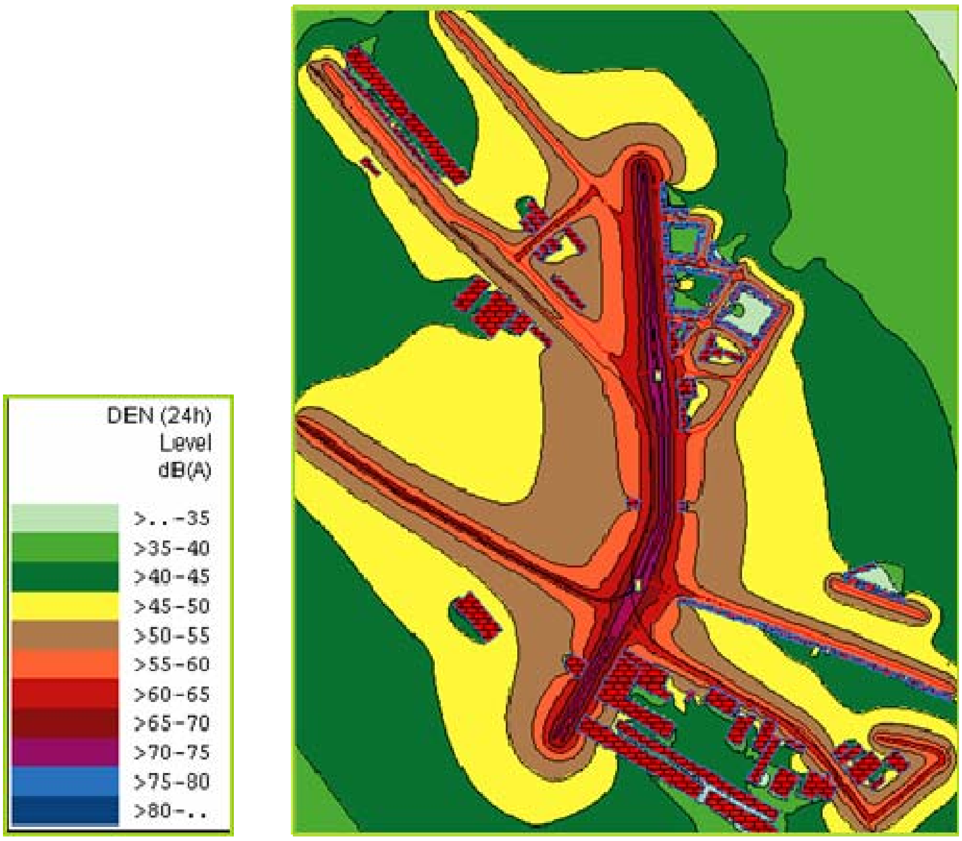


Figure 2.2.3: Calculation of L_{night}

2.2.2 Mitigation measures

As recalled from D6.2, four mitigation measures are proposed as local mitigation measures:

LC-RAIL-13	moving special track work (switches, expansion joints, ...) away from bridges
LC-RAIL-14	vibration isolation of rail
LC-RAIL-15	bridge vibration damper
LC-RAIL-16	plate damping

Integration of these modification inside a noise prediction calculation method such as SRM II has to be studied.

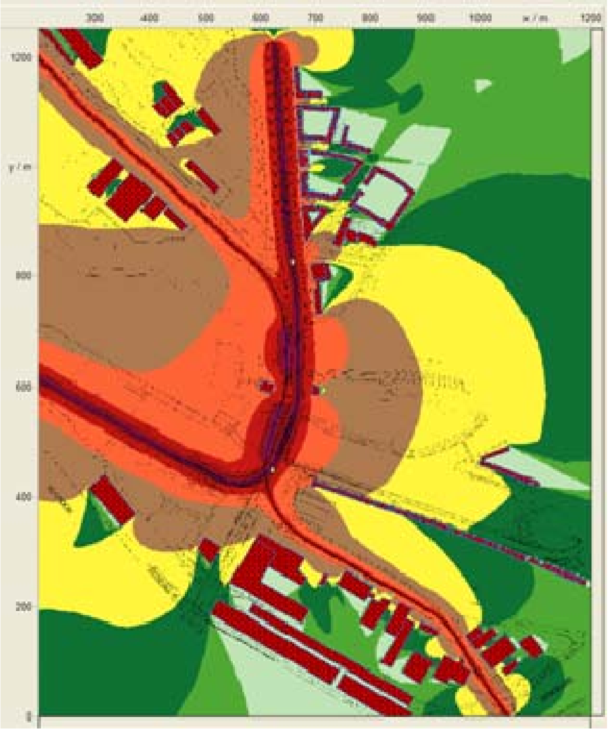
For this feasibility study, three mitigation measures are retained:

- moving special track work: -10 dB;
- vibration isolation of rail: -6 dB;
- plate damping: -4 dB.

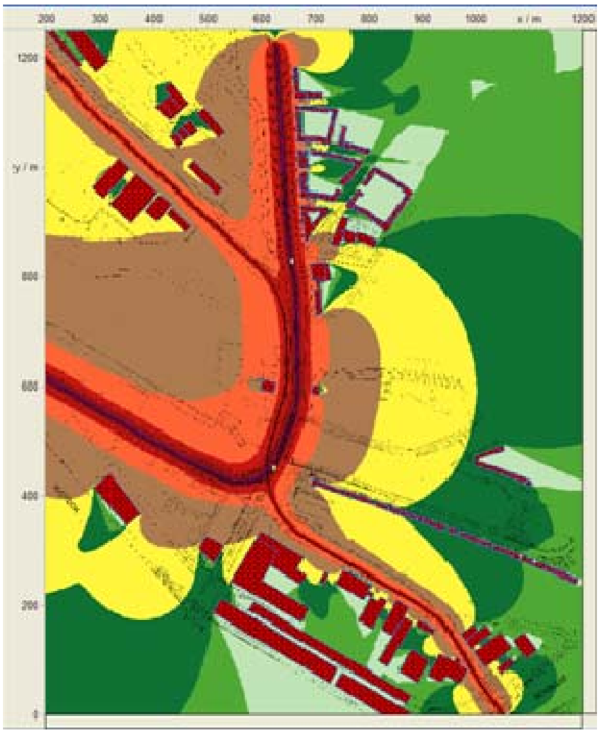
These aspects will be studied further in:

- WP1.2: integration in SRM II;
- WP5.7: bridge noise reduction.

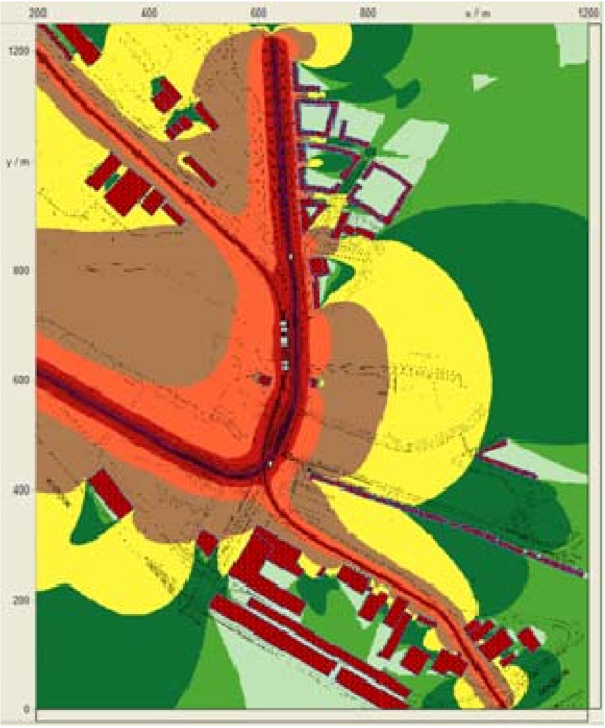
Calculation of both parameters leads to following L_{den} figures (effect of train and tram only).



Basic



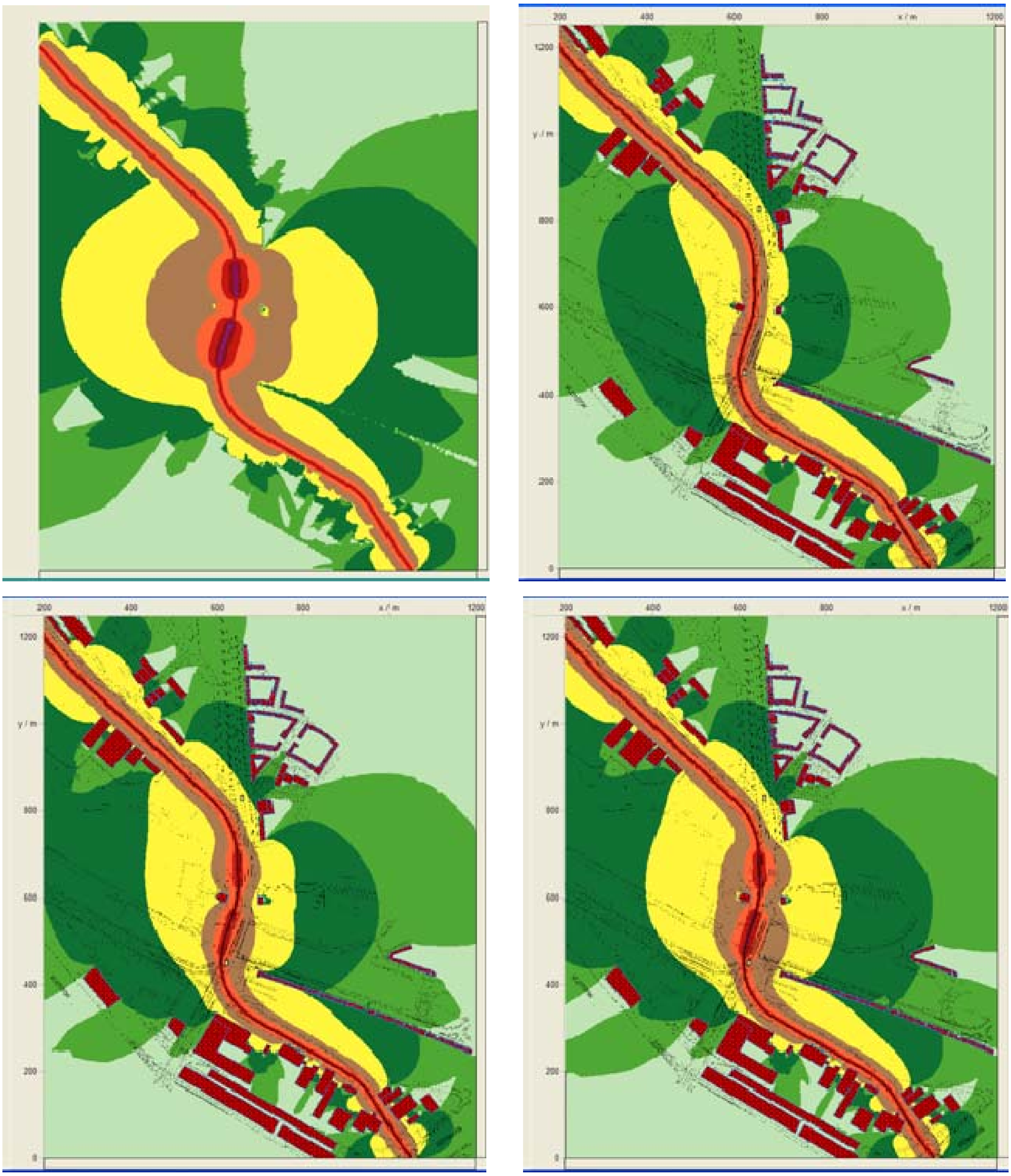
Moving track work: -10 dB



Rail isolation: -6 dB

Plate damping: -4 dB

When studying the effect of the rail isolation of the freight track only, it should be studied by the train contribution only.



In the tables below, all effects are analysed based on the number of annoyed people:

- table 2.2.1: total number of annoyed;
- table 2.2.2: difference of number of annoyed as function of mitigation measure.

		# of people exposed

Noise index	Range /dB	Evaluate using methods A & B actual situation	moving track work	rail isolation	plate damping
	All sources				
DEN (24h)	... < Lden < 55 dB	20	20	20	20
	55 ≤ Lden < 60 dB	0	0	0	0
	60 ≤ Lden < 65 dB	565	565	565	565
	65 ≤ Lden < 70 dB	606	606	606	606
	70 ≤ Lden < 75 dB	143	143	143	143
	75 ≤ Lden <... dB	332	332	332	332
	Sum	1666	1666	1666	1666
Variant:	***Train & tram***				
DEN (24h)	... < Lden < 55 dB	1317	1325	1325	1325
	55 ≤ Lden < 60 dB	44	96	96	96
	60 ≤ Lden < 65 dB	305	245	245	245
	65 ≤ Lden < 70 dB	0	0	0	0
	70 ≤ Lden < 75 dB	0	0	0	0
	75 ≤ Lden <... dB	0	0	0	0
	Sum	1666	1666	1666	1666
Variant:	***Freight train only***				
DEN (24h)	... < Lden < 55 dB	1639	1666	1666	1639
	55 ≤ Lden < 60 dB	27	0	0	27
	60 ≤ Lden < 65 dB	0	0	0	0
	65 ≤ Lden < 70 dB	0	0	0	0
	70 ≤ Lden < 75 dB	0	0	0	0
	75 ≤ Lden <... dB	0	0	0	0
	Sum	1666	1666	1666	1666

Table 2.2.1

Noise index	Range /dB	difference of number of annoyed: moving track work	rail isolation	plate damping
	All sources			
DEN (24h)	... < Lden < 55 dB	0	0	0
	55 ≤ Lden < 60 dB	0	0	0
	60 ≤ Lden < 65 dB	0	0	0
	65 ≤ Lden < 70 dB	0	0	0
	70 ≤ Lden < 75 dB	0	0	0
	75 ≤ Lden <... dB	0	0	0
	Sum	0	0	0
Variant:	***Train & tram***			
DEN (24h)	... < Lden < 55 dB	8	-8	-8
	55 ≤ Lden < 60 dB	52	-52	-52
	60 ≤ Lden < 65 dB	-60	60	60
	65 ≤ Lden < 70 dB	0	0	0
	70 ≤ Lden < 75 dB	0	0	0
	75 ≤ Lden <... dB	0	0	0
	Sum	0	0	0
Variant:	***Freight train only***			
DEN (24h)	... < Lden < 55 dB	27	-27	0
	55 ≤ Lden < 60 dB	-27	27	0
	60 ≤ Lden < 65 dB	0	0	0
	65 ≤ Lden < 70 dB	0	0	0
	70 ≤ Lden < 75 dB	0	0	0
	75 ≤ Lden <... dB	0	0	0
	Sum	0	0	0

Table 2.2.2

Out of table 2.2.2, it can be seen that the effect of a local measure has very little or no effect on the global L_{den} values and its derived parameters.

This will be studied further in WP1.2.

2.3 Ghent

A major extension of the tramway in Ghent was realised towards a new congress centre. Although this concept was realised according to state of the art technology, major complaints were received.

2.3.1 Noise map

Situation

- area: Voskenslaan - Gent
- local map of refurbishment project
- 1 km² - 6000 inhabitants

Aim

- validation of new combined tram/noise concepts in large refurbishment project.
- new state of the art of project, but still complaints.

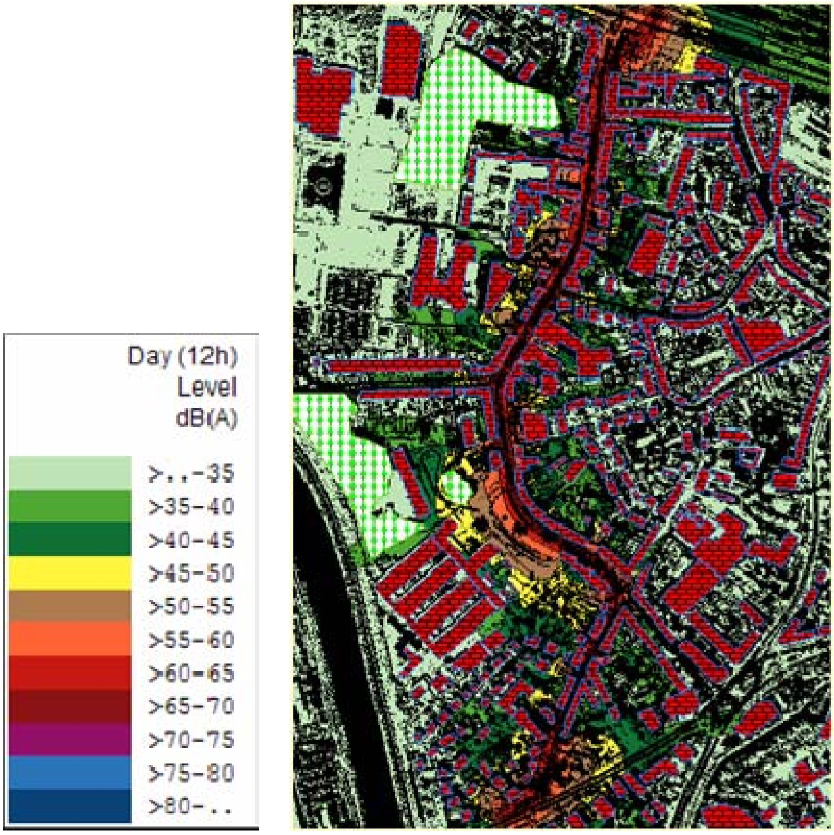


Figure 2.3.1: Initial situation – L_{den}

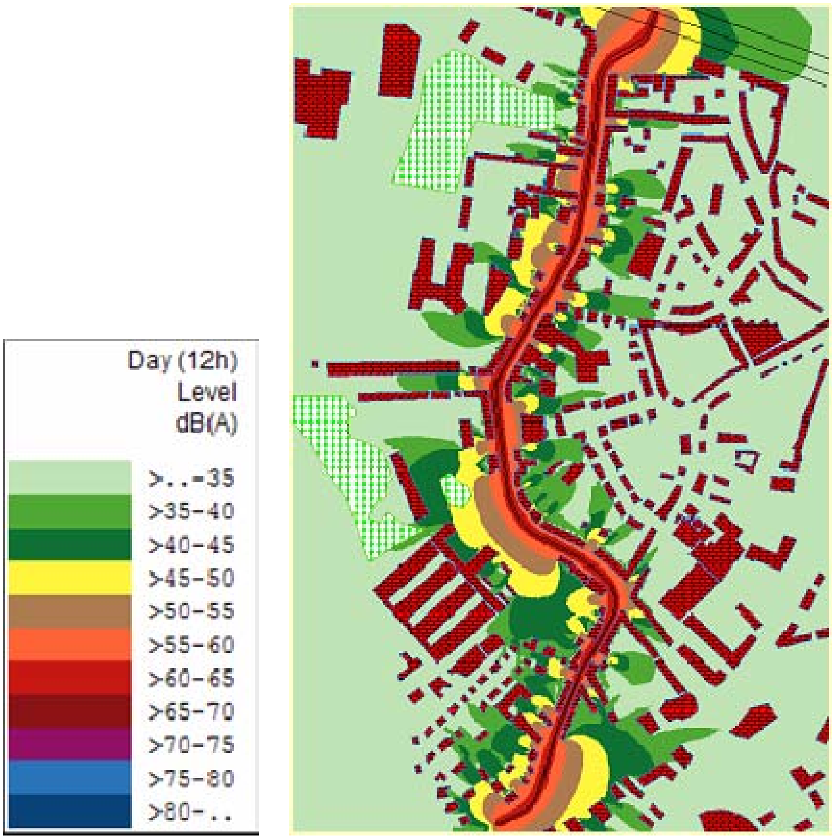


Figure 2.3.2: Initial situation – L_{night}

Noise index	Range /dB	P1A *)	P1B *)	P2A *)	P2B *)
DEN (24h)	... < Lden < 55 dB	2885	3508	289	466
	55 <= Lden < 60 dB	486	221	479	0
	60 <= Lden < 65 dB	449	91	434	0
	65 <= Lden < 70 dB	0	0	0	0
	70 <= Lden < 75 dB	0	0	0	0
	75 <= Lden <... dB	0	0	0	0
	Sum	3820	3820	1202	467
Night (9h)	...< Ln < 45 dB	2823	3395	231	468
	45 <= Ln < 50 dB	77	129	73	0
	50 <= Ln < 55 dB	475	214	468	0
	55 <= Ln < 60 dB	445	82	430	0
	60 <= Ln < 65 dB	0	0	0	0
	65 <= Ln < 70 dB	0	0	0	0
	70 <= Ln <... dB	0	0	0	0
	Sum	3820	3820	1202	469

P1A *) Inhabitants of a building with a value at the most exposed façade inside the specified range

P1B *) People assigned to a partial façade with the façade pollution

P2A *) Number of people from the set P1 living in a building with a quiet façade

P2B *) Number of people from the set P1 living in a building with a quiet façade

Table 3.3.1: Number of annoyed

2.3.2 Mitigation measures

One of the few mitigation measures possible is the increase of track bed absorption: see D6.2 – GM-RAIL-2.

Depending on the initial situation and the environmental limitations, up to 5 dB(A) reduction on emission can be obtained.

It has been evaluated if this value also can be found back in the resulting noise maps.

Track bed absorption is an input parameter that can be modified in the SRM II software.

Both L_{den} maps are given below.

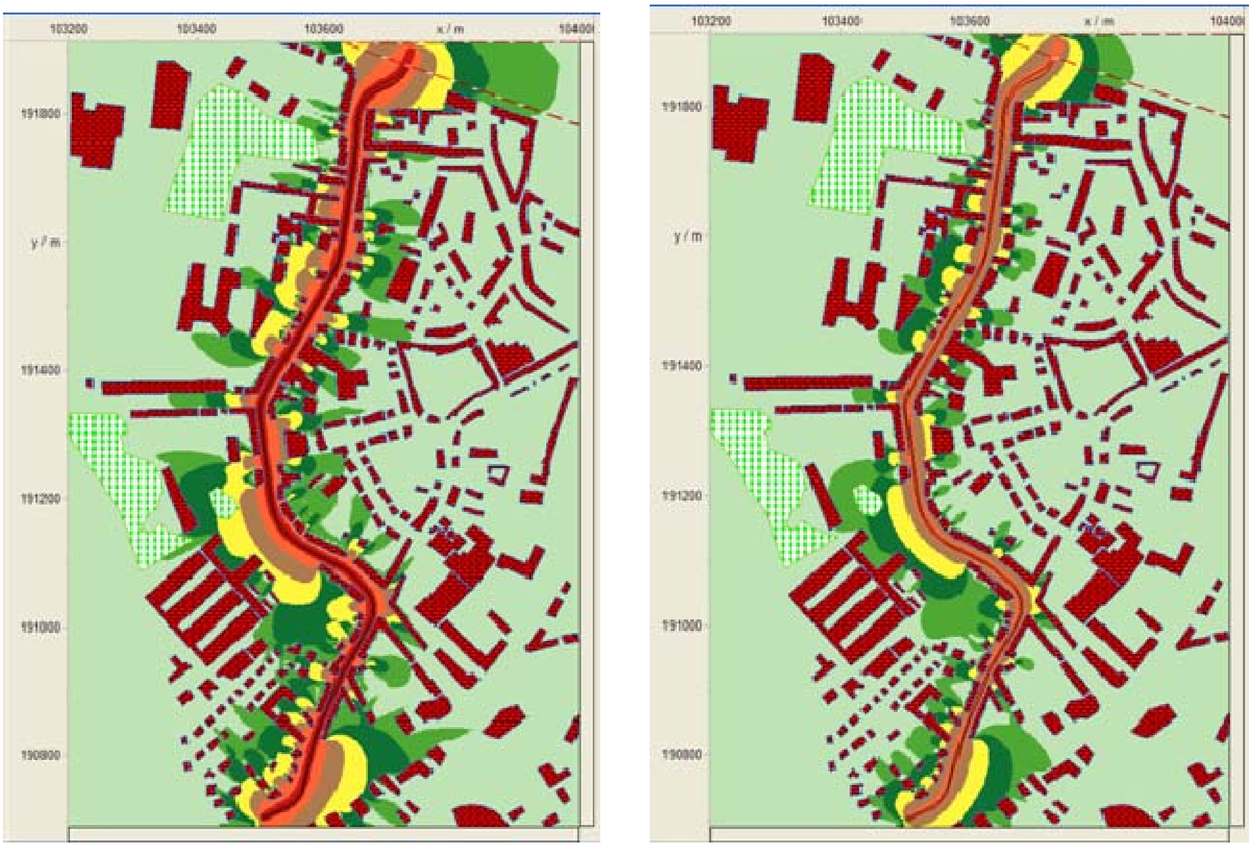


Figure 2.3.3: Original versus modified situation

The table of annoyed people gives the same information, table 2.3.2.

One can observe that the load during the night time is higher than the overall average. The mitigation measure thus is also more interesting at night.

Noise index	Range /dB	number of annoyed original	modified	difference
DEN (24h)	... < Lden < 55 dB	2885	3371	486
	55 <= Lden < 60 dB	486	449	-37
	60 <= Lden < 65 dB	449	0	-449
	65 <= Lden < 70 dB	0	0	0
	70 <= Lden < 75 dB	0	0	0
	75 <= Lden <... dB	0	0	0
	Sum	3820	3820	
Night (9h)	... < Ln < 45 dB	2823	2900	77
	45 <= Ln < 50 dB	77	475	398
	50 <= Ln < 55 dB	475	445	-30
	55 <= Ln < 60 dB	445	0	-445
	60 <= Ln < 65 dB	0	0	0
	65 <= Ln < 70 dB	0	0	0
	70 <= Ln <... dB	0	0	0
	Sum	3820	3820	

Table 2.3.2

3 FULL CITY AREAS

Four cities have been modelled in full scale, two German and two Swedish. The **Göteborg and Stuttgart** sites covers over 500 km^2, the **Augsburg** sites covers 150 km^2, the **Stockholm** site covers 75 km^2.

The software used has been CadnaA, an environmental noise mapping software developed by DataKustik GmbH, Greifenberg, Germany.

The noise mapped traffic situations have for all four cities covered road traffic. For Stockholm it has also covered tram rail tracks and railway. For Stuttgart it has also covered railway and aircraft noise, so that a basis for testing the developed Noise Environmental Rating System was created.

3.1 Göteborg

3.1.1 General area information

The municipality of Göteborg have chosen to noise map the entire area defined by the municipality border. The city is the second largest in Sweden and is located on the west coast.

Figure 3.1.1: General overview map of Göteborg

The noise mapped area is 525 km². It features 120 000 buildings where 50 000 are residential buildings inhabited by 485 000 people. The combined length of all calculated roads is 2 383 km.

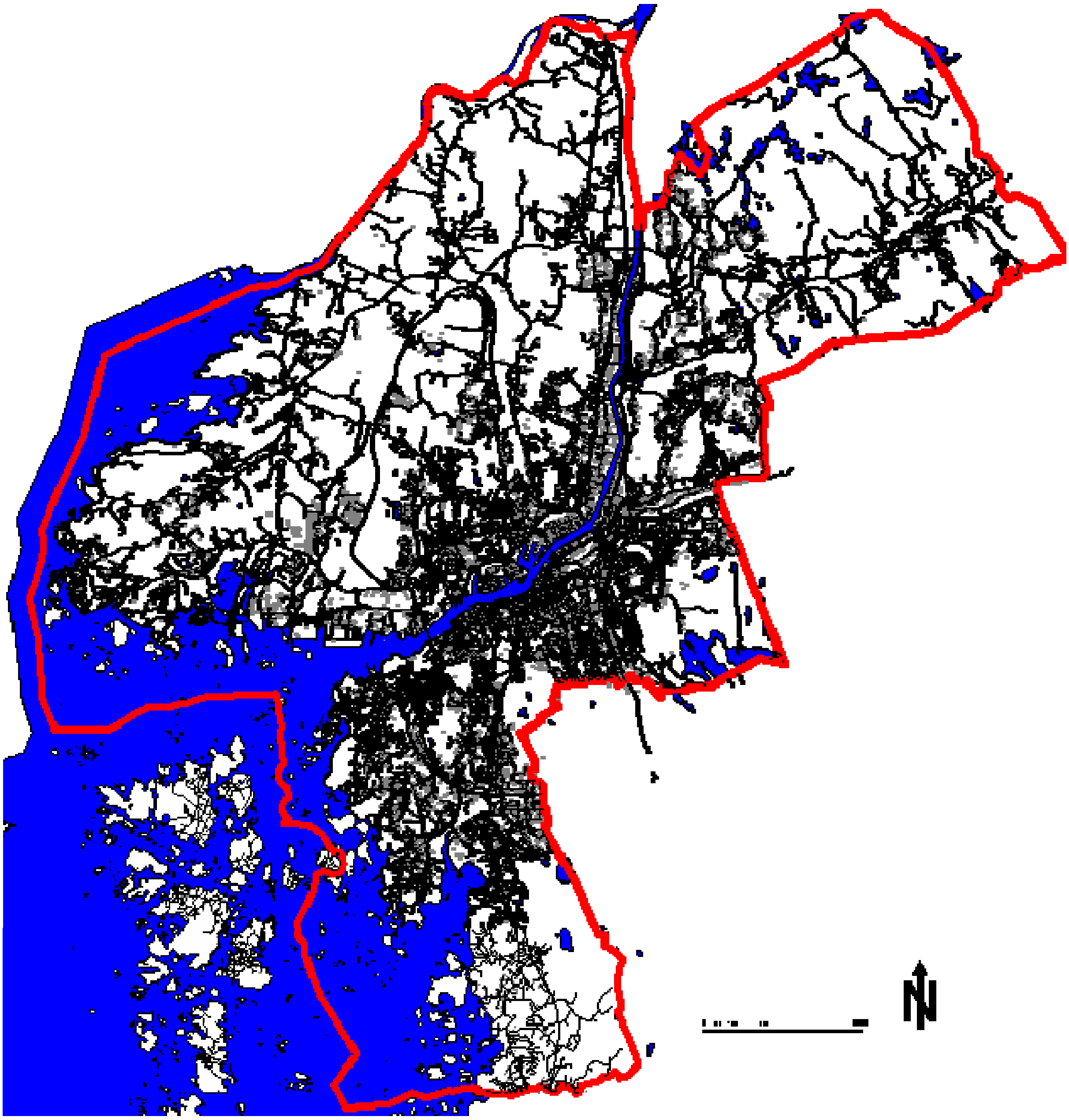


Figure 3.1.2: General overview map of Göteborg

3.1.2 Description of methods used

Calculation methods

The Swedish national computation methods are adopted and used according to EC directive:

- Road: Nordic prediction method[1], rev 1996:525

The calculated receiving grid was 10 by 10 meters and the receiving height was set to 4 meters according to the EC Directive 2002/49. All calculations have been made with one reflection due to the extensive area and calculation time.

Calculations of (free field corrected) noise levels at facades have been preformed for one height, 4 meters above ground level.

The roads were in advance categorized in five groups. Group 1 are the main roads and high-ways and group 5 bicycle roads and walkways. Measured data were available for most roads in group 1. Data for group 2 to 4 was given typical data according to the corresponding road group.

No data of the number of inhabitants for each single house were available, however exact data from the election areas were. This problem was solved using the exact number of people in each election area of the city. This was then distributed to all residential buildings inside each election area using the default calculated value of inhabitants in each house divided by the true value for the whole area as a multiplying factor. In short the method could be described as using the volume of each house as a factor for calculating the number of inhabitants.

Hot Spot detection method

The hot spot detection was made using the method presented in annex 4.1. No data for the sound insulation of the buildings were available, thus this parameter was set to 0 resulting in a Hot-Spot calculation that still shows the relative differences within Göteborg. Five locations were chosen to be studied further in an attempt to exemplify some of the causes of the hot spot detection.

1 **Road Traffic Noise – Nordic Prediction Method,** TemaNord 1996:525 Part 1: Prediction Method Revised 1996 Part 2: Background Revised 1996. ISBN 92 9120 836 1

3.1.3 Results

Noise map of the municipal of Göteborg

The noise maps presented in this report show L_{den} and L_{night} in accordance with Directive 2002/49/EC.

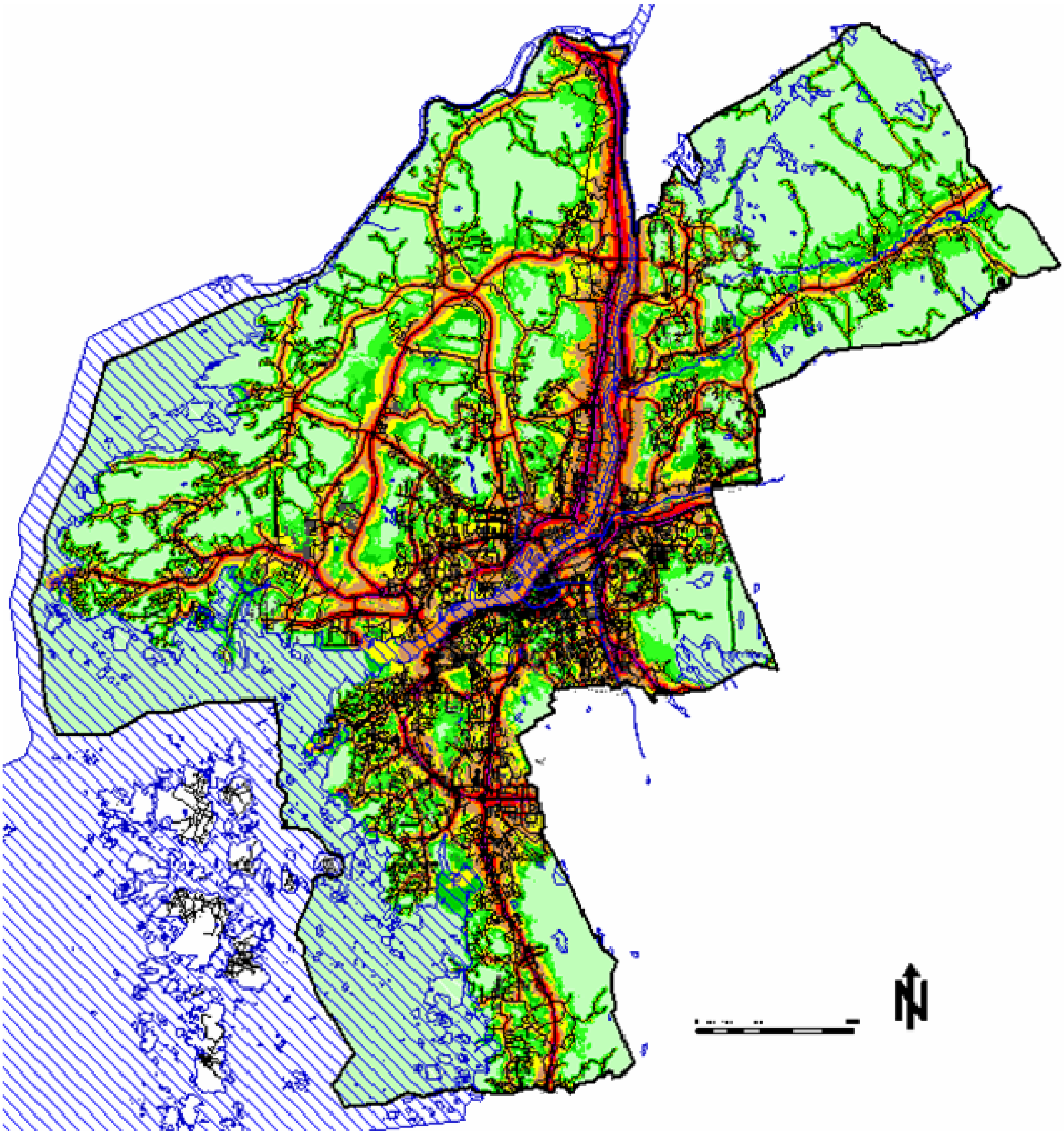


Figure 3.1.3: L_{den} calculated from road traffic in the municipal of Göteborg

Number of inhabitants in noise-classes

Due to some overlapping buildings the total calculated number of inhabitants is slightly increased in the model. The results in noise intervals are therefore presented in percent of the total population.

Interval [dB(A)]	L_{den} [inhabitants (part of population)]		L_{night} [inhabitants (part of population)]	
<50	161736	(33.5%)	380349	(78.7%)
50-55	139253	(28.8%)	57890	(12.0%)
55-60	80888	(16.7%)	29660	(6.1%)
60-65	57212	(11.8%)	10073	(2.1%)
65-70	30440	(6.3%)	4049	(0.8%)
70-75	10098	(2.1%)	1343	(0.3%)
>75	3787	(0.8%)	8	(0.0%)
Total	483418		483418	

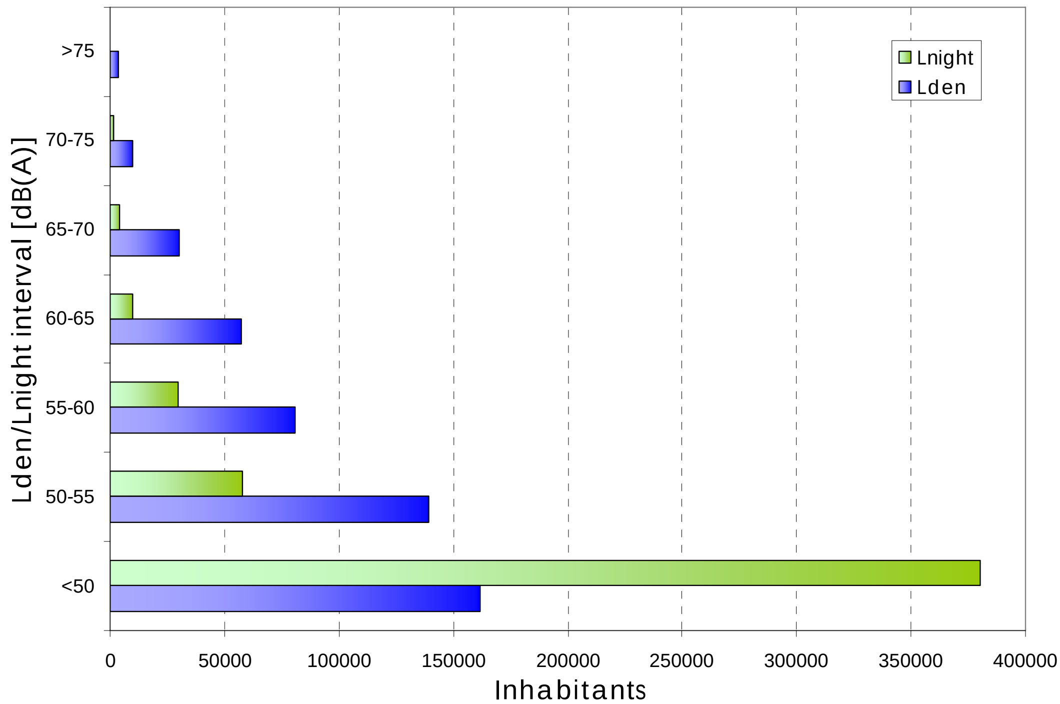


Table 3.1.1

As seen in the diagram, the façade levels are obviously shifted down during the night. But still 1.1% (or ~5300 persons) of the population has a maximum façade level greater than 65 dB(A) during night time and over 45 000 people have a maximum façade level greater than 55 dB(A) night-time.

Hot Spot detection

A complete Hot-Spot map was calculated for the municipal of Göteborg.

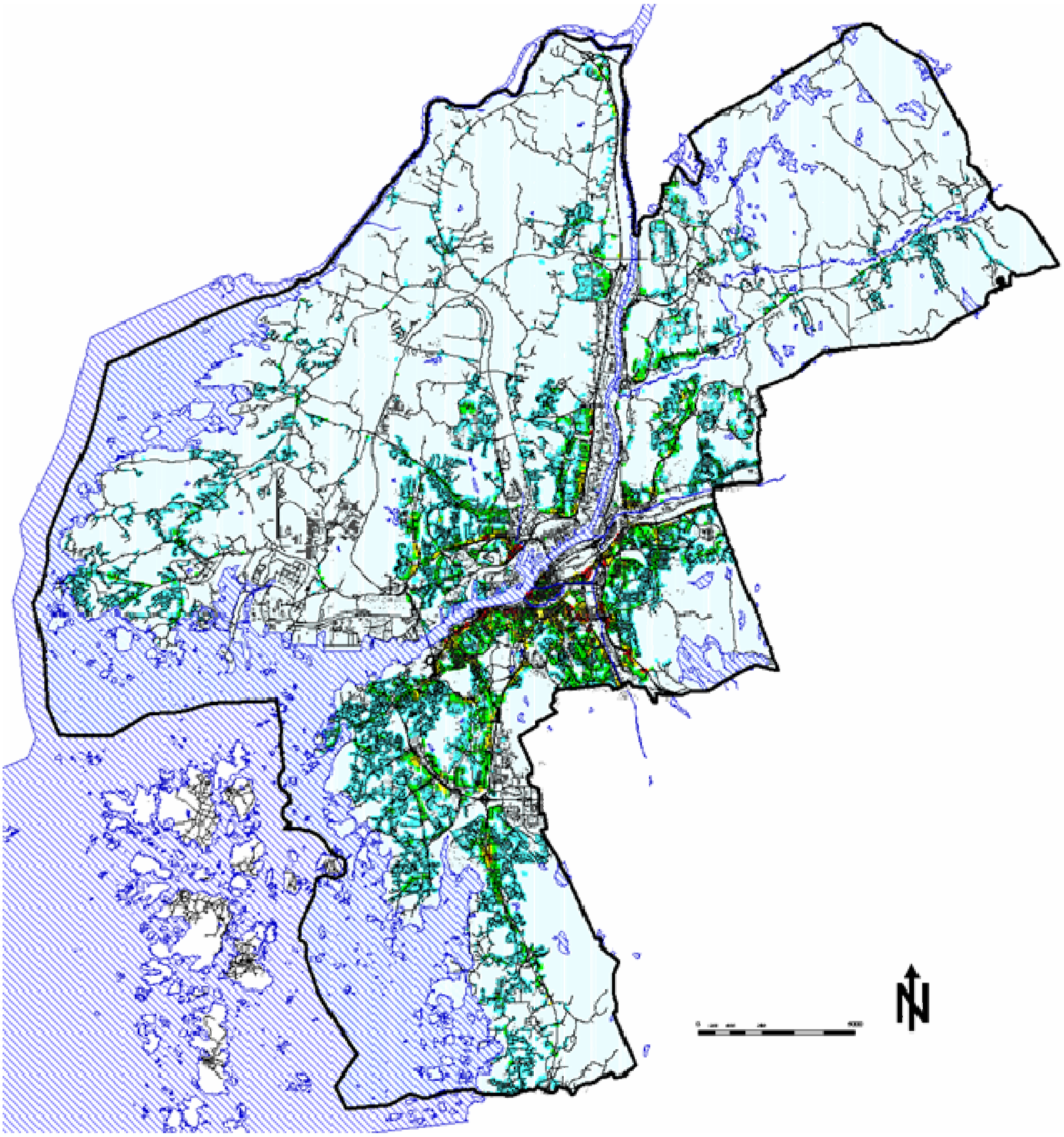


Figure 3.1.4: Hot-Spot calculated from L_{den}

Selected Hot Spots in Göteborg

After making the hot-spot analysis, five locations were selected for further investigation. The sites have been chosen to exemplify some different causes of hot-spot detection.

The first one lay near the Majnabbe harbour. It generally consists of residential buildings situated near a major road that connects the southwest part with central Göteborg.

Figure 3.1.5: Hotspot 1

Hotspot 2 is located north of Göta kanal. It features residential buildings located close to Lundbyleden.

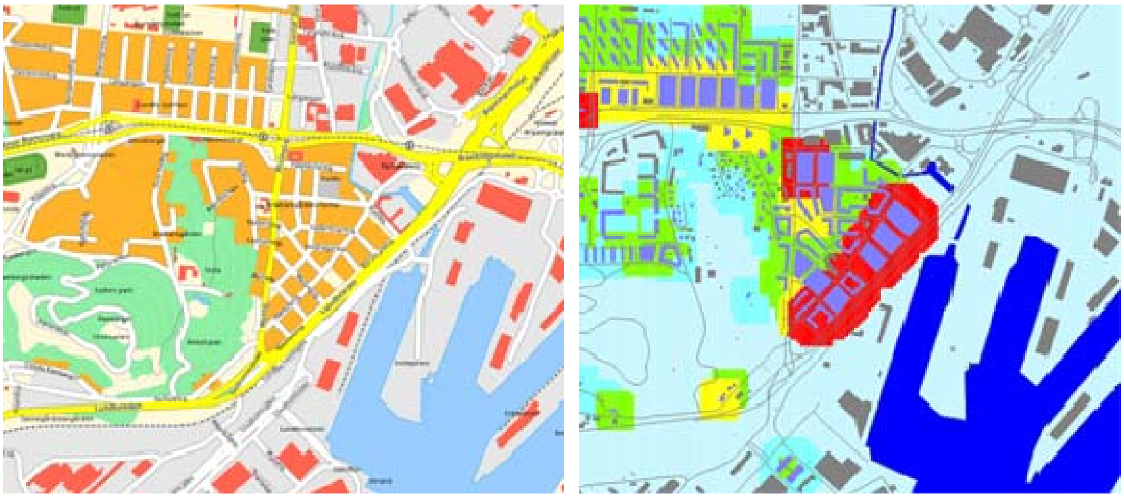


Figure 3.1.6: Hotspot 2

As seen in the map, a railway track may also contribute to the noise levels, though this is not included in the calculations.

Hot Spot #1 and #2 are “conventional” hot spots. Residential buildings located near a heavily trafficked road. In both these cases, poroelastic asphalt or screening probably would be the best measure. The later is most certainly implemented though not included in the calculations.

The third hotspot is situated by Riddaregatan. Later in the report facts about why this may have been considered a hotspot is displayed.

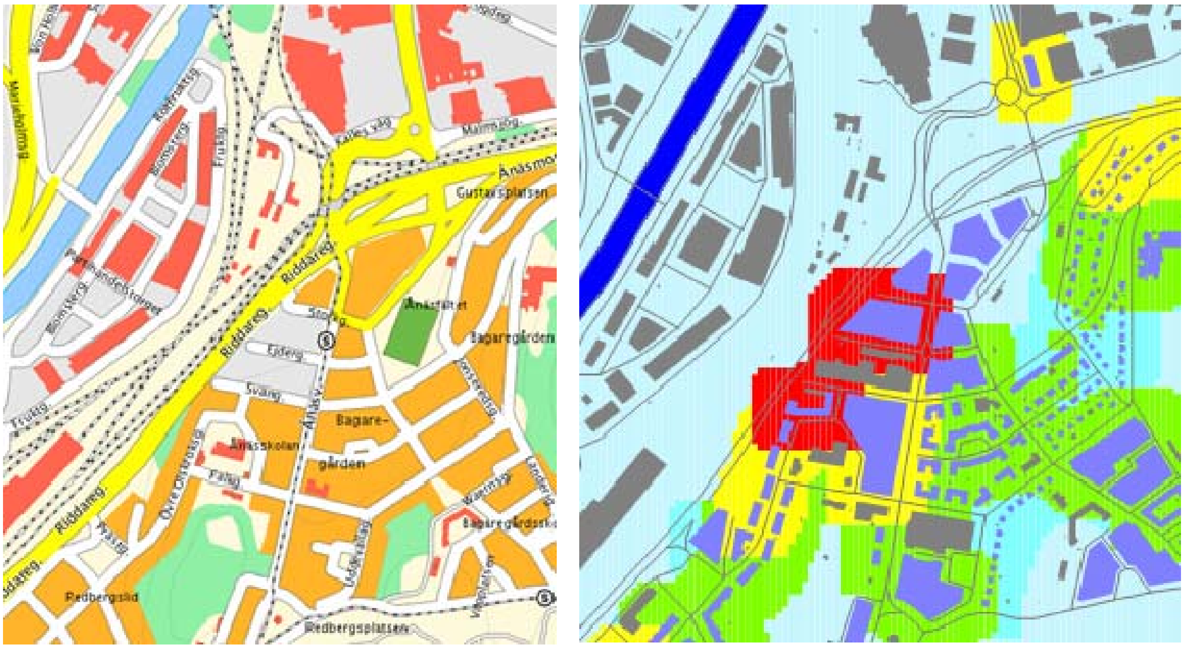


Figure 3.1.7: Hotspot 3

In the third hot spot it can be seen that a whole block is represented by a single building in the model. The cause is the available data of the buildings. The method of distributing inhabitants, described in the previous chapter, benefit large buildings and therefore the number of inhabitants in these building may have been overestimated, leading to more people exposed to high noise levels. In addition the buildings are not divided into smaller sections. People living in apartments facing east are therefore also exposed to the façade levels at the west side. This problem can partly be solved by distributing the inhabitants of each building to the corresponding façade points, thus exposing only a part of the buildings inhabitants to the high façade levels.

Close to the junction between Boråsleden and Kungsbackaleden hotspot no. four is located. This may be a typical example where the buildings closest to the roads could have been used as barriers, sheltering the adjacent buildings from road traffic noise.

Figure 3.1.8: Hotspot 4

Hot spot #4 will serve as an example how to not locate buildings. The four rectangular buildings north of Boråsleden are situated in such a way that the traffic noise is distributed into the adjacent housing area further north. The houses were probably built before Boråsleden became a heavily trafficked road. If built today the houses would have better sound insulation on the road side and would be set to shield the smaller houses to the north.

Hotspot 5 is located along Säröleden. The buildings in the area are mainly one or two storey buildings.

Figure 3.1.9: Hotspot 5

Number 5 is shown because it is an isolated occurrence along Säröleden. The reason is the available geometrical data. In the calculation, no data regarding screens were available. This show how the input data is some cases can generate false indications and stresses the issue of correct geometrical and source input data.

3.1.4 Further work

The noise map of the municipal of Göteborg is to be complemented with calculation of tram noise and railway noise. These calculations will most certainly bring further understanding and highlighting of areas where noise measures should be prioritized.

The Hot-Spot detection will be further developed to generate more accurate results. The inhabitants of each building will be distributed to the corresponding façade points and more geometrical data will be available to further increase quality.

3.2 Augsburg

3.2.1 General area information

The city of Augsburg with its 280.000 inhabitants is a central point of Bavaria. In 2000 years of development a townscape occurred which is characterized by its old town. From 1800 until 1950 Augsburg was famous for its textile industry which nowadays leaves big industrial areas to be reintegrated into urban management. Since the 19th century large scale industry (mechanical engineering, paper manufacturing) was established in the inner city.

Traffic situation

The transport network of Augsburg contains 625 km of public roads, 73 km of tram rail tracks and 70 km of railway. There is no underground network.

Noise exposure

The historical city wall which is surrounding Augsburg creates a traffic situation with very few main roads leading into and out of Augsburg. This causes a noise exposure of road traffic which is to be seen as problematic. Narrow roads, highly dense areas and historical roadbeds contribute considerably to the noise situation in the city.

The contribution of national railway, tram and industrial noise is to be neglected compared to the noise exposure caused by road traffic. The aircraft noise contribution is to be classified as insignificant.
Already in 2000 the city of Augsburg began to develop a noise information system which enables them to show the noise exposure in every region. Besides that citizens are able to access information about the noise situation via Internet at any time (www.laermkarten.de).

In 2003 the city of Augsburg started developing noise reduction plans. Together with rehabilitation programmes for different parts of the city noise reduction arrangements are planned and implemented. In line with urbanism and traffic planning noise reduction and noise prevention methods are investigated and arranged.

The noise reduction plans are made by the urban management office, the environmental agency and the Civil Engineering Office.

Possibilities of noise reduction

First of all together with town planning projects there are possibilities to reduce the noise exposure in the inner city. The first steps are:

- Planning the building layout with noise sensitive rooms at quiet side
- Additional or improved insulation glazing and ventilation provisions as well as
- Land utilisation plans to reduce acoustical conflicts in living areas near by.

3.2.2 Description of methods used

The level of noise exposure has been evaluated using a 3-dimensional calculation model of local geographical conditions which was set up with an accuracy that meets the requirements of noise propagation. In its essence the model is based on generally / countrywide available data, but was reconstructed and advanced with additional data given by single communes.
The software used for modelling and calculating was Cadna/A Version 3.5.116 (DataKustik GmbH, Greifenberg).
The calculations themselves were processed in a cluster with 24 computers connected to each other.

Following digital input data was used:

- three-dimensional digital terrain model
  (despite the enormous amount of the terrain model data in ASCII-format with geodetic points in a grid size of 5m has been used)
- three-dimensional digital models of buildings with information about their main usage
- Information about noise insulation arrangements like sound barriers,
- geographical and acoustical attributes of noise sources (streets) including the actual traffic data
- data about the number of inhabitants of every residential house as a base for evaluating noise exposure
- digital land utilisation plans, topographic maps and geographically referenced pictures to ease the model building

The calculations of noise maps are based on the European directive 2002/49/EC and its implementation in national (German) law (34.BImSchV) with use of noise indicators L_{den} and L_{night}. The day-evening-night level L_{den} is the A-weighted long term average sound level for the period day (06.00 – 18.00), evening (18.00 – 22.00) and night (22.00 – 06.00). The night-time noise indicator L_{night} is the A-weighted long-long term average sound level as defined in ISO 1996-2: 1987 determined over all the night periods of a year.

The national calculation method VBUS (Vorläufige Berechnungsmethode für den Umgebungslärm an Straßen) has been applied. Compared to RLS-90 (Richtlinie für den Lärmschutz an Straßen RLS-90) the VBUS calculation method differs in following points:

- The diffusion of sonic rays was assumed to be parabolic. This was done to make sure the results of this calculation method are equal to those of the French calculation method “NMPB-Routes-96”, which is what the directive 2002/49/EC asks for.
- The calculation method of the “long, straight road” was not taken over from RLS-90 as nowadays noise maps are processed merely by computer programs based on “sectional processing” of roads, which means that roads get split up in small pieces with single noise sources in mid of each piece.
- The distinction of cars and trucks has been set to 3.5 tons permissible maximum weight instead of 2.8 tons according to RLS-90.
- Parking lots do not get mapped as the French method “NMPB-Routes-96” which is to be regarded as an interim calculation method does not regard them either.

All noise maps have been calculated with a receiver grid of 10 by 10 meters and a receiver height of 4.0 meters above terrain. Ground effects as well as reflections at building facades and screens have been taken into account.

Directive 2002/49/EG gives a number of guidelines how detailed information should be presented to inform the citizen and for the development of action plans. Creating maps disclosing the exceedance of a so called limiting-value or tripping level is one example.
To identify the amount and geographical position of buildings affected by sound levels exceeding these limiting values and for the quantification of people exposed the calculation-points have been set on the building facades. The last reflection at each building facade on which the calculation points are placed therefore has not been regarded. The calculation height here also was set to 4.0 meters above terrain. When the highest facade level of a building exceeds the limiting value the building is marked in the map and noise mitigation measures have to be considered. As the directive 2002/49/EC does not mention general tripping levels there are currently discussions in Germany to agree on an appropriate value.

Following tripping levels have been chosen for the analysis:[2]

- L_{den} > 65 dB(A) (and/ or)
- L_{night} > 55 dB(A).

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2 according to the 34. BImSchV (Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Lärmkartierung- 34.BImSchV) 2006-03-06

To quantify the estimated number of people (in hundreds) living in dwellings that are exposed the German calculation method VBEB (Vorläufige Berechnungs-methode zur Ermittlung der Belastetenzahlen durch Umgebungslärm) has been applied. This calculation method is based on the VDI 3722, but got adjusted though to the requirements mentioned in 34. BImSchV as well as in the appendices I, IV and VI of the directive 2002/49/EC.

Since in general the exact position, size and floor plan of dwellings are not known the total amount of people living inside gets equally spread over the immission points placed on the building facades.
The value “inhabitants per immission point” which was determined gets related to the immission level at that point. Afterwards the amount of people attributed to a facade level exceeding the tripping value gets summed up.

Detection of focal points / hot spots

The hot spot detection has been carried out using NERS (Noise Environmental Rating System)[3]. Using NERS it is possible to sum up the noise score within an area in one single numerical value. Thus the benefits of different measures become comparable which is why NERS has been used to design and evaluate different town planning measures.

In order to identify focal points of noise exposure the noise exposure levels of buildings are summed up within a grid of 100 by 100m or 50 by 50m. The grid itself gets relocated along a smaller grid of 10 by 10m. This method causes the exact contours of focal points (houses with at least one facade level exceeding the tripping value) to become more “blurry”. As a result those points are not fully attached and limited to building contour lines, but expand over an area. By categorizing the noise score levels and correlating them with colours, focal points can be displayed.

[3] Described by Wolfgang Probst and Henk Miedema in QCity Report D.1.1 and Chapter 1 of this report

The "object scan" is illustrated in following picture:

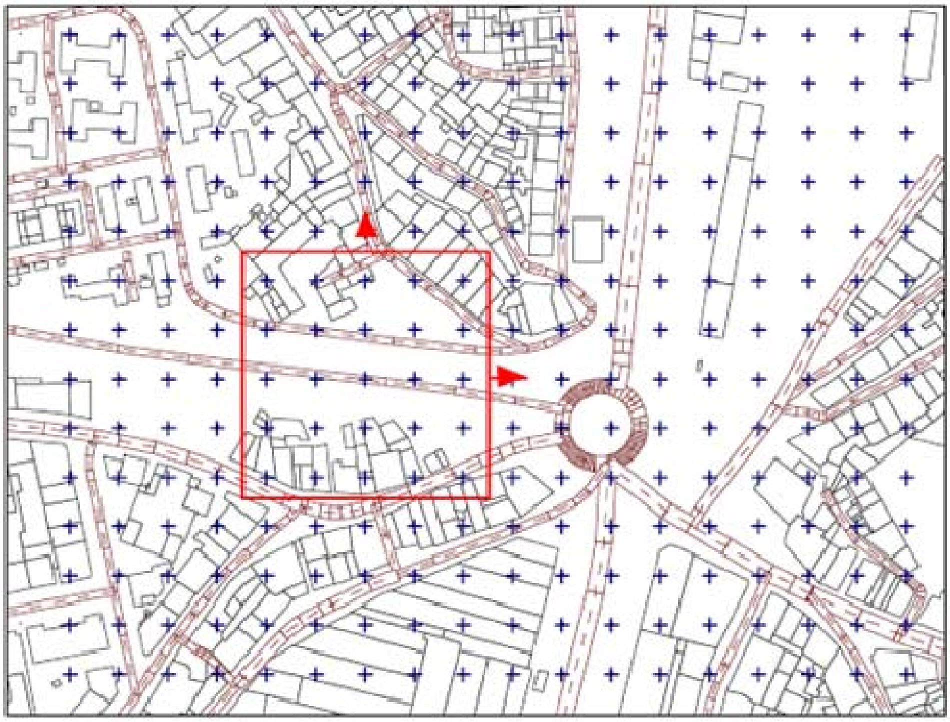

Figure 3.2.1: Object Scan and relocation of bigger grid along the smaller grid size

3.2.3 Results

Noise maps of the agglomeration of Augsburg have been produced for noise levels L_{den} and L_{night}. They will be accessible on http://www.qcity.org/maps with scales of 1:400000 up to 1:25000.

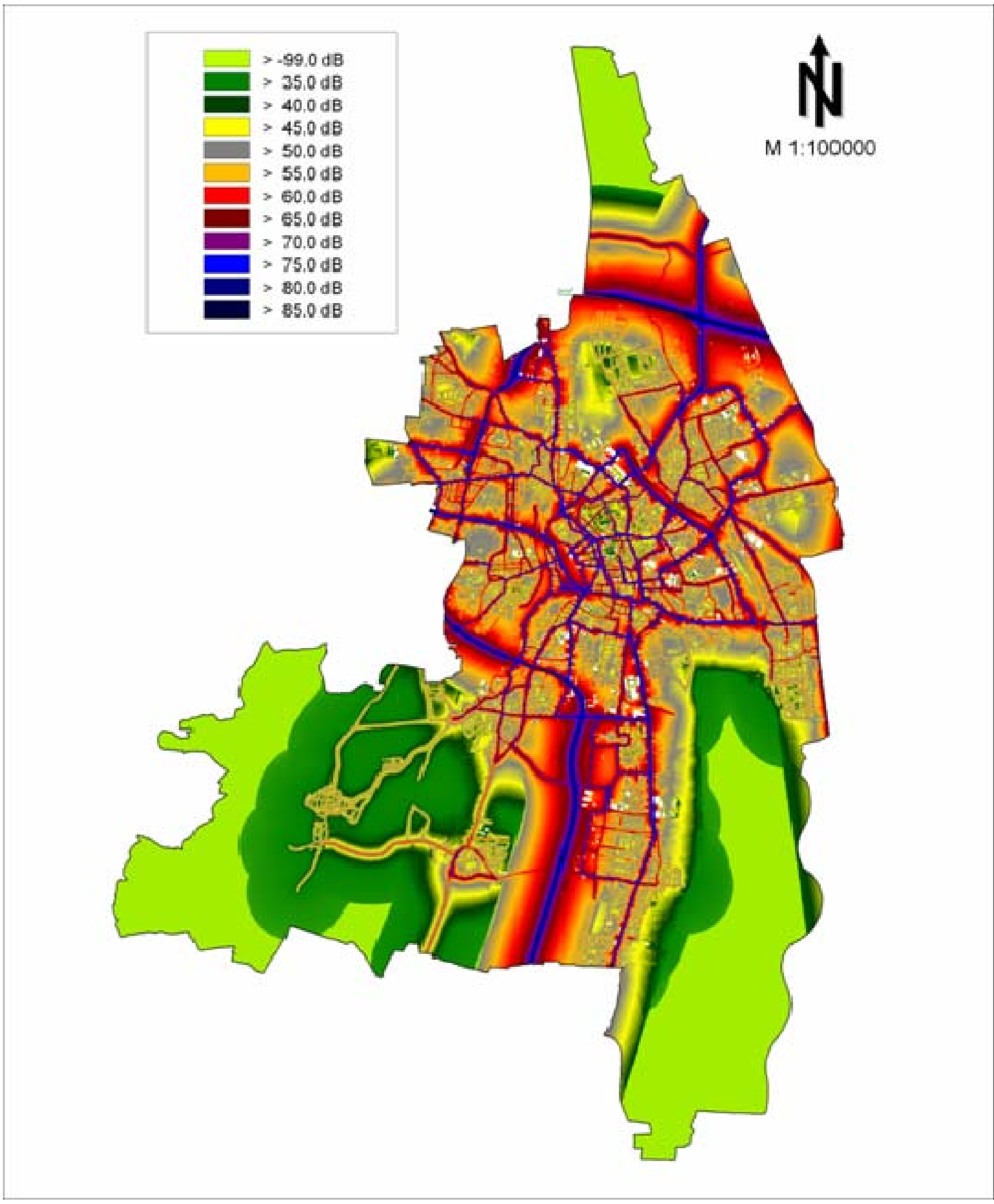

Figure 3.2.2: Noise map - traffic noise L_{den} / Augsburg

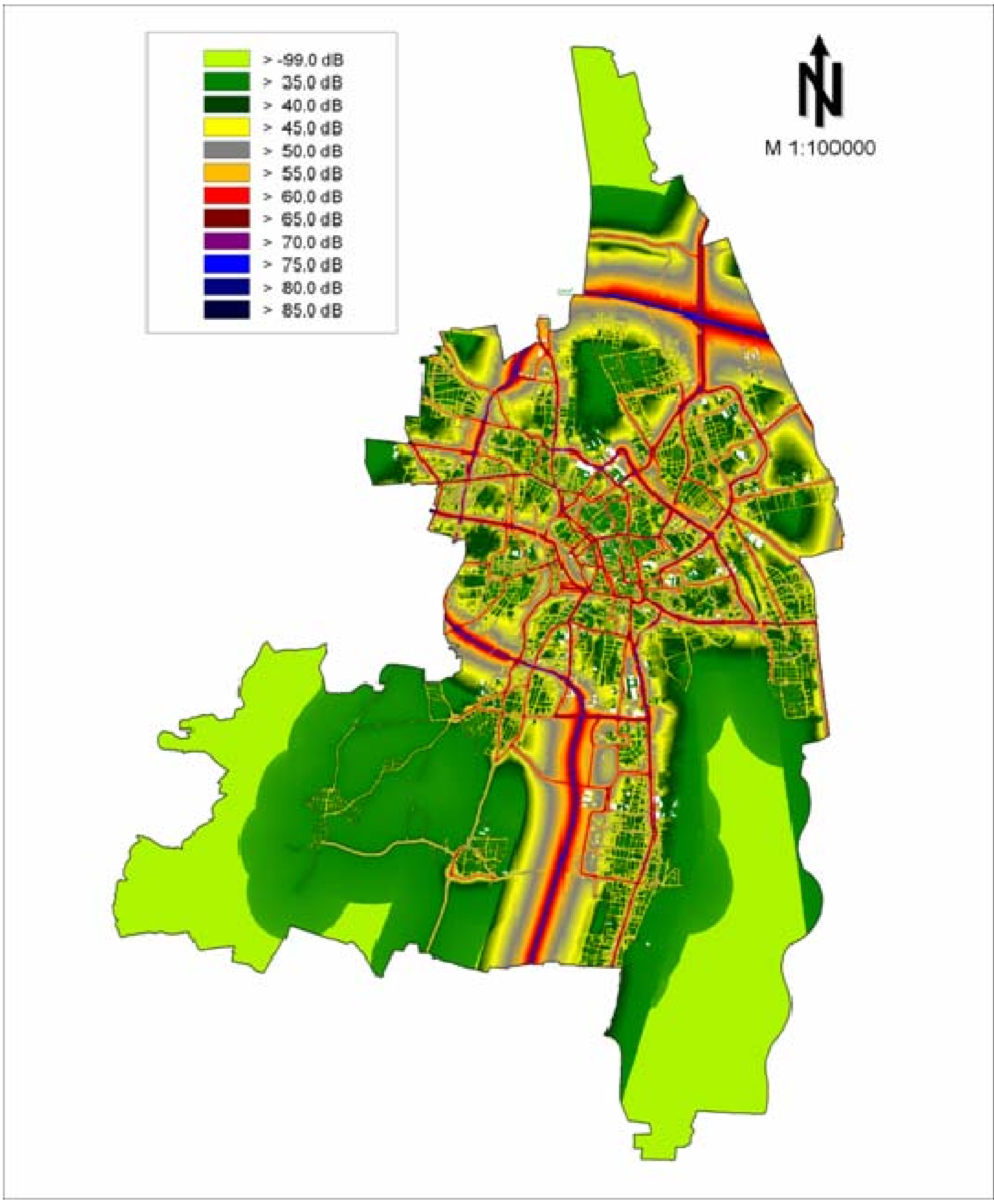

Figure 3.2.3: Noise map - traffic noise L_{night} / Augsburg

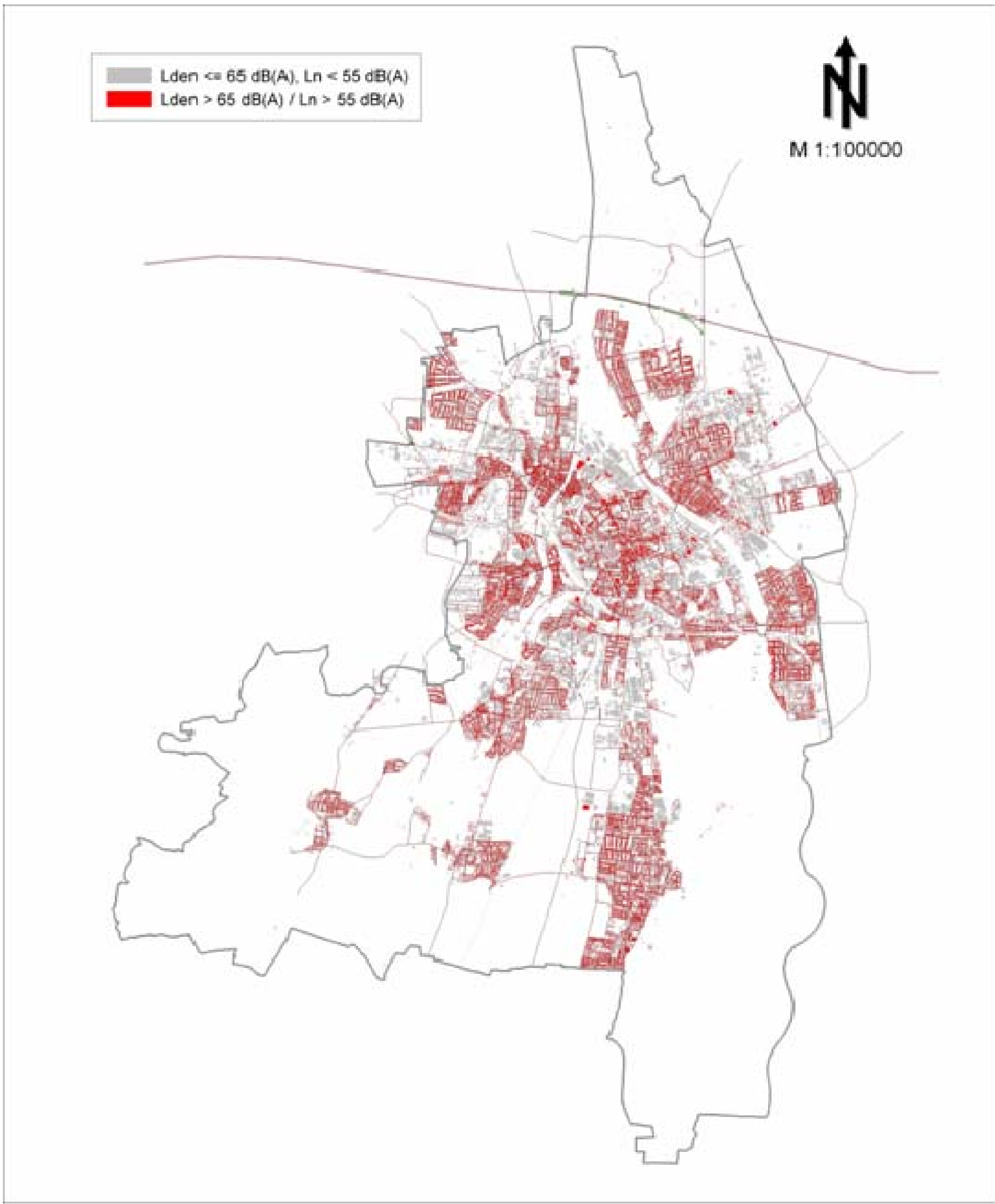

Figure 3.2.4: Residential buildings with facade levels exceeding limiting values / Augsburg

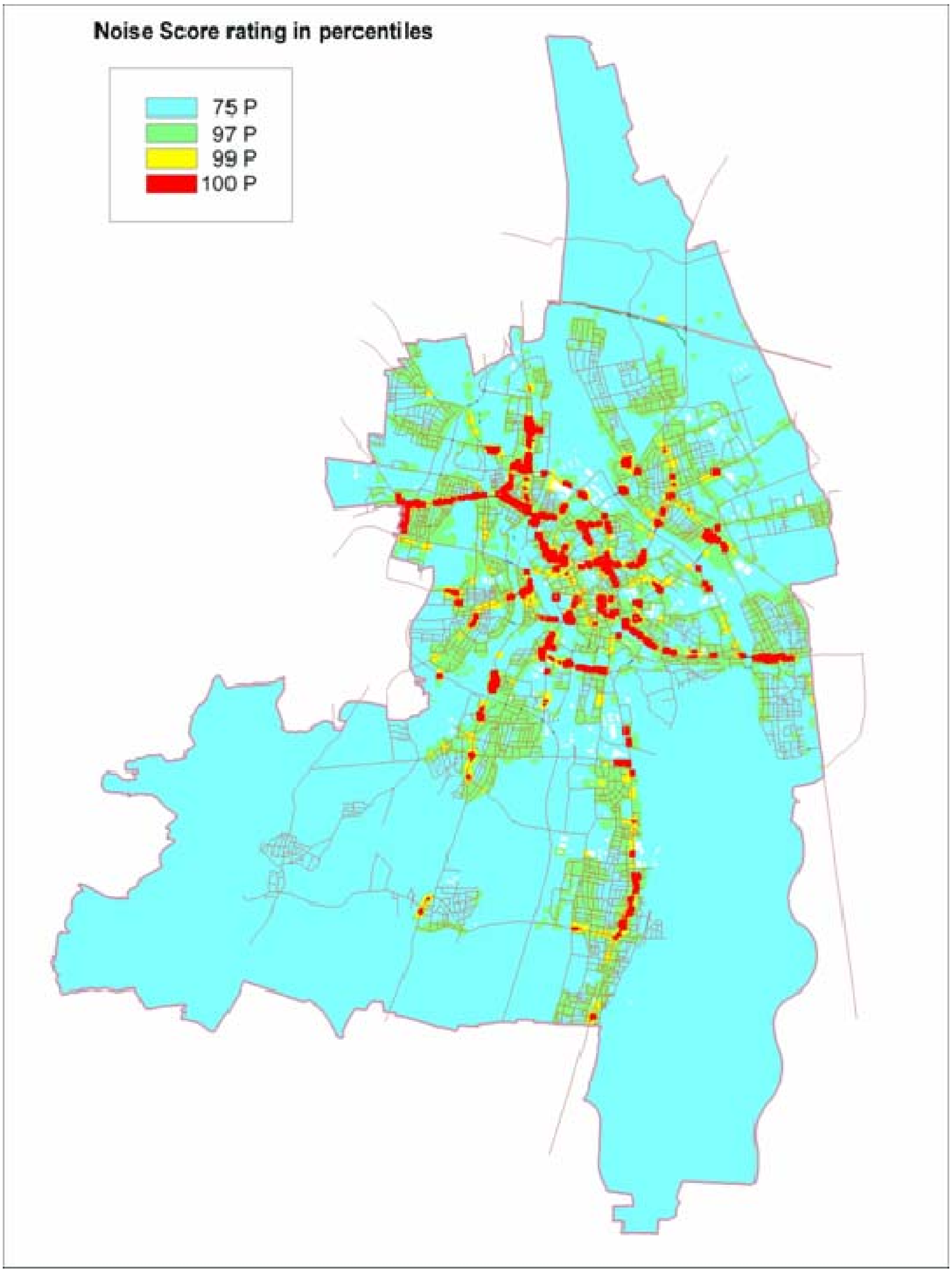

Figure 3.2.5: Noise exposure / hot spots in Augsburg

The picture shows the detected hot spots using NERS. The Noise Score of every building was tabulated so that percentiles could be marked.

Number of inhabitants in noise-classes and Noise Score

The table shows the amount of people in noise classes and the total noise score (using NERS) for a small part of Augsburg (area of Maximilianstrasse) at actual state and after implementing different measures. The calculation has been carried out according to the German calculation method VBEB (Vorläufige Berechnungsmethode der Belastetenzahlen).

When insulated glazing and ventilation provisions are implemented only the noise level L_{night} has been reduced by 15 dB(A) as it was assumed that this measure would be effective only at night. At daytime the theory is that windows would be opened which nullifies the positive effect of additional insulated glazing.

For this analysis the façade levels of each facade point and the apportioned amount of inhabitants have been considered.

		actual state (Status Quo) 2005		**insulated glazing and ventilation provisions**		**building layout with noise sensitive rooms at quiet side**	
interval		value		value		value	
from	till	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}
	50.0	1614	1780	1636	2056	1805	2017
50.0	55.0	78	92	81	92	112	131
55.0	60.0	86	184	89	0	106	0
60.0	65.0	86	92	128	0	124	0
65.0	70.0	169	0	127	0	0	0
70.0	75.0	114	0	87	0	0	0
75.0		0	0	0	0	0	0

Noise Score	2.547.561	971.275	12.510

Analysis of hot spots with focus on town planning

In order to see the effects of town planning measures in a prototypical situation detailed diagnostic of hot spots has been carried out for the area "Maximilianstrasse". The area is popular for shopping and living. It has been chosen as it is highly exposed to traffic noise which gets intensified by the coarse historic paving.

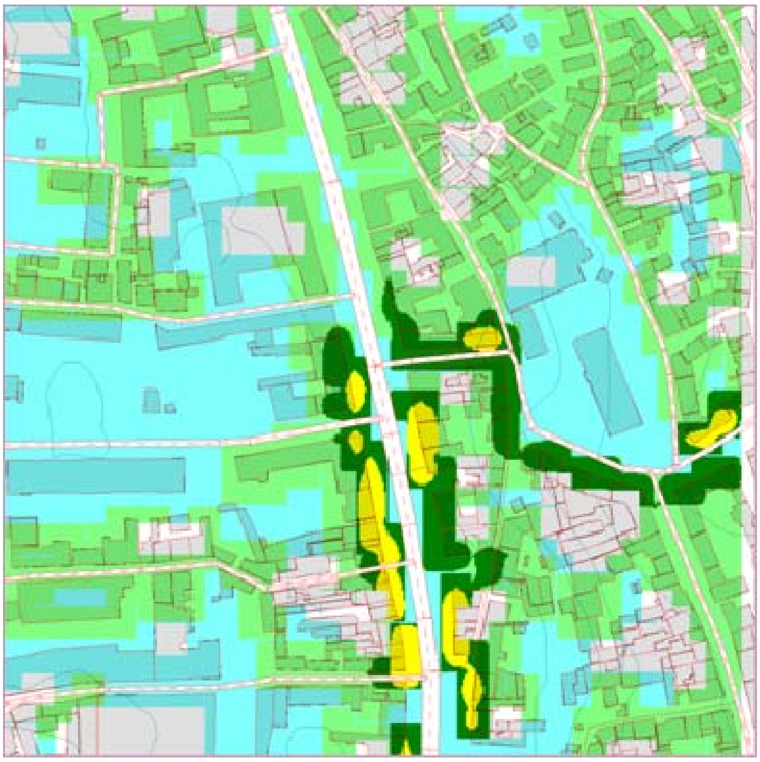

Figure3.2.6: Actual state (Status Quo 2005) / Augsburg "Maximilianstrasse"

The hot spots of the actual state can be found primarily alongside the facades that are facing main roads.

Investigation of mitigation measures

The following picture shows the calculated hot spots and the distribution of noise within the prototypical situation when insulation glazing and ventilation provisions have been implemented.

Figure 3.2.7: Hot spots when insulation glazing and ventilation provisions have been implemented / Augsburg "Maximilianstrasse"

The calculation is based on the assumption that the noise reduction effect can be simulated with NERS by subtracting 15 dB(A) from the L_{night} level. However this strong simplification correlates quite good to the noise effects (medical and psychological) of mitigation measures implemented at receiver points.

Another mitigation study concerns the potential effect of planning the building layout with noise sensitive rooms at quiet side. It is assumed that the total amount of inhabitants is equally shared over the quiet facades. Quiet facades in this context are facades whose noise level does not exceed the limiting value of 65 dB(A) for L_{den} and 55 dB(A) for L_{night}. One can recognize that the total amount and intensity of hot spots have changed dramatically when applying this measure which is, because theoretically no inhabitant is exposed to noise levels exceeding the limiting values. When implementing this measure the hot spots switch from facades that face the main roads to facades on the reverse side.

Planning the building layout with noise sensitive rooms at quiet side is subjected to restrictions just like any other measure. One of these restrictions is placed through the geographical orientation of the facades. Allocating inhabitants on north sides is to be regarded critical. Since the subject of this examination was to explore the potential when changing the building layout the geographical orientation of facades has not been regarded.

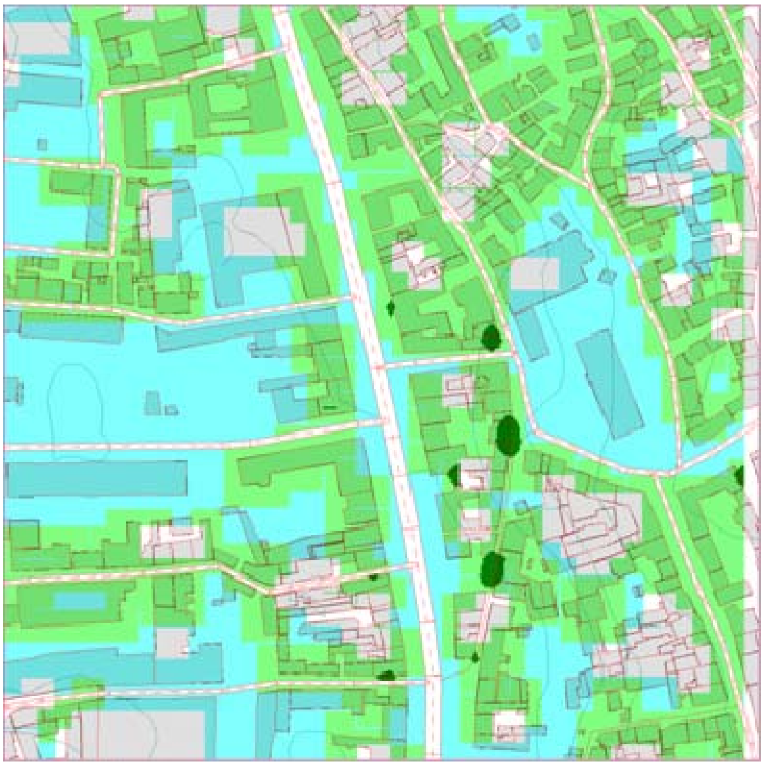

Figure 3.2.8: Hot spot scenario when building layout with noise sensitive rooms at quiet side has been implemented / Augsburg "Maximilianstrasse"

Mitigation measures at receiver points can not be regarded equal to those that are implemented at source or close by. These types of mitigation measures reduce the noise level area wide which takes a much wider effect so that living areas outside of buildings like balconies, terraces or gardens would be less exposed. The noise climate would be improved inside and outside buildings.
One possibility to reduce noise at source (wheel/ road surface) is to improve the acoustical attributes of the surface. When changing parts of the road surface from paving stones to sawed paving stones a noise reduction of 5 dB(A) can be expected.

Following map shows the effect of silent road surface (L_{den} -5 dB(A)).

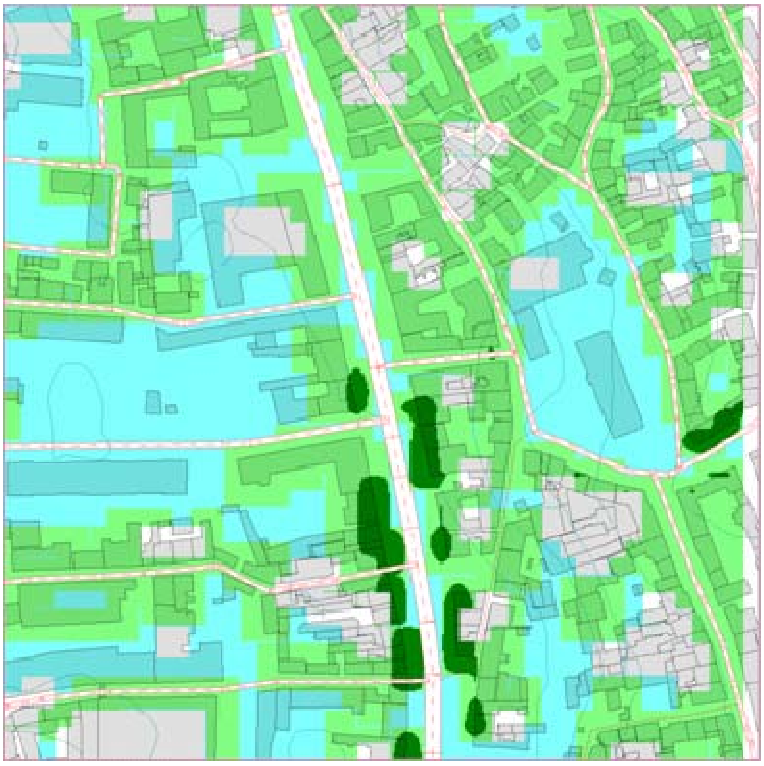

Figure 3.2.9: Hot Spot scenario when L_{den} is reduced by 5 dB caused by new road surface / Augsburg “Maximilianstrasse”

Optimization

For detailed diagnostic of town planning measures the calculation of Noise Scores will be done taking into account an area specific noise level. Therefore the so called “area 50” criteria will be added to the “L_{den} based façade level” criteria of NERS.

Expected improvement

The expected improvements will be investigated in detail in Subproject 5 when specific mitigation measures will be developed, implemented and the effectiveness quantified.

Intermediate evaluation of benefits

The noise score has been determined using NERS. When using the Object Scan to determine the noise score within the prototypical situation the noise levels of each facade point have been regarded rather than taking only the highest noise level (most exposed facade) into account.
The number of inhabitants has been apportioned equal on the amount of facade points of each building. Within the scenario of planning the building layout with noise sensitive rooms at quiet side, the amount of inhabitants has been apportioned equally on the total number of facade points whose noise level does not exceed the limiting values.

	Status Quo	insulated glazing and ventilation provisions	building layout with noise sensitive rooms at quiet side	5 dB reduction caused by new road surface
Noise Score	2.547.561	971.275	12.510	85.029

In view of the criterions “annoyance” and “sleep disturbance” the noise score exclusively evaluates the noise exposure at buildings. Therefore the measure of planning the building layout with noise sensitive rooms at quiet side shows the highest noise reduction potential. However when working on noise abatement plans it would be wise to regard sectors alongside roads in city areas with high inhabitation quality next to the regard of outside living quarters.
Thus in principle measures at or close by noise sources like traffic calming, traffic reduction or silent road surface have to be preferred to measures at receiver points.

3.2.4 Further work

In WP 5.3 the feasibility of measures inside Augsburg and its efficiency will be investigated.

3.2.5 Relation with the other subprojects

Relation to SP5, WP 5.3

Results are basis for detailed mitigation studies and design of prototype for implementation.

3.3 Stockholm

3.3.1 General area information

Stockholm has been divided into three major areas. One of these, Stockholm west, has been chosen to be studied further in this project. Information about the noise mapping process, methods and results is found in D1.1.

A hot spot analysis has been made to extract problem-areas. Three hot spots were chosen to be studied further. Below follows a brief description of them.

Hot spot #1 show the area around Brommaplan and Abrahamsberg. The specific hot spots are concentrated to Bergslagsvägen, Kvambacksvägen and Drottningholmsvägen. Both Drottningholmsvägen and Bergslagsvägen are heavily trafficked roads, connecting the northern part of Stockholm west with central Stockholm.

Figure 3.3.1: Hotspot 1

The second hot spot is located near Alvik and Traneberg. The main road, Drottningholmsvägen, is elevated before reaching Tranebergsbron leading to central and southern Stockholm.

Figure 3.3.2: Hotspot 2

The last hot spot (#3) is found along Enköpingsvägen near Tensta. The area is heavily populated and consists almost entirely of houses higher than three floors.

Figure 3.3.3: Hotspot 3

3.3.2 Description of methods used

Hot Spot detection method

The hot spot detection was made using the method presented in annex 4.1. No data for the sound insulation of the buildings were available, thus this parameter was set to 0. Three locations were chosen to be studied further in an attempt to exemplify some of the causes of the hot spot detection.

3.3.3 Results

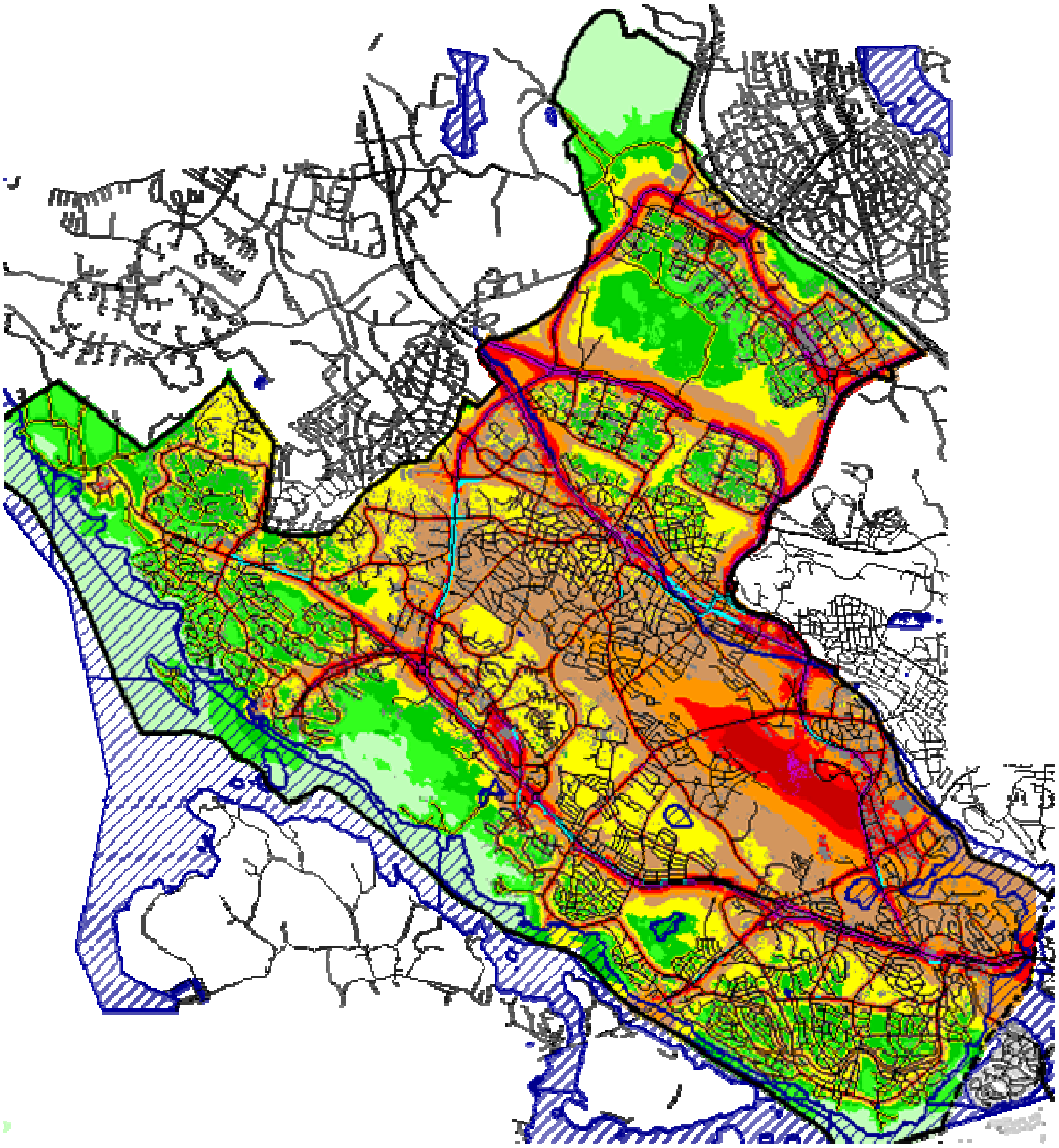

Figure 3.3.4: L_{den}, Stockholm West

Number of inhabitants in noise-classes

The inhabitants of Stockholm west have been divided into noise classes. The diagram shows L_{den} and L_{night}. As expected, the diagram is shifted “down” during night-time.

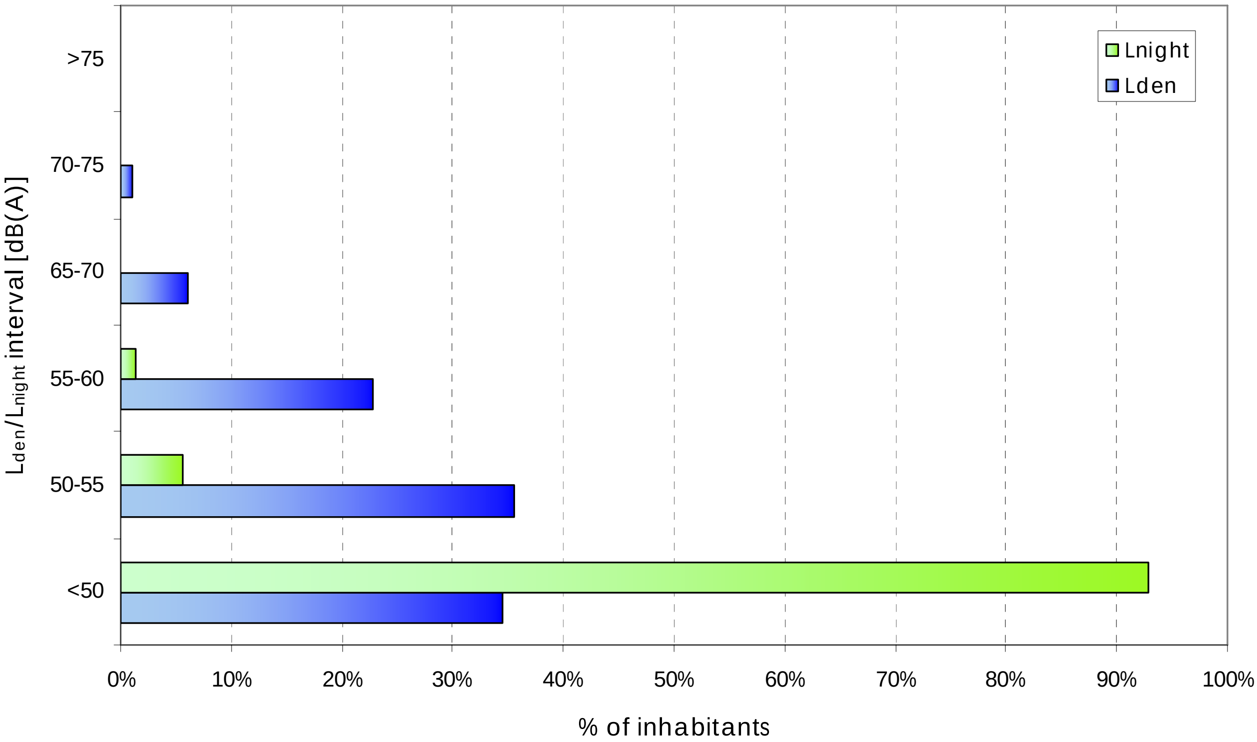

Figure 3.3.5:

Hot Spot detection

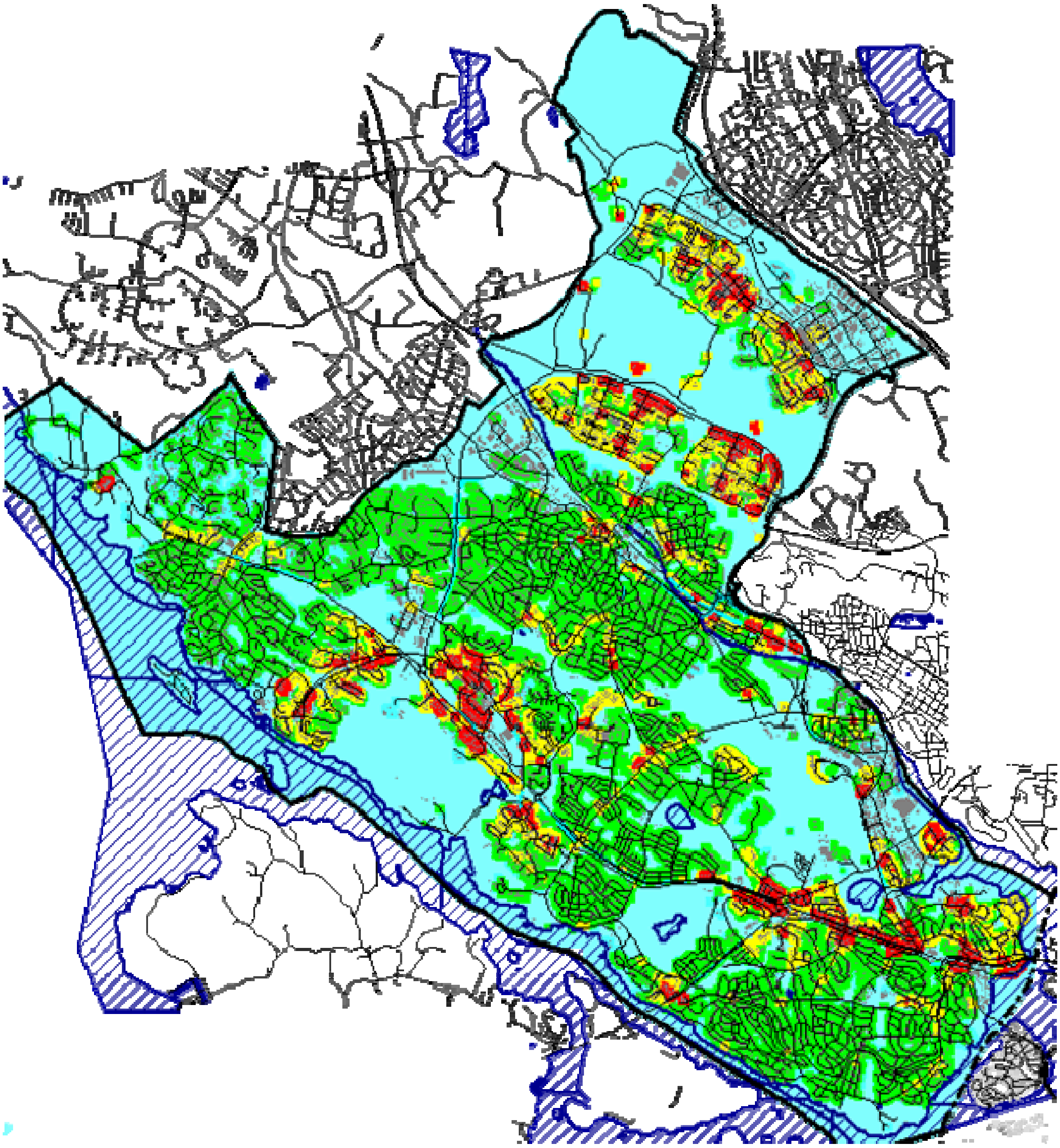

Figure 3.3.6: Hotspot, Stockholm west

A calculation of Noise Score was performed for the complete Stockholm west area. From the calculations three Hot-Spots were chosen to be studied further.

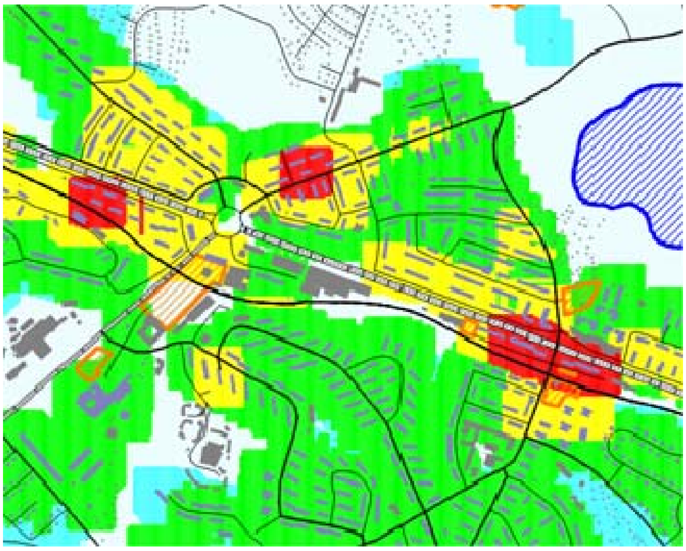

Figure 3.3.7: Hotspot 1

The first hot spot is probably due to a combination of tram and road traffic. The tram is elevated where it crosses Drottningholmsvägen witch strongly contributes to the overall noise levels. At Abrahamsberg's tram station three buildings that lay between the road and the tram tracks have been classed as inhabited buildings. Therefore it may have been deemed as a hot spot. These buildings have received measures to windows but are still exposed to high noise levels.

Figure 3.3.8: Hotspot 2

The area around hot spot #2 shows some interesting results. The hot spot close to the bridge is apparent due to the elevation of both the tram and the road. Solutions to this problem would incorporate damping of the bridge itself. Screening is difficult due to the slope but using a low, damping screen close to the tram screening should be possible. From inspection at the site, it would be most likely to find another hot spot at the road junction to the far left of the figure (Alviksplan). This is not the case due to planning of housing areas and an upwards slope north of the junction that works as a screen for the road traffic noise.

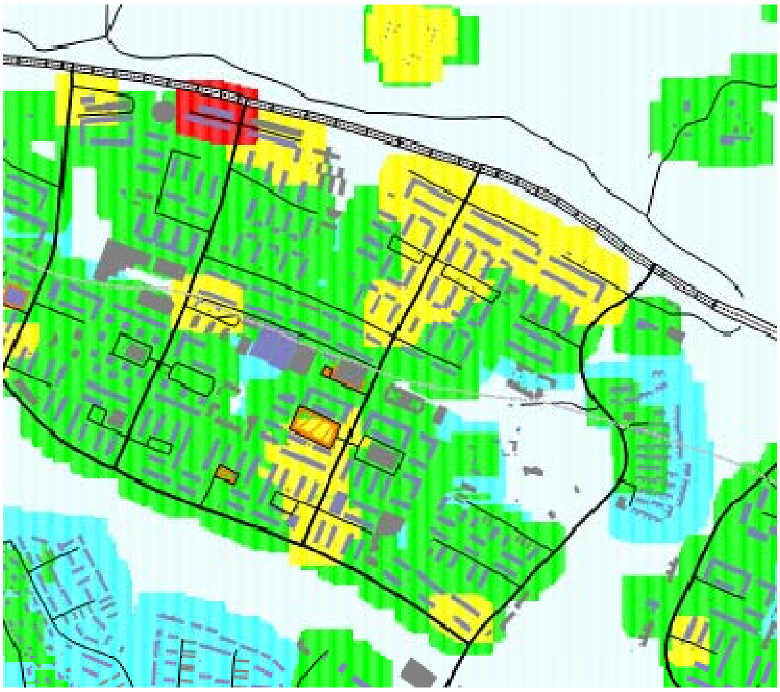

Figure 3.3.9: Hotspot 3

Hot spot #3, Tensta, show high noise score values also inside the housing area itself. Inspection at this site tells us that the noise levels inside the first row of houses are surprisingly low. The area is built so the tallest buildings shield the adjacent housing to the south. The built up area slopes down from Enköpingsvägen which also contributes to the shielding effect. A further expansion of Enköpingsvägen is planned and would most certainly increase the need for further noise actions along the first row of buildings. The overall noise level in the adjacent area would also increase making a quiet asphalt solution a good choice of action.

3.3.4 Further work

The Hot-Spot analysis of Stockholm west will be further developed using new data for the buildings including what buildings have received window measures etc. From this calculation new Hot-Spots will be investigated. The new Hot-Spot analysis will also include the distribution of inhabitants of each building to the corresponding façade points for more accurate results.

3.4 Stuttgart

3.4.1 General area information

Based on noise data and noise models from earlier investigations in parts of the agglomeration Stuttgart the agglomeration Stuttgart was mapped.

The area of investigation embraces the extended conurbation of Stuttgart with an expanse of 867 km². Thus the investigated area covers a much bigger scope than required according to the directive 2002/49/EC. This area has about 1.375 million inhabitants with about 600.000 inhabitants in Stuttgart itself which is the economic centre of Baden-Württemberg. The next biggest cities of that area are Esslingen with about 95.000 inhabitants, Ludwigsburg (about 90.000), Sindelfingen (about 66.000), Waiblingen (about 55.000) and Böblingen (about 51.000). All remaining communes have less than 50.000 inhabitants. Within the investigated area are about 433.000 buildings of which about 228.000 (approx. 53%) are residential buildings. Stuttgart distinguishes itself from other towns due to the surrounding hills. Stuttgart's lowest point is located 207 meters above sea level and its highest point is on 549 m absolute altitude.

Figure 3.4.1: Overview of the agglomeration of Stuttgart

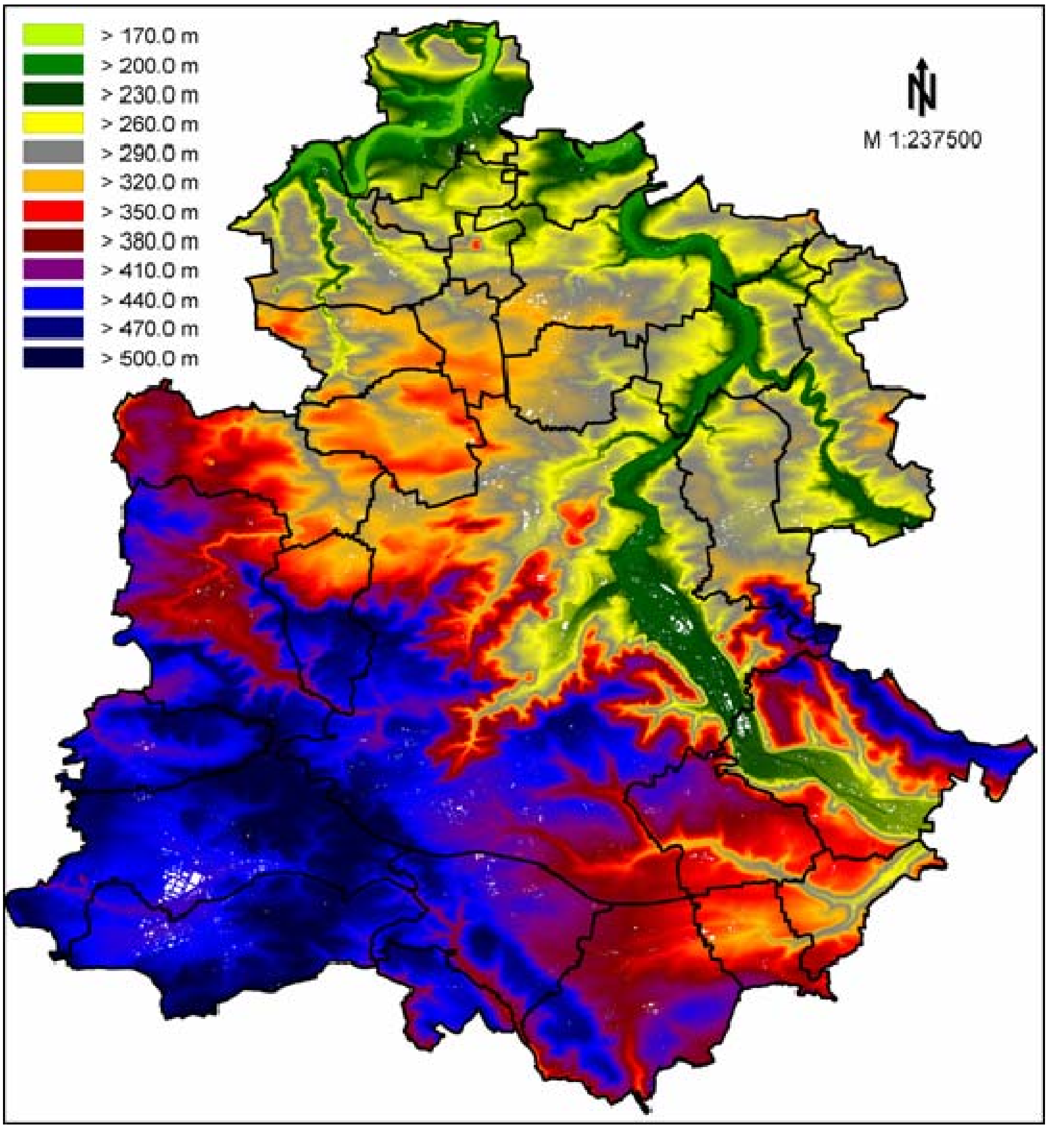

Figure 3.4.2: Lithographic map of the agglomeration of Stuttgart

The railway track between Karlsruhe-Mannheim-Stuttgart and Ulm is an important piece of the central European West-East connection of Paris over Stuttgart and Munich to Vienna. Since 1991 Stuttgart is connected to the high speed tracks of the German Railway system.
The federal motorway A 8 and the main road B 27 cross the region from west to east, the motorway A 81 and main road B14 intersect from north to south.

The traffic situation of the agglomeration of Stuttgart (total investigated area) is as follows:

- length of motorway: 75 km
- length of trunk road maintained by the Federal Government: 100 km
- length of superordinated road network: 1100 km
- length of subordinated road network: 4500 km

The region of Fildern is characterised by its rural environment. However the region and its communes Esslingen-Berkheim, Leinfelden-Echterdingen, Filderstadt, Ostfildern, Denkendorf and Neuhausen just like the southern parts of Stuttgart are highly affected by noise because of the important traffic routes and the airport. Therefore the region and its authorities are occupied with noise reduction planning for years.

The traffic situation of the area of Filder (part of total investigated area) is as follows:

- length motorway 32 km
- length of trunk road maintained by the Federal Government 34 km
- length of superordinated road network 213 km
- length of subordinated road network 671 km
- length of rail network 22 km
- aircraft movements per year 80.000

Stuttgart also started practicing noise mitigation planning already in 1996. For the districts of Vaihingen and Zuffenhausen noise mitigation measures were discussed with public participation. Some of them have already been put into practise.

3.4.2 Description of methods used

The level of noise exposure has been evaluated using a 3-dimensional calculation model of local geographical conditions which was set up with an accuracy that meets the requirements of noise propagation. In its essence the model is based on generally / countrywide available data, but was reconstructed and advanced with additional data given by single communes.
The software used for modelling and calculating was Cadna/A Version 3.5.116 (DataKustik GmbH, Greifenberg).
The calculations themselves were processed in a cluster with 24 computers connected to each other.

Following digital input data was used:

- three-dimensional digital terrain model
  (despite the enormous amount of the terrain model data in ASCII-format with geodetic points in a grid size of 5m has been used)
- three-dimensional digital models of buildings with information about their main usage
- Information about noise insulation arrangements like sound barriers
- geographical and acoustical attributes of noise sources (streets) including the actual traffic data
- data about the number of inhabitants of every residential house as a base for evaluating noise exposure
- digital land utilisation plans, topographic maps and geographically referenced pictures to ease the model building

The calculations of noise maps are based on the European directive 2002/49/EC and its implementation in national (German) law (34.BImSchV) with use of noise indicators L_{den} and L_{night}. The day-evening-night level L_{den} is the A-weighted long term average sound level for the period day (06.00 – 18.00), evening (18.00 – 22.00) and night (22.00 – 06.00). The night-time noise indicator L_{night} is the A-weighted long-long term average sound level as defined in ISO 1996-2: 1987 determined over all the night periods of a year.

The national calculation method VBUS (Vorläufige Berechnungsmethode für den Umgebungslärm an Straßen) has been applied. Compared to RLS-90 (Richtlinie für den Lärmschutz an Straßen RLS-90) the VBUS calculation method differs in following points:

- The diffusion of sonic rays was assumed to be parabolic. This was done to make sure the results of this calculation method are equal to those of the French calculation method “NMPB-Routes-96”, which is what the directive 2002/49/EC asks for.
- The calculation method of the “long, straight road” was not taken over from RLS-90 as nowadays noise maps are processed merely by computer programs based on “sectional processing” of roads, which means that roads get split up in small pieces with single noise sources in mid of each piece.
- The distinction of cars and trucks has been set to 3.5 tons permissible maximum weight instead of 2.8 tons according to RLS-90.
- Parking lots do not get mapped, as the French method “NMPB-Routes-96” which is to be regarded as an interim calculation method, does not regard them either.

All noise maps have been calculated with a receiver grid of 10 by 10 meters and a receiver height of 4.0 meters above terrain. Ground effects as well as reflections at building facades and screens have been taken into account.
Directive 2002/49/EG gives a number of guidelines how detailed information should be presented to inform the citizen and for the development of action plans. Creating maps disclosing the exceedance of a so called limiting-value or tripping level is one example.
To identify the amount and geographical position of buildings affected by sound levels exceeding those limiting values and for the quantification of people exposed the calculation-points have been set on the building facades. The last reflection at each building facade on which the calculation points are placed therefore has not been regarded. The calculation height here also was set to 4.0 meters above terrain. When the highest facade level of a building exceeds the limiting value, the building is marked in the map and noise mitigation measures have to be considered. As the directive 2002/49/EC does not mention general tripping levels there are currently discussions in Germany to agree on an appropriate value.

Following tripping levels have been chosen for the analysis:[4]

- L_{den} > 65 dB(A) (and/ or)
- L_{night} > 55 dB(A).

To quantify the estimated number of people (in hundreds) living in dwellings that are exposed the German calculation method VBEB (Vorläufige Berechnungs-methode zur Ermittlung der Belastetenzahlen durch Umgebungslärm) has been applied. This calculation method is based on the VDI 3722, but got adjusted though to the requirements mentioned in 34. BImSchV as well as in the appendices I, IV and VI of the directive 2002/49/EC.

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4 according to the 34. BImSchV (Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Lärmkartierung- 34.BImSchV) 2006-03-06

Since in general the exact position, size and floor plan of dwellings are not known, the total amount of people living inside each building gets equally spread over the immission points placed on the building facades.
The value “inhabitants per immission point” which was determined gets related to the immission level at that point. Afterwards the amount of people attributed to a facade level exceeding the tripping value gets summed up.

Detection of focal points / hot spots

The hot spot detection has been carried out using NERS (Noise Environmental Rating System)[5]. Using NERS it is possible to sum up the noise score within an area in one single numerical value. Thus the benefits of different measures become comparable which is why NERS has been used to design and evaluate a concept for truck routing.
To identify focal points of noise exposure the noise score levels of buildings are summed up within a grid of 100 by 100m. The grid itself gets relocated along a smaller grid of 10 by 10m. This method causes the exact contours of focal points (houses with at least one facade level exceeding the tripping value) to become more “blurry”. As a result those points are not fully attached and limited to building contour lines, but expand over an area. By categorizing the noise exposure levels and correlating them with colours, focal points can be displayed.

[5] Described by Wolfgang Probst and Henk Miedema in QCity Report D1.1

The so called "object scan" is illustrated in following picture:

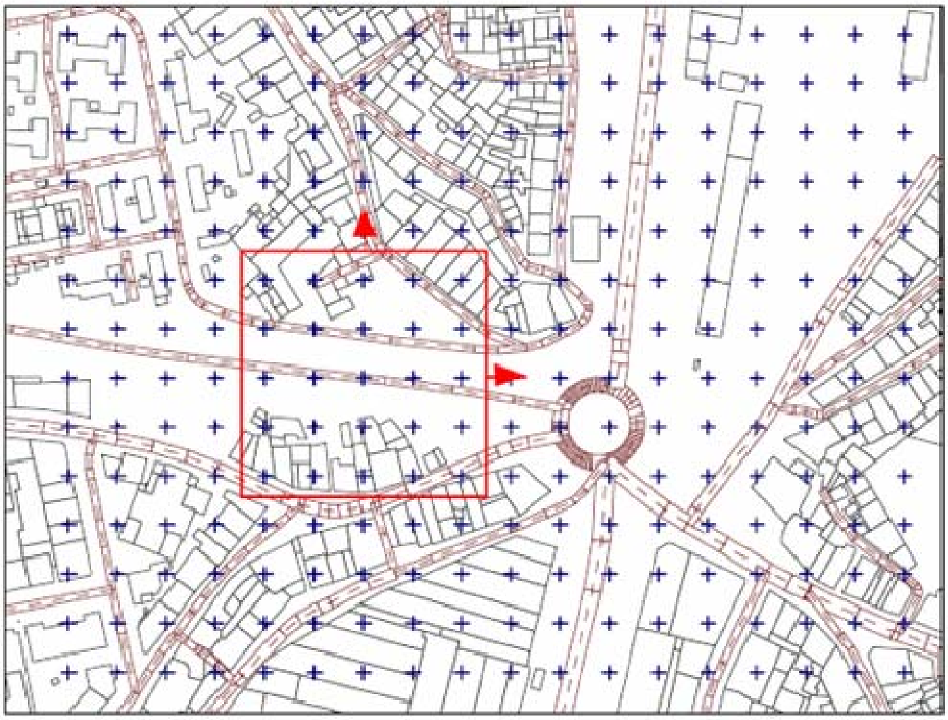

Figure 3.4.3: Object Scan and relocation of bigger grid along the smaller grid size

3.4.3 Results

Noise maps of the agglomeration of Stuttgart have been produced for noise levels L_{den} and L_{night}. They are accessible on http://www.qcity.org/maps with scales of 1:400000 up to 1:25000.

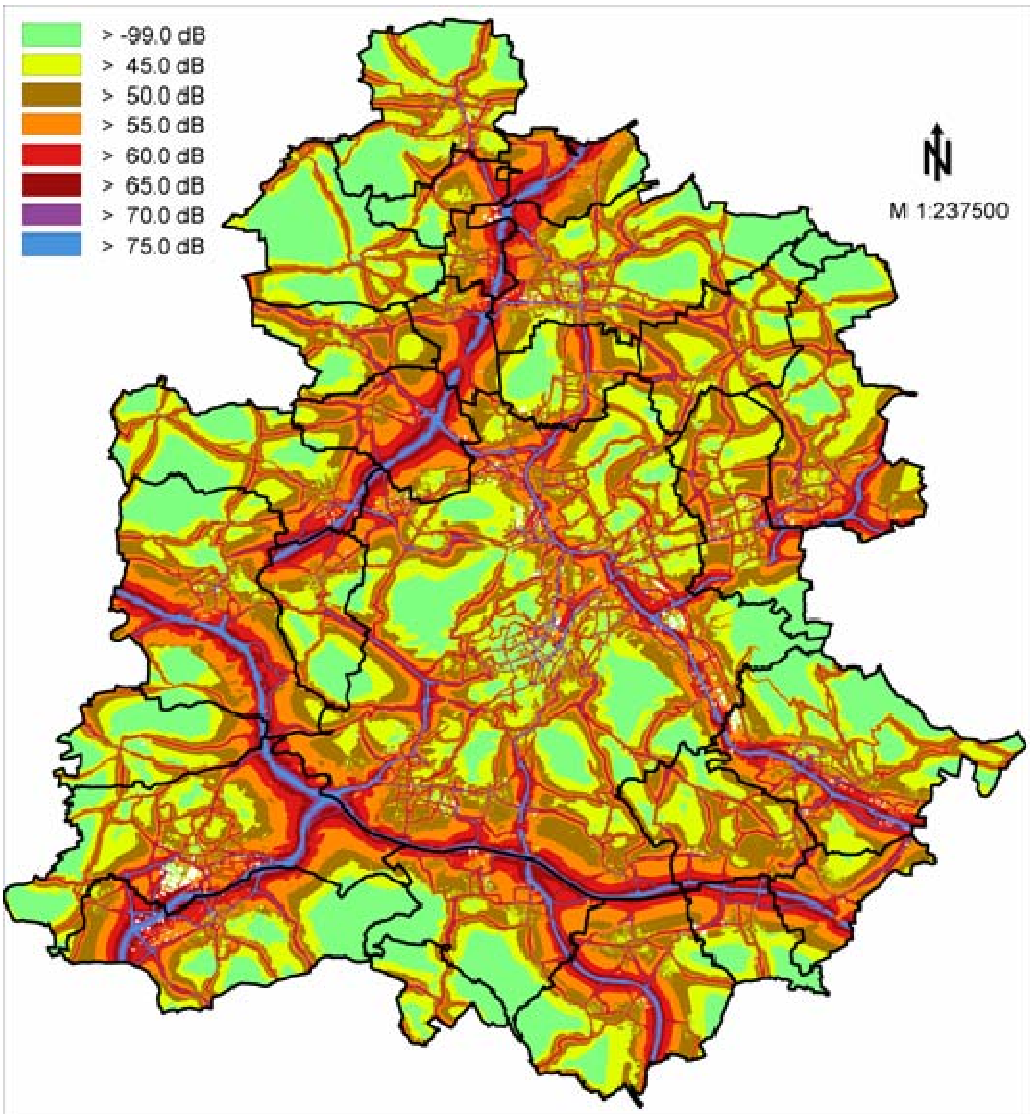

Figure 3.4.3: Noise map - traffic noise L_{den} / agglomeration of Stuttgart

As the map shows the main noise exposure can be found alongside the main routes:

- federal motorway A8 (west – east connection)
- federal motorway A81 (north – south connection)
- main road B27 (in south of Stuttgart)

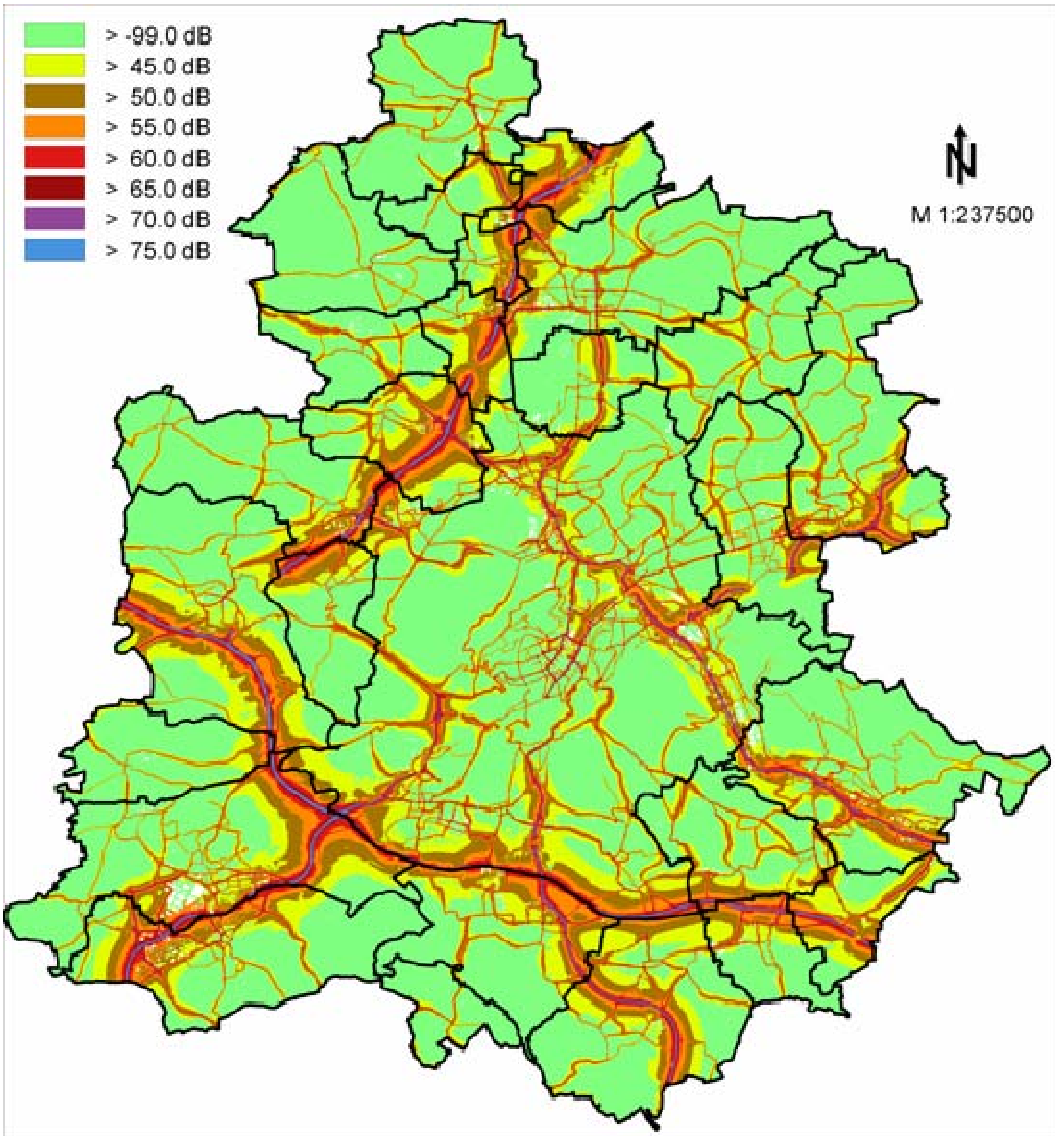

Figure 3.4.4: Noise map – traffic noise L_{night} / agglomeration of Stuttgart

The night-time noise indicator L_{night} within the area of investigation in average is approx. 5 – 10 dB(A) lower than the noise indicator L_{den}.

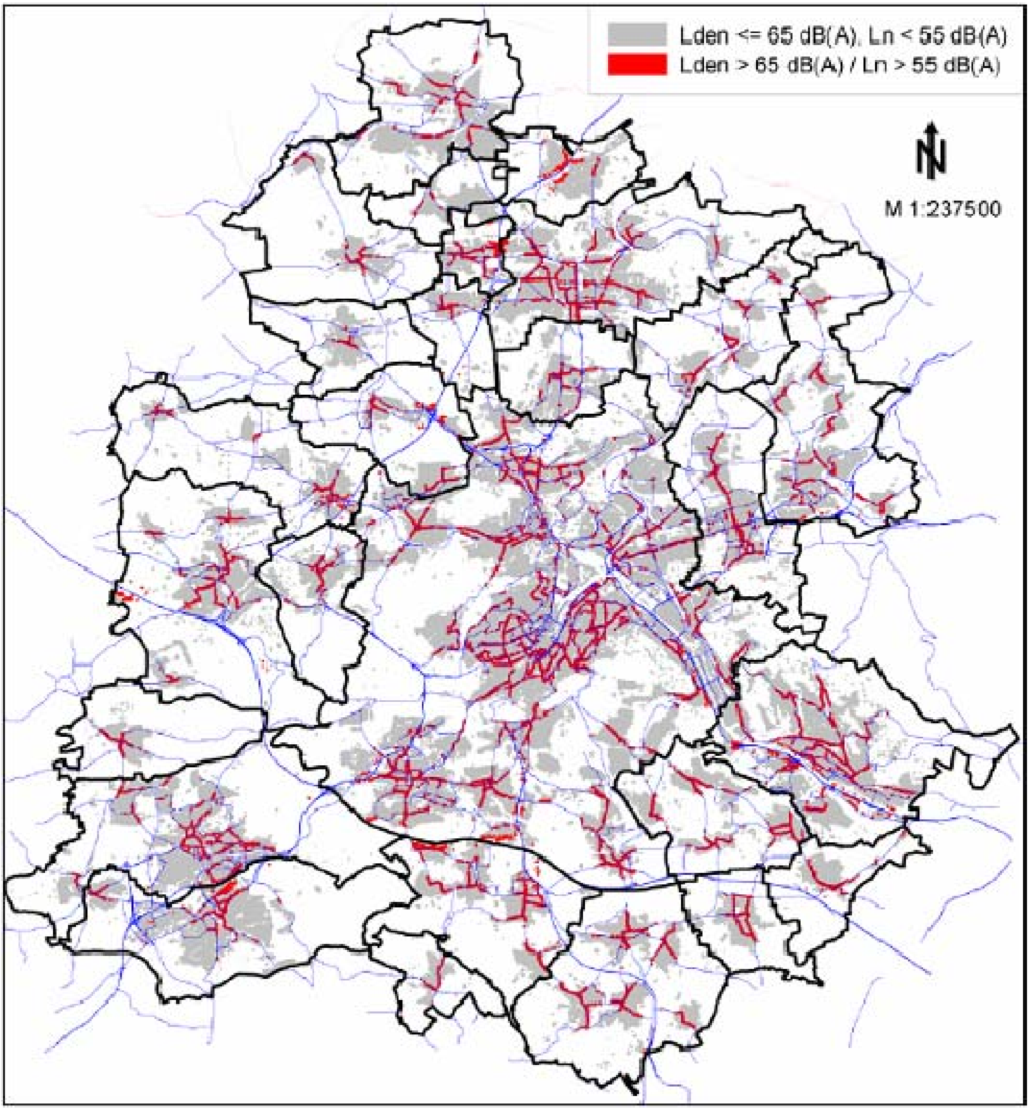

Figure 3.4.5: Residential buildings with facade levels exceeding limiting values / agglomeration of Stuttgart

As can be seen alongside of practically every main road within the agglomeration the tripping levels get exceeded. Therefore hot spots analysis should not be carried out simply by judging whether a facade level does or does not exceed a tripping value as hot spots are special points with a significant noise annoyance.

The total area exposed to values of L_{den} greater-than-or-equal to 55 dB(A) is about 210 km², greater-than-or-equal to 65 dB(A) is about 82 km² and greater-than-or-equal to 75 dB(A) is about 19 km².

The following picture shows the detected hot spots using NERS. The Noise Scores of every building were tabulated so that percentiles could be marked.

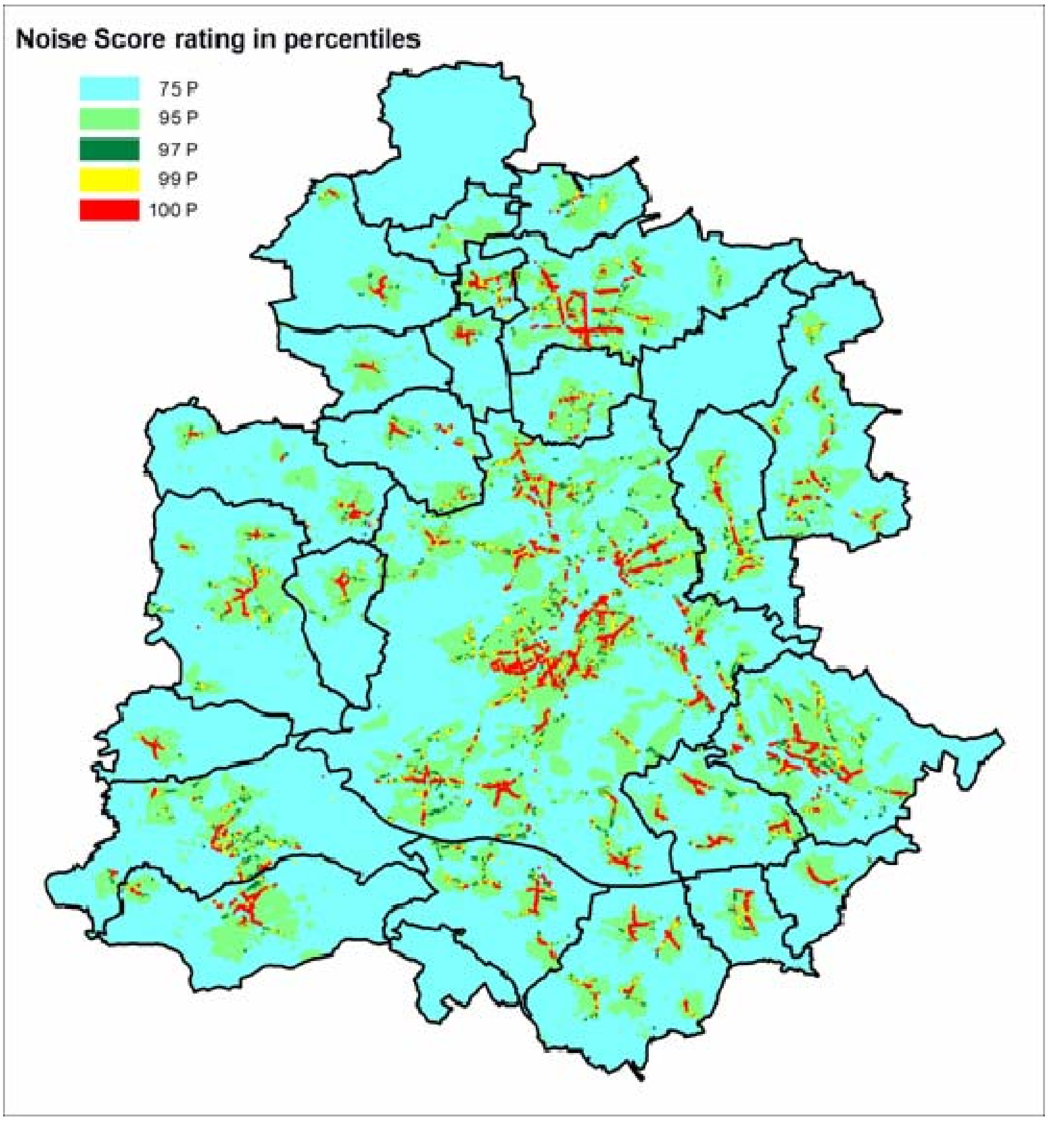

Figure 3.4.6: Noise exposure / hot spots in agglomeration of Stuttgart

The picture shows the detected hot spots using NERS. The Noise Score of every building was tabulated so that percentiles could be marked.

Table 3.4.1: Number of inhabitants in noise-classes

Interval		Exposed people			
		L_{den}		L_{night}	
from	to	absolute	%	absolute	%
	50	572.600	41,7 %	1.062.700	77,3 %
50	55	314.700	22,9 %	130.300	9,5 %
55	60	201.200	14,6 %	120.800	8,8 %
60	65	116.900	8,5 %	51.400	3,7 %
65	70	113.000	8,2 %	8.500	0,6 %
70	75	48.700	3,5 %	800	0,1 %
75		7.200	0,5 %	-	-
Sum		**1.374.300**		**1.374.500**	

The table shows, that in the entire investigated area (agglomeration of Stuttgart) about 12.2 % of the inhabitants are affected by facade levels L_{den} > 65 dB(A) and 13.2 % are affected by facade levels L_{night} > 55 dB(A).
(Within this analysis the total amount of inhabitants of each building was related to its most exposed facade.)

Table 3.4.2: Number of people exposed per commune (in total)

Communes	number of inhabitants in dB(A) – categories on base of L_{den} (roads, 2005)					
	< 55	55...60	60...65	65...70	70...75	>75
Vaihingen	9511	18022	7420	3483	1316	139
Möhringen	7122	11395	4338	2351	1303	146
Plieningen	3046	3010	1208	792	304	7
Birkach	2786	1038	898	481	0	0
Kemnat	2025	1879	242	306	391	0
Ruit	3509	2626	456	450	658	16
Scharnhausen	1196	1841	400	465	604	0
Nellingen	8922	7220	2077	1120	1201	20
Berkheim	2222	3801	1065	465	235	0
Denkendorf	2357	5150	1376	557	785	38
Neuhausen	4244	3952	1631	1060	483	9
Bernhausen	3570	6860	1827	661	887	48
Sielmingen	2622	3719	560	549	402	14
Harthausen	1700	1846	152	251	132	0
Bonlanden	2267	5395	1623	704	211	0
Plattenhardt	2706	3456	560	1250	118	0
Stetten	2235	2160	532	247	254	0
Echterdingen	2089	5255	1819	1139	1078	45
Leinfelden	3216	5524	2918	1371	324	0
Musberg	2726	1745	267	283	42	0
Steinenbronn	3156	1518	703	615	22	0
Total number	73.227	97.412	32.072	18.600	10.750	482
Total in %	31.5	41.9	13.8	8.0	4.6	0.2

Analysis of hot spots with focus on "truck restrictions"

In line with the project of Q-City the region of Fildern has one of the highest demands of noise reduction plans concerning "truck traffic". Noise maps and hot spot detection have been produced for the areas of Denkendorf, Esslingen, Leinfelden- Echterdingen, Neuhausen and Ostfildern and parts of Stuttgart.
The truck-routing concept presented in this paper is to be regarded as one suggestion in context of an overall planning for noise mitigation in the region of Fildern.
Using a traffic model it was possible to analyse the impact of blocking specific roads and redirecting trucks, by use of different scenario-techniques. Therefore at first the actual state (Status Quo) for years 2005 and 2010 was calculated. Later on multiple scenarios were calculated and benchmarked using NERS.

Figure 3.4.7: Overview of communities in region of Fildern

The following pictures show

- the daily traffic flow of heavy load > 3.5t on weekdays
- the identified hot spots using NERS (Noise Environmental Rating System)
- the investigated single measures of truck restrictions in the area of Fildern
- the maximum potential of truck restriction measures
- the optimized combination of truck restrictions (combination K1)
- the change of noise exposure inside the communities and in total

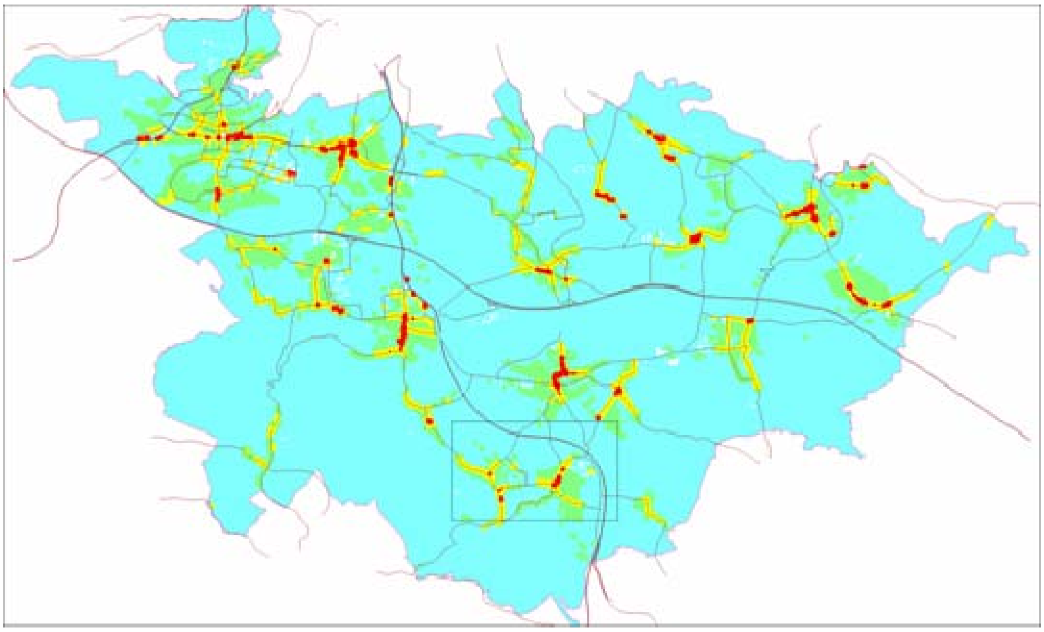

Figure 3.4.8: Hot spots of annoyance in region of Fildern caused by road traffic based on L_{den}, 2005, using NERS

Further analyses have been carried out in order to develop a truck routing concept:

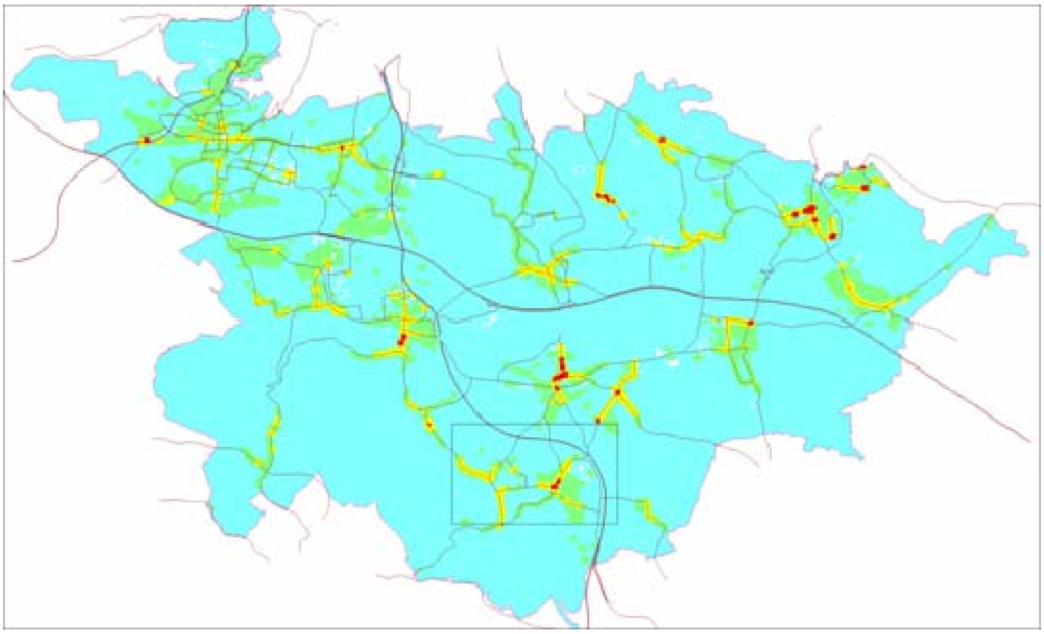

Figure 3.4.9: Hot spots of annoyance in region of Fildern caused by heavy traffic based on L_{den}, 2005, using NERS

The results of the hot spot analysis clearly show that focal points not necessarily have to be alongside main roads, but can be located elsewhere. This can be caused through a dense population or especially high noise levels.

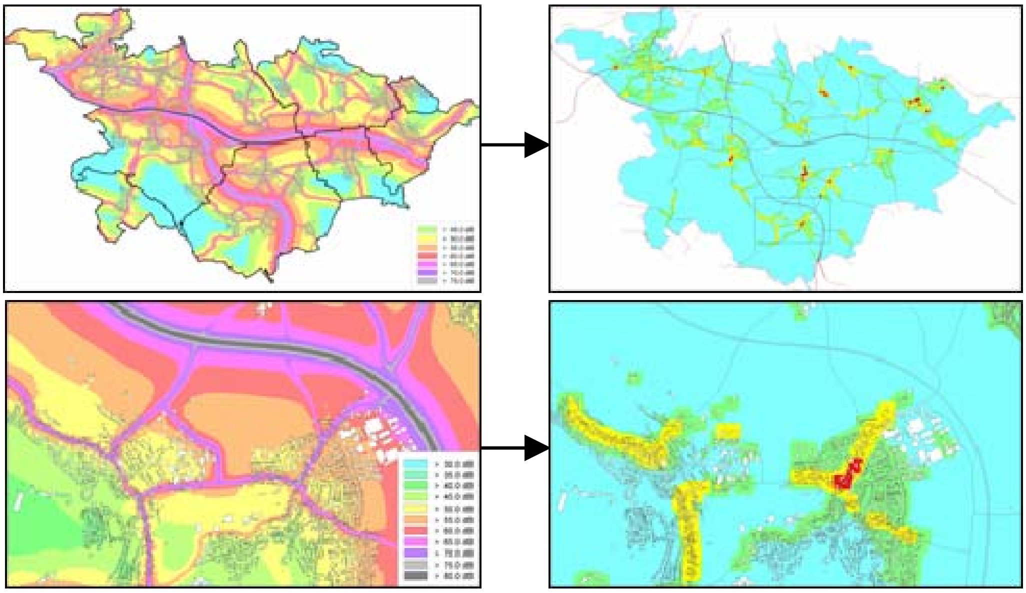

Figure 3.4.10: Area-wide noise exposure compared to detected hot-spots

It seems reasonable to design and implement truck routing systems regionally. Truck restrictions can be implemented for main roads of communes (e. g. restriction of transit traffic for the communes of Filder region), as area-wide truck restrictions in single city districts (e. g. Stuttgart Vaihingen) or area-wide restrictions on transit traffic for the entire urban area of Stuttgart.[6]

Following picture shows the maximum potential of truck restrictions for the area of Fildern when all roads have been blocked for trucks.

[6] truck restrictions are meant for transit traffic - not for traffic between a source or destination inside the city

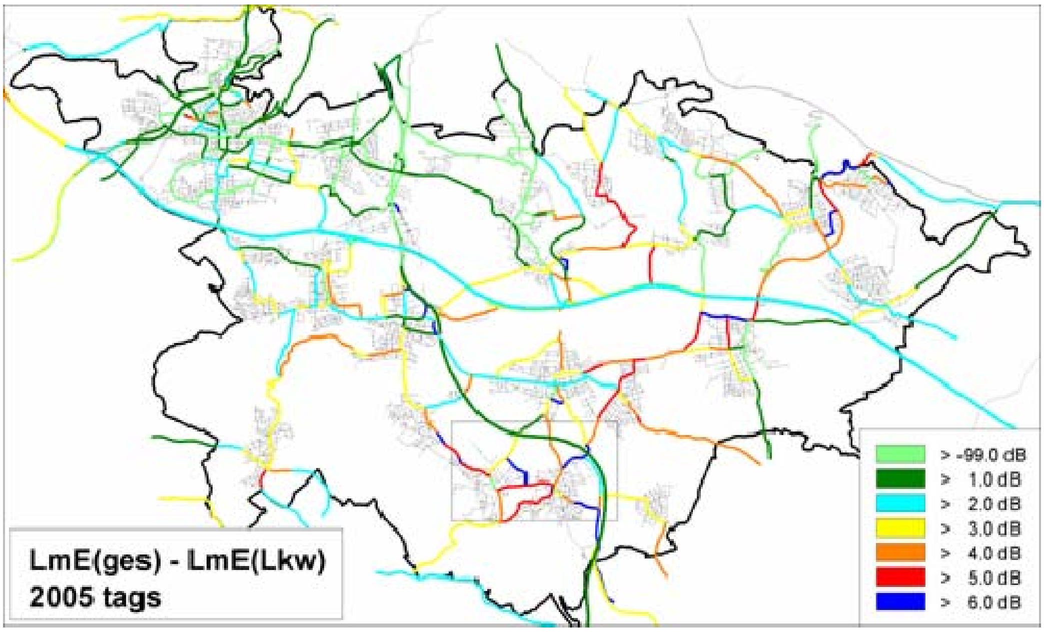

Figure 3.4.11: Maximum potential of noise reduction
caused by 100 % truck restrictions on each road / region of Fildern

Mitigation measures

The effectiveness of single restrictions on transit traffic of trucks has been evaluated for the important cross-town roads with 22 single measures of road blockages as shown in following picture. It is based on the detected noise exposure of the Status Quo 2005 and the forecasting horizon 2010+x. Also it is based on calculations showing the effect of these traffic assignments for cars and trucks.

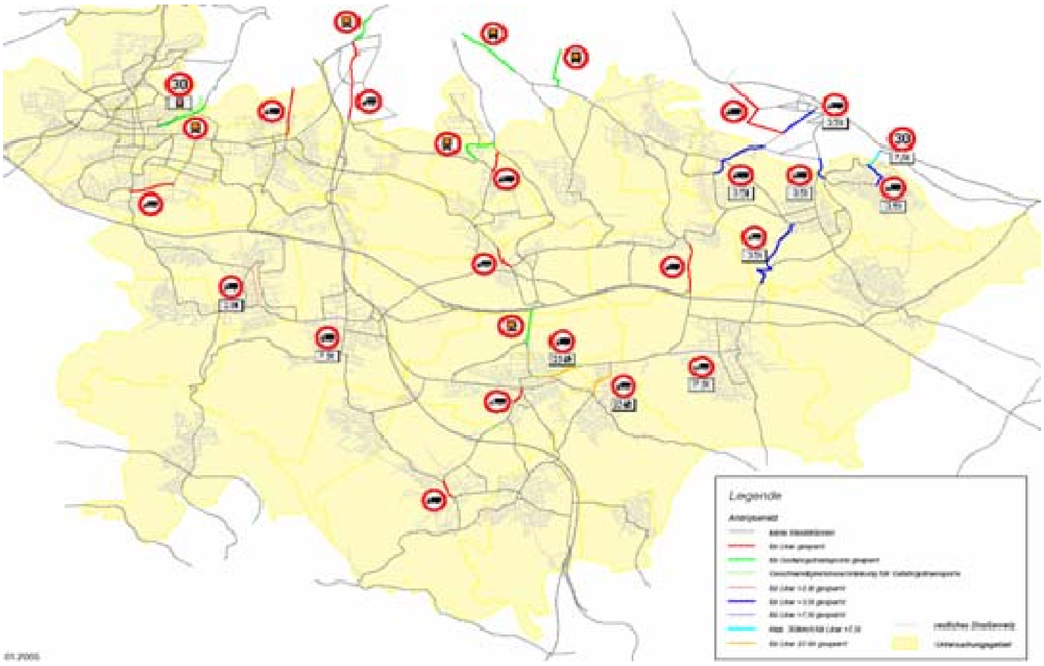

Figure 3.4.12: Existing truck-restrictions in the investigated area data from July 2004, (updated 01. 2005) / region of Fildern

Single measures

(Roads have been blocked for heavy load at the marked spots (not all at once but rather in different combinations))

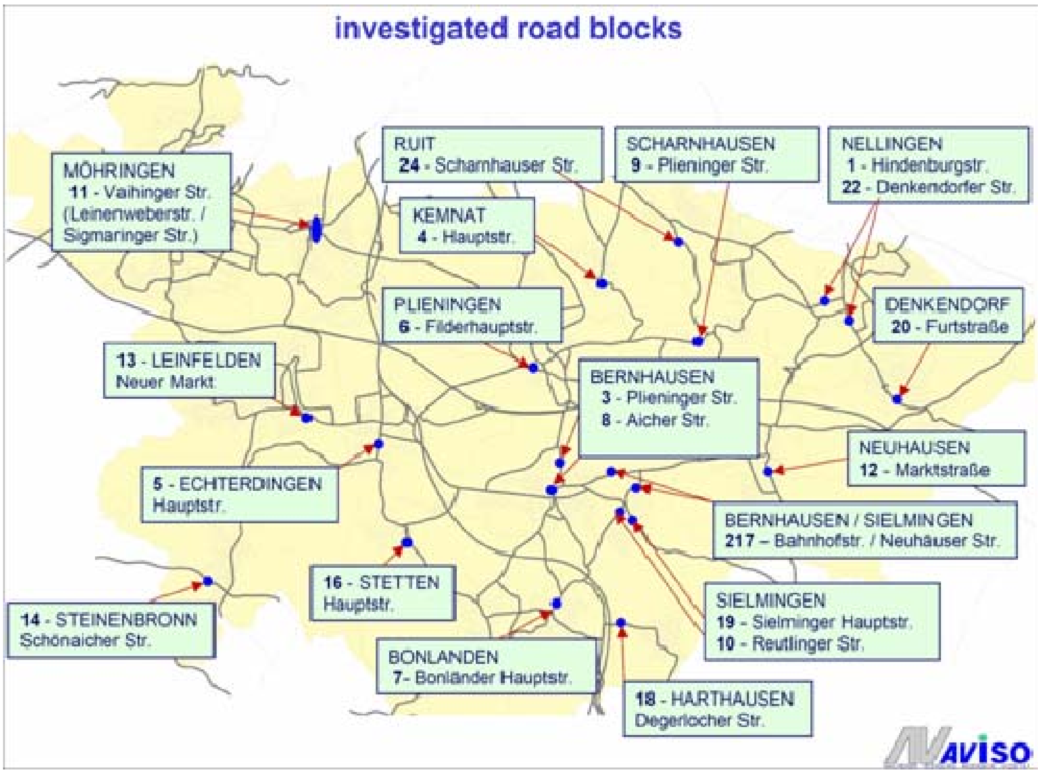

Figure 3.4.13: Investigates road blocks in region of Fildern

Intermediate evaluation of benefits from regional truck routing (area of Fildern)

The implementation of truck routing concepts is most fruitful when being designed and implemented regionally. Nevertheless effective measures do not always implicate positive effects all over. For the good of some areas others will have to step back from an improvement or might even have to accept a limited change for the worse. Applying truck-routing systems regionally will not necessarily be the best solution for local spots. Therefore it is important to keep an eye also on their local effects so that no unacceptable surplus exposure will arise. Mostly multiple communes will be involved when establishing effective truck routing systems which will make it hard to find agreement if certain areas are much more exposed than others.
Truck routing can only be regarded as a building block amongst others to reduce noise exposure and will in most cases have to be combined with other measures like silent road surfaces or structural noise insulations.

Following picture shows the regional effect when a package of truck routing measure (K1) is applied.

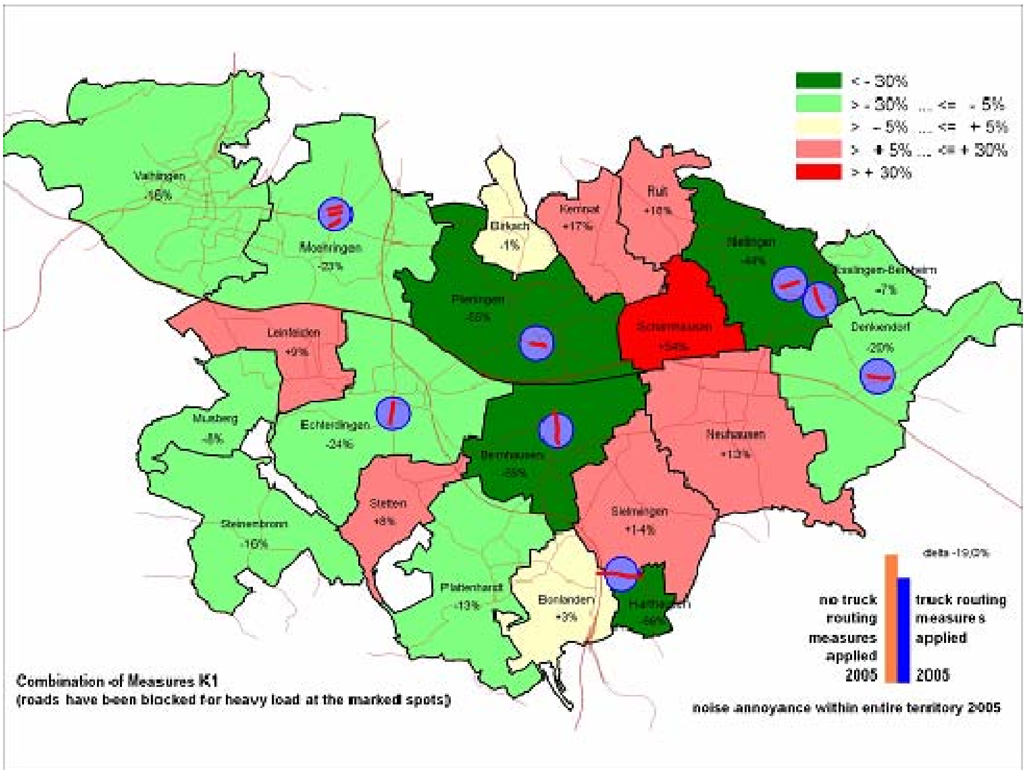

Figure 3.4.14: Change of noise exposure in each community when reasonable truck routing package K1 is applied / region of Fildern

As one can see it is possible to reduce noise exposure significantly using specific traffic restrictions for heavy load. The expected improvement is about 19 %. When applying truck-routing measure K1 in the region of Fildern persisting and negatively changed amounts of noise exposure can still be found in:

- Kemnat / Ruit
- Sielmingen / Neuhausen
- Leinfelden

For these areas other noise mitigation measures like road enhancement (new road construction, local bypasses) sound insulation and changed usage of buildings have to be discussed. In order to avoid further increase of noise exposure in the region of Fildern it is necessary to design and implement noise mitigation measures regionally with consensus of the local communities.

3.4.4 Further work

In WP 5.10 the feasibility of truck routing inside the agglomeration of Stuttgart and its efficiency will be investigated.

3.4.5 Relation with other subprojects

Relation to SP5, WP 5.10

Results are basis for detailed mitigation studies and design of prototype for implementation.

4 ANNEXES

4.1 THE ASSESSMENT OF NOISE TAKING INTO ACCOUNT NOISE LEVELS AND PEOPLE ANNOYED, Wolfgang Probst, ACCON GmbH and DataKustik GmbH, D-86926 Greifenberg, Germany

Zur Bewertung von Umgebungslärm

Wolfgang Probst

Zusammenfassung Mit einer Reihe von Untersuchungen zur Wirkung von Lärm auf Menschen hat sich unsere Kenntnis über den Zusammenhang von Lärmbelastung und dadurch verursachter Belästigung in den letzten 20 Jahren erheblich verbessert. Mit den inzwischen verfügbaren Berechnungstechniken zur Ermittlung der Lärmpegel aus den Computermodellen der Ballungsgebiete und insbesondere infolge der Europäischen Richtlinie zum Umgebungslärm kann dieses Wissen in automatisierte Beurteilungssysteme transformiert und somit zur vergleichenden Bewertung alternativ möglicher Konzepte zur Lärmminderung verwendet werden. Die veröffentlichte Literatur zu diesem Thema zeigt, dass zur Einzahlbewertung und damit zur Skalierung der Lärmbelastung größerer Umgriffe stets Belastungs-Belästigungsrelationen verwendet werden, mit deren Hilfe die Anzahl der „Erheblich Belästigten" (Highly Annoyed – HA) gezählt werden. Dieses Konzept ist methodisch ungeeignet, wie nachfolgend gezeigt wird. Soll ein gegenüber dem Istzustand geändertes Lärmszenario richtig beurteilt werden, müssen die jeweilige Belästigung bewertende Maße gebildet und für alle Personen aufsummiert werden – es ist methodisch falsch, nur die dem Bereich über einer festen Grenze dieser Belästigung zuzurechnenden Personen zu zählen, wie es bei der Anwendung des HA-Konzepts getan wird. Ausgangspunkt für ein angemessenes Bewertungssystem ist die Feststellung, dass die relative Gewichtung unterschiedlicher Belästigungsgrade bei der Beurteilung von Wohnbereichen wie die anderer Wirkungen auch keine wissenschaftlich ableitbare Skalierung, sondern eine politische Festsetzung ist, die den Willen der Gesellschaft über die gewünschte Verteilung nicht vermeidbarer Belastungen widerspiegelt. Untersucht man die Konsequenzen des Highly-Annoyed-Konzepts, so zeigt sich, dass dieses eine extrem schwache Gewichtung der Lärmpegelhöhe darstellt und zu unakzeptablen Strategien bei der Ausarbeitung von Lärmminderungsprogrammen führt. Unter Berücksichtigung dieser Ergebnisse wird ein Bewertungssystem vorgeschlagen und im praktischen Beispiel angewendet. Es kann leicht auf die Einbeziehung unterschiedlicher Lärmarten erweitert werden und ist geeignet, durch Minimierung des so gebildeten Lärmbelastungsmaßes effektive und für alle Betroffenen „faire" Gesamtkonzepte zu ermitteln.

Schlüsselwörter Lärmbewertung – Belästigung – erheblich Belästigte

Assessment of environmental noise

Summary Numerous research on annoyance caused by noise improved our knowledge and understanding of peoples reactions. With our computerized methods to determine the noise levels for large scale scenarios and as a consequence of the European Directive about Environmental Noise this knowledge can be transformed into assessment methods allowing the relative scaling of different noise mitigation measures. A thorough review showed that ranking of noise exposures was always based on exposure – effect relations where the number of highly annoyed persons was used to quantify complex situations with spatial varying noise exposures. It will be shown that this concept fails. If noise exposures change, we must sum up an annoyance quantity for all persons concerned and not only count the number of persons above a threshold. It is postulated that the relative weighting of different grades of annoyance is a political decision and should be defined taking into account the communities opinion about the best acceptable distribution of unavoidable hazards. Looking to the expressions used to calculate a single number result for assessing noise scenarios, it will be shown that the "Highly Annoyed" expression causes an extremely weak weighting of noise levels – the consequences are unacceptable. On the basis of these findings a new assessment expression was developed and used for decision-making in the planning phase for simple and complex scenarios. This method can easily be extended to inclose different noise types and it may help to find effective and "fair" noise mitigation measures acceptable for all people concerned.

Key words Noise Assessment – Annoyance – Highly Annoyed

1 Einleitung

Nach der Europäischen Richtlinie zum Umgebungslärm [1] werden Strategische Lärmkarten erstellt und auf dieser Basis Aktionspläne zur Lärmminderung entwickelt. In der Praxis gibt es stets eine Fülle von Möglichkeiten, um aus einzelnen Lärmminderungsmaßnahmen ein geeignetes und im Hinblick auf Kosten und Wirksamkeit optimales Paket zu schnüren. Um dies bei Berücksichtigung der Komplexität üblicher Stadtszenarien mit noch akzeptablem Aufwand leisten zu können, ist ein formalisierbares Verfahren zur schalltechnischen Bewertung erforderlich.
Solche Bewertungssysteme beruhen stets darauf, die „unerwünschte" Lärmwirkung, wie z. B. die Belästigung und/oder Schlafstörung, in Abhängigkeit vom verwendeten Lärmindikator zu quantifizieren und diese Größe dann für alle betroffenen Personen innerhalb des Planungsumgriffs zu summieren. Das Endergebnis ist ein Einzahlwert, der eine Skalierung unterschiedlicher Lärmszenarien ermöglicht.
Zur Ermittlung dieser im Folgenden als „Lärmbewertungsmaß" *NS* (Noise Score) bezeichneten Größe sind unterschiedliche Konzepte vorgeschlagen und angewendet worden:

Konzept 1 – Linearansatz (Lärmkennziffer *LKZ*)

$$NS = \sum_i n_i \cdot (L_i - L_R) \qquad (1)$$

n_i – Anzahl Personen in Gruppe i, L_i – Lärmindikator der Gruppe i, L_R – Grenz- oder Bezugspegel

Konzept 2 – Anteil der erheblich Belästigten (*%HA* Highly Annoyed)

$$\%HA_i = 9{,}87 \cdot 10^{-4}(L_i - 42)^3 - 1{,}44 \cdot 10^{-2}(L_i - 42)^2 + 0{,}51(L_i - 42) \qquad (2)$$

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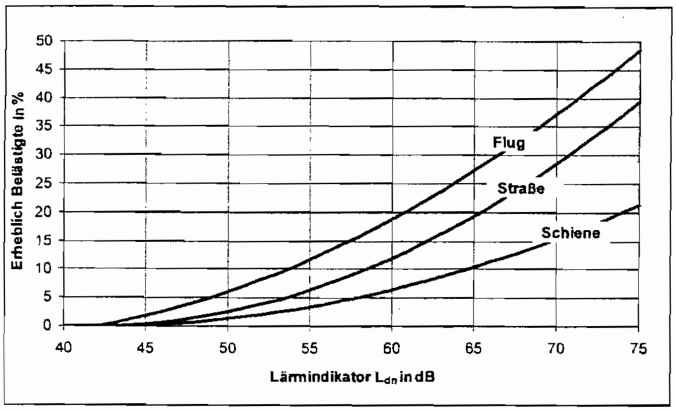

Bild 1. Prozentsatz der erheblich Belästigten (%*HA*) bezogen auf unterschiedliche Lärmarten [4].

$$NS = HA = \sum_{i} n_i \cdot \frac{\%}{1}$$

Konzept 3 – Exponentialansatz

$$NS = \sum_{i} n_i \cdot 10^{k \cdot (L_i - L_R)} \tag{3}$$

Der Parameter k bestimmt die Steilheit der Bewertungskurve.

Der lineare Ansatz nach Konzept 1 soll hier nicht weiter diskutiert werden – es ist offensichtlich, dass die Kompensation des Pegelanstiegs für eine Person von 70 dB(A) auf 75 dB(A) durch eine Pegelminderung für eine andere Person von 55 dB(A) auf 50 dB(A) keine geeignete Strategie sein kann, die Lärmbelastungen in einem Ballungsraum zu minimieren.

In den meisten Fällen wurde die Anzahl der erheblich Belästigten HA als Lärmbewertungsmaß verwendet. *Schultz* [2] veröffentlichte eine Beziehung zwischen dem A-bewerteten Tag-Nacht-Pegel L_{dn} und dem Prozentsatz der „Erheblich Belästigten" (%*HA*). Einige Jahre später untersuchte *Kryter* [3] den Prozentsatz der „Erheblich Belästigten" für unterschiedliche Lärmarten. Seither wurde das HA-Konzept, also die Bewertung nach der Zahl der "Erheblich Belästigten" von zahlreichen Autoren angewendet

Miedema und *Vos* [4] werteten 45 Lärmstudien aus und entwickelten daraus Funktionen, die den Prozentsatz %*HA* zum Tag-Nacht-Pegel L_{dn} für Flug-, Straßen- und Eisenbahnlärm getrennt in Beziehung setzen. Gleichung (2) beschreibt die entsprechende Funktion nach [5] für Straßenverkehrslärm. *Miedema* verwendet diese Funktionen nicht nur zur Darstellung des Anteils der „Erheblich Belästigten" von der vorhandenen Lärmbelastung, sondern empfiehlt auch die Verwendung des für alle Betroffenen summierten Werts als Einzahlgröße, um unterschiedliche Planungskonzepte hinsichtlich der Lärmeinwirkung zu vergleichen.

In vielen anderen Publikationen ist das HA-Konzept zur Ermittlung einer Lärmskalierung beim Vergleich unterschiedlicher Lärmszenarien verwendet worden (z. B. auch in [6 bis 8]).

Einen zusammenfassenden Überblick zur Forschung bezüglich der Belastungs-Wirkungs-Relationen enthält [9; 10]. Auch daraus ergibt sich, dass die Bewertung von Lärmszenarien meist darauf basiert, die Anzahl der erheblich Belästigten zu bestimmen und als Bewertungsgröße zu verwenden. Auch im Rahmen der Normung (z. B. [11; 12] wird diese Strategie angewendet.

In Deutschland begannen die Versuche einer einheitlichen Lärmbewertung für den Bereich der Stadtplanung 1975 [13]. Der Autor dieses Beitrags [14; 15] wies auf die Problematik hin, die sich aus der Verwendung der Anzahl der mit einem bestimmten Grad Belästigten zur Bewertung ergibt. Bei der Behandlung derselben Problematik in VDI 3722-2 [16] wird wiederum das HA-Konzept zugrundegelegt.

Die Techniken der großräumigen Lärmberechnung (siehe z. B. [17; 18] und die damit sich eröffnenden Möglichkeiten der rechnerbasierten Lärmminderungsplanung könnten durch ein geeignetes „Noise Scoring" hervorragend unterstützt werden. Im Folgenden wird deshalb im ersten Schritt ein einfaches Gedankenmodell zur Reaktion von Menschen auf Lärm verwendet, um die Beziehung zwischen dem Grad der Belästigung und der Anzahl der „Erheblich Belästigten" entsprechend dem genannten HA-Konzept zu untersuchen. Es wird gezeigt, welche Konsequenz die detaillierte Konstruktion einer Bewertungsfunktion auf die „optimale" Verkehrsverteilung hat, wobei das Optimum durch Minimierung des mit dieser Funktion berechneten Lärmbewertungsmaßes NS bestimmt ist. Auf der Basis dieser Ergebnisse wird eine geeignete Methodik vorgeschlagen und an einem praktischen Beispiel angewendet.

2 Das Highly-Annoyed-Konzept

Aus Befragungen kann die Beziehung zwischen einem geeigneten Lärmindikator – im Beispiel **Bild 1** ist es der Tag-Nacht-Pegel L_{dn} – und dem Anteil der bei diesem Pegel erheblich belästigten Personen ermittelt werden. Der Begriff „Lärmindikator" wird hier und im Folgenden allgemein als Größe zur Quantifizierung der Lärmbelastung verwendet – der Lärmindikator nach [1] ist somit eine spezielle Ausbildung dieser Größe.

Bei gegebener Lärmbelastung kann mit diesen Funktionen (Bild 1) für jede Person die Wahrscheinlichkeit, dass sie sich durch Lärm erheblich belästigt fühlt, ermittelt werden. Summiert man diesen Wert für alle Personen in einem gegebenen Planungsumgriff auf, erhält man die Anzahl der erheblich belästigten Personen. Diese Zahl *HA* wird i. d. R. als Kenngröße zur Einzahlbeschreibung eines beliebigen Lärmszenarios und zur Auswahl der geeignetsten unter mehreren möglichen Lärmminderungsalternativen herangezogen.

Tatsächlich ist die Zahl der erheblich belästigten Personen (*HA*) kein faires Maß zur Bewertung der Lärmbelastung einer Population. Bei der Bewertung einer ansteigenden Lärmbelastung zählt man mit dieser Methodik lediglich die Anzahl der Personen, die die Grenzlinie zwischen zwei Belästigungsstufen überschreiten, während die ebenfalls ansteigende Belästigung für alle anderen Personen vernachlässigt bzw. nicht berücksichtigt wird. Dies zeigt schon die Betrachtung der vollständigen HA-Kurve – in Darstellungen nach Bild 1 ist nur der Anstiegsbereich der Kurven wiedergegeben, weil in praktischen Feldstudien keine Personengruppen vorkommen können, bei denen mehr sich mehr als 50 % erheblich belästigt fühlen.

Bild 2 zeigt den Prinzipverlauf der vollständigen HA-Kurve. Es ist offensichtlich, dass sich selbst bei noch so hoher Belastung nicht mehr als 100 % erheblich belästigt fühlen können

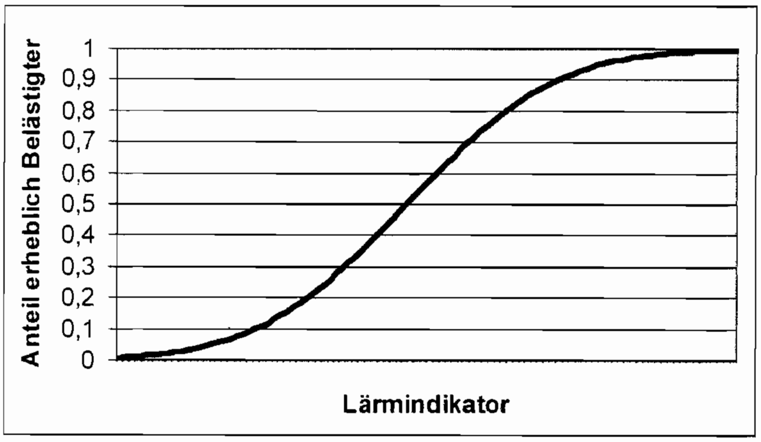

Bild 2. Anteil der erheblich Belästigten in Abhängigkeit von der Lärmbelastung (Prinzipdarstellung).

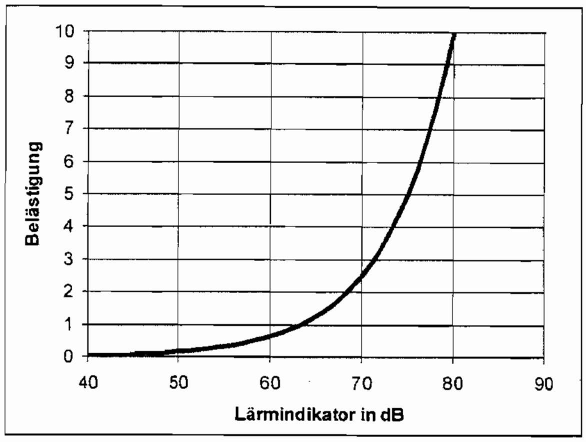

Bild 3. Hypothetische Belastungs-Belästigungs-Funktion einer Person (AE-Kurve).

und dass die Kurve deshalb gegen diesen Wert konvergieren muss. Wird die dieser Kurve zugrundeliegende funktionale Beziehung zur relativen Bewertung von Lärmszenarien verwendet, dann ergibt ein Pegelanstieg von X dB im mittleren Pegelbereich einen größeren Zuwachs an erheblich Belästigten als derselbe Pegelanstieg von X dB bei schon hoher Ausgangsbelastung im oberen Pegelbereich. Es wäre eine fatale Konsequenz hieraus zu schließen, dass Menschen mit schon hoher Lärmbelastung weniger unter einem bestimmten Pegelanstieg leiden als Personen in ruhigem Umfeld.

3 Beziehung zwischen dem Belästigungsgrad und dem Anteil erheblich Belästigter

Das im Folgenden verwendete und sicher vereinfachende Gedankenmodell ist geeignet, die Beziehung zwischen den Funktionen Lärmindikator – Belästigungsgrad (im Folgenden als AE-Funktion bezeichnet) einerseits sowie Lärmindikator – Anteil der erheblich Belästigten (%HA-Funktion) andererseits herzuleiten und darzustellen.

Wenn man unterstellt, dass der verwendete Lärmindikator eine geeignete Größe zur Beschreibung der Lärmbelastung ist und wenn Personen, deren Wohnumfeld mit einem bestimmten Wert dieses Lärmindikators beschrieben werden kann, nach dem Grad ihrer lärmbedingten Belästigung befragt werden, so erhält man die Beziehung Lärmindikator – Belästigungsgrad. Es sind bereits viele solcher Studien durchgeführt und unterschiedliche Skalen zur Quantifizierung des Belästigungsgrads verwendet worden. Im Folgenden wird eine einfache 1-10-Ordinalskala zugrundegelegt, wobei die Zahlenwerte mit den Belästigungsstufen wie „kaum belästigt", „leicht belästigt", „belästigt" und „erheblich belästigt" korrespondieren.

Die mit den o.g. Belästigungsgraden korrespondierende 0-10-Skala wird als Arbeitshypothese verwendet – später wird gezeigt, welche erheblichen Konsequenzen diese mehr oder weniger willkürliche Festlegung für ein daraus abgeleitetes Lärmminderungskonzept hat.

Um eine Bewertungsfunktion in unsere Skalierung einzupassen, können vorhandene Erfahrungen über die Zumutbarkeit von Lärmbelastungen herangezogen werden. Wichtige Grundsätze und „Kalibrierpunkte" ergeben sich aus folgenden Feststellungen:

- Die meisten Studien belegen, dass unter 40 dB(A) keine wesentliche Belästigungsreaktion zu erwarten ist – hieraus ergibt sich die Untergrenze der Skala des Lärmindikators.
- Wohnen bei oder über 80 dB(A) ist unzumutbar bzw. unmöglich – dies zeigt der Bereich des Lärmindikators, in dem die Steigung der Bewertungskurve gegen 90 ° konvergieren muss.
- Der Anstieg der Belästigung mit einem gegebenem Anstieg des Lärmindikators ist bei schon vorhandenem hohem Ausgangspegel größer als bei niedrigem Ausgangspegel – die zweite Ableitung der Funktion muss im gesamten Wertebereich positiv sein

Die Exponentialfunktion

$$A(L) = c \cdot 10^{k \cdot (L - L_R)} \tag{4}$$

mit

A Belästigungsgrad (gewählte Skalierung)
L Lärmindikator (z. B. Tag-Abend-Nacht-Pegel L_{den} nach [1])
L_R Bezugswert des Lärmindikators
k Exponentialparameter ($0{,}03 \leq k \leq 0{,}3$)

ist mit diesen Bedingungen verträglich und soll deshalb im Weiteren verwendet werden.

c ist ein Faktor zur Kalibrierung der Exponentialfunktion. Soll der Funktionswert beim Lärmindikator L_{cal} den Wert A_{cal} annehmen, so ergibt sich c zu

$$c = A_{cal} \cdot 10^{-k \cdot (L_{cal} - L_R)} \tag{5}$$

k legt den Verdopplungsparameter q fest. Wenn ein Anstieg des Lärmindikators L um q den Funktionswert A verdoppeln soll, ergibt sich k aus

$$k = \frac{\lg(2)}{q} \tag{6}$$

Die in **Bild 3** dargestellte Kurve ist mit einem Wert 0,06 für k berechnet worden – dies entspricht einer Verdopplung des Funktionswerts bei einem Anstieg des Lärmindikators um 5 dB. Um bei 80 dB einen Funktionswert von 10 zu erhalten, wird für c der Wert 0,04 verwendet.

Nach dieser Modellvorstellung sind unterschiedliche Personen unterschiedlich lärmempfindlich – die AE-Kurven werden deshalb, bezogen auf die Achse des Lärmindikators,

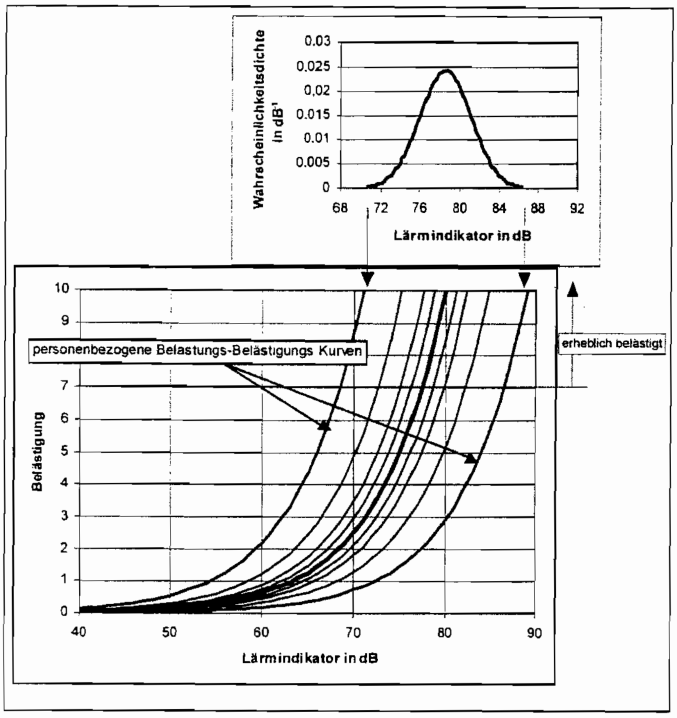

Bild 4. Streuung (angenähert durch eine Normalverteilung) von personenbezogenen AE-Funktionen.

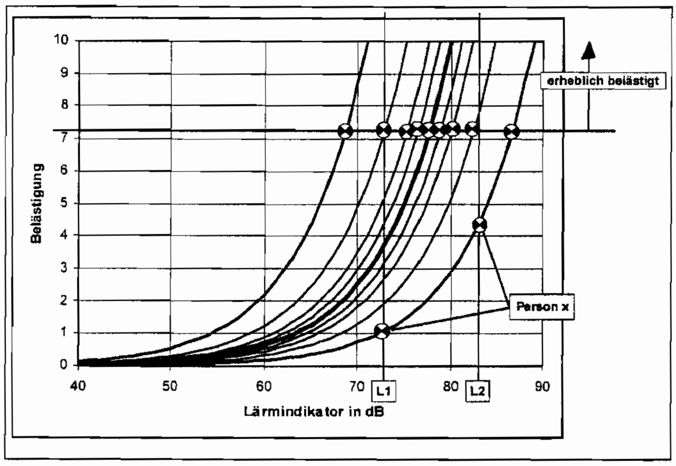

Bild 5. Zur Beziehung Annoyance – Highly Annoyed.

streuen. Um die Beziehung zwischen AE-Kurven und HA-Kurven zu untersuchen, wird die in Bild 3 dargestellte AE-Kurve als kennzeichnend für die mittlere Reaktion der Bevölkerung auf Lärm betrachtet und von einer Normalverteilung der individuellen auf Einzelpersonen bezogenen AE-Kurven ausgegangen. Eine derartig streuende Gesamtheit ist durch ihren Mittelwert und die Standardabweichung gekennzeichnet. Die Annahme einer Normalverteilung ist zwar hypothetisch, aber nicht zwingend für die im Folgenden aufgezeigten Zusammenhänge.

Die neun in **Bild 4** dargestellten AE-Kurven stellen die Reaktion von neun Personen auf unterschiedliche Lärmbelastung dar. Im Diagramm ist auch die Untergrenze des Bereichs „erhebliche Belästigung" als horizontale Linie eingetragen. Nach *Miedema* and *Vos* [4] ergäbe sich dafür aus vielen Studien ein Wert von 72 auf einer 0-100-Skala.

Mit dieser Modellvorstellung von streuenden personenbezogenen AE-Kurven kann die %HA-Kurve nach Bild 1 oder 2 hergeleitet werden. Unter Berücksichtigung des Schwellenwerts

$$A_T = 7{,}2 \tag{7}$$

auf der 0-10- Skala ergibt sich der Anteil der bei einem Lärmindikator L' erheblich Belästigten zu

$$w(L') = 1 - \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot \int_{-\infty}^{L'} e^{-\frac{(L-L_m)^2}{2\sigma^2}} \, dL \tag{8}$$

mit

$$L_m = \frac{1}{k} \cdot \lg\left(\frac{A_T}{c}\right) + L_R \tag{9}$$

Durch Einsetzen der Gln. (7) und (9) in Gl. (8) ergibt sich auch der Wert des Lärmindikators, der für die Mittelwertkurve mit der Untergrenze des HA-Bereichs korrespondiert. Durch Integration der Wahrscheinlichkeitsdichtefunktion (8) unter Berücksichtigung der genannten Parameterwerte und einer Standardabweichung von 3 dB ergibt sich die in Bild 2 dargestellte %HA-Kurve.

Aus dieser Modellvorstellung zur Reaktion von Menschen auf Lärm ergeben sich wichtige Konsequenzen für eine zur Lärmbewertung geeignete Einzahlgröße. Die Ableitung der HA-Kurve in Bild 2 aus den streuenden AE-Kurven in Bild 4 beweist, dass diese HA Kurve eine Erhöhung der Lärmbelastung nicht bewerten kann, weil ihre Steigung lediglich die Streuung der personenbezogenen Lärmempfindlichkeiten widerspiegelt. Mit den Diagrammen in Bild 3 oder 4 wird dagegen in Übereinstimmung mit der Erfahrung dargestellt, dass die Belästigung kontinuierlich und progressiv mit der Belastung jeder einzelnen Person ansteigt. Erhöht sich der Wert des eine Lärmbelastung kennzeichnenden Lärmindikators, steigt die Belästigungsreaktion aller betroffenen Personen an.

Mit **Bild 5** kann der Zusammenhang der Belästigungs-Kurven mit der Highly-Annoyed-Kurve (Bild 2) verdeutlicht werden: Die dargestellten neun Kurven repräsentieren die Belästigungsreaktion von neun unterschiedlichen Personen auf Lärm. Die horizontale Linie mit dem Belästigungswert 7,2 ist die untere Grenze des HA-Bereichs. Die Anzahl der erheblich belästigten Personen bei einem bestimmten Wert L des Lärmindikators ergibt sich, indem die vertikale Linie bei diesem Wert L mit den AE-Kurven geschnitten wird – jeder Schnittpunkt oberhalb dieser Linie beim AE-Wert 7,2 repräsentiert eine erheblich belästigte Person. Alternativ kann die Zahl der Schnittpunkte von AE-Kurven mit der horizontalen Linie bei 7,2 links von der vertikalen Linie beim Lärmindikator L ermittelt werden. Für den Wert des Lärmindikators $L1$ ergeben sich so zwei erheblich Belästigte – bei Erhöhung der Lärmbelastung auf $L2$ steigt dieser Wert um sechs auf acht erheblich Belästigte. Damit gilt

$$\%HA(L_1) = \frac{2}{9} \cdot 100\,\% = 22{,}2\,\% \tag{10}$$

und für $\%HA(L_2)$ ergibt sich in gleicher Weise ein Wert von 88 %.

In diesem Beispiel erhöht sich also beim Pegelanstieg von $L1$ auf $L2$ der Wert $\%HA$ und damit die Zahl der erheblich Beläs-

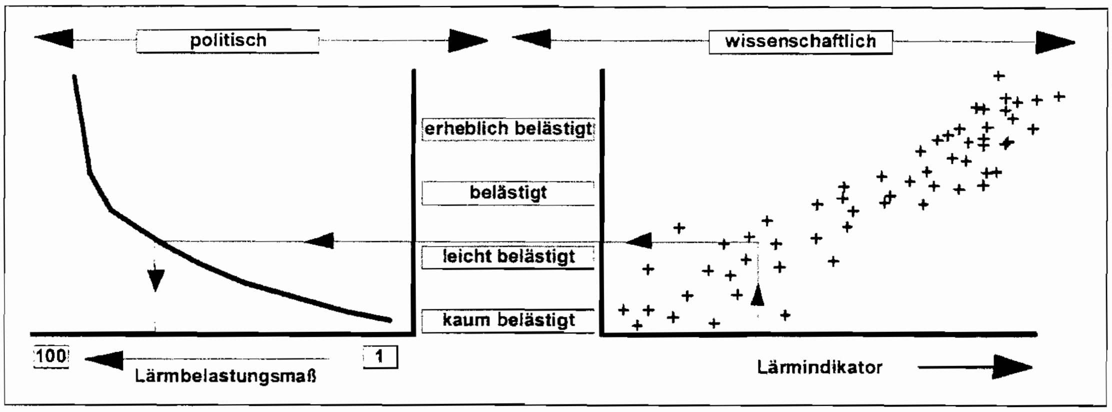

Bild 6. Wissenschaftlich begründbarer und durch Setzung festgelegter Teil einer Lärmbewertung.

tigten um den Faktor 4, wobei dieser Anstieg durch die Zahl der Personen bestimmt wird, deren AE-Wert die Untergrenze des HA-Bereichs überschreitet. Dabei wurde aber nicht berücksichtigt, dass sich der AE-Wert aller Personen – auch jener, deren AE-Wert sowohl bei $L1$ als auch bei $L2$ unterhalb oder oberhalb dieser 7,2-Grenze liegt – entsprechend erhöht. Dies ist im Diagramm in **Bild 6** beispielhaft für die Person x gezeigt – obwohl sich ihr Annoyance-Wert von 1,3 auf 4,9 erhöht, wird diese Verschlechterung bei der Verwendung der HA-Kurve zur Bewertung nicht berücksichtigt. Auch die weitere Verschlechterung für die beiden Personen, die bei $L1$ schon erheblich belästigt waren, spielt bei dieser Bewertung keine Rolle.

Eine angemessene Lärmbewertung muss den Anstieg der Belästigung für alle betroffenen Personen – bzw. für alle neun Personen im dargestellten Beispiel – einbeziehen. Der Anstieg der Anzahl der erheblich Belästigten steht zu diesem Anstieg des Belästigungsgrads in keiner Beziehung. Dies zeigt ein einfaches Gedankenexperiment: Da die Zahl der erheblich Belästigten beim Lärmindikator L gleich der Zahl der Schnittpunkte ⊗ links von der vertikalen Linie bei L ist, würde sich für alle Werte L der zugehörige %HA-Wert nicht ändern, wenn die neun eingezeichneten AE-Kurven unter Beibehaltung dieser Schnittpunkte wesentlich steiler verliefen – obwohl dann bei Pegelerhöhung der Grad der Belästigung für jede einzelne Person wesentlich mehr anstiege.

Aus diesen Überlegungen folgt zwingend, dass die Zunahme der Belästigung bei einem Anstieg der Lärmbelastung nur durch Einbeziehung der AE-Kurven charakterisiert werden kann.

Dies ist das Dilemma der Lärmbewertung – wie auch jeder anderen Bewertung von schädlichen Einwirkungen:

- Die mit wissenschaftlicher Evidenz unter Einbeziehung psychoakustischer Studien herleitbaren Highly-Annoyed-Funktionen sind schon aus methodischen Gründen nicht zur Lärmbewertung geeignet – ob sie zum empirischen Ansatz taugen, wird noch zu untersuchen sein.
- Die Skalierung der ausschließlich verwendbaren AE-Kurven nach Bild 3 bzw. die AE-Funktion bei gegebener Skalierung ist eine Setzung und kann mit wissenschaftlichen Methoden nicht hergeleitet werden.

Man kann eine Lärmbewertungsfunktion zweistufig entsprechend Bild 6 darstellen. Das Diagramm rechts enthält die Zuordnung von verbal beschriebenen Belästigungsgraden zur Lärmbelastung bzw. zum verwendeten Lärmindikator – wie bereits ausgeführt, ist diese Zuordnung mit wissenschaftlichen Methoden durch geeignete Feldstudien klärbar. Werden diesen Belästigungsgraden Skalenwerte (z.B. linear, logarithmisch, exponentiell usw.) zugeordnet, so ist dies eine im Grunde politische Setzung. In Bild 6 ist stattdessen diesen Belästigungsgraden im linken Diagramm eine lineare Ordinalskala zugeordnet. Die gewünschte Zuordnung unterschiedlicher Belästigungsgrade zueinander wird durch den festgelegten Kurvenverlauf bzw. die Funktionskonstruktion erreicht.

Es gibt keine wissenschaftlich begründbare Methodik, wie festgelegt werden kann, wie viele „leicht belästigte" Personen um X dB entlastet werden müssen, um dadurch eine bereits „erheblich belästigte" Person um weitere X dB mehr belasten zu dürfen. Genau diese Frage wird aber durch die Festlegung einer Skalierung eindeutig beantwortet.

Letztlich drückt die Lärmbewertungsfunktion die gesellschaftliche Meinung aus, wie nicht vermeidbare Belastungen unterschiedlichen Grades verteilt werden sollen. Wir sollten uns dies nicht von einer angeblich wissenschaftlich evidenten %HA-Funktion in technokratischer Weise vorschreiben lassen, sondern umgekehrt eine Bewertungsfunktion so konstruieren, dass sie zumindest in beschreibbaren einfachen Fällen den gesellschaftlichen Willen in dieser Frage wiedergibt. Hierzu ist es erforderlich, den Zusammenhang zwischen Funktionskonstruktion und den daraus folgenden Konsequenzen für die Lärmstrategie einer Stadt zu untersuchen.

4 Untersuchung der exponentiellen Lärmbewertungsfunktion

Bei mehreren Alternativen zur Durchführung von Lärmminderungsprogrammen soll dasjenige das optimale Paket darstellen, das zum minimalen NS-Wert führt. Dieser NS-Wert ist der über alle Betroffenen summierte Wert der Lärmbewertungsfunktion.

Aufgrund der erheblichen Konsequenzen einer derartigen Festlegung ist es zweckmäßig, den Einfluss der justierbaren Parameter genauer zu untersuchen. Hierzu wird im Folgenden der bereits als geeignet erkannte Exponentialansatz gewählt:

$$NS = \sum_i n_i \cdot 10^{k \cdot (L_i - L_R)} \qquad (11)$$

Der Kurvenverlauf bzw. die Steilheit der Kurve wird hier ausschließlich vom Parameter k bestimmt. Sein Einfluss wird an dem in **Bild 7** dargestellten einfachen Straßenmodell untersucht.

Ein Verkehrsstrom von N Kraftfahrzeugen pro Stunde wird über eine Verzweigung auf zwei Straßen mit $N1$ und $N2$ Kfz/h aufgeteilt, wobei beide Straßen am Ende wieder zusammen-

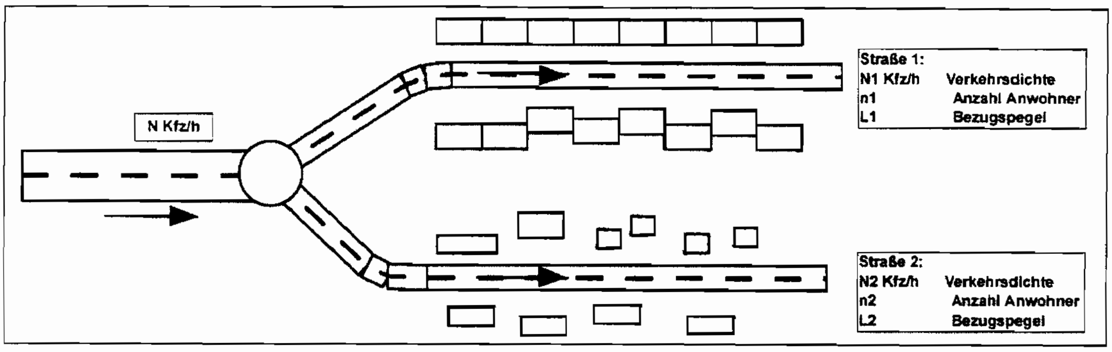

Bild 7. Straße mit Verkehrsstrom N Kfz/h, verzweigt auf zwei Straßen mit $N1$ Kfz/h und $N2$ Kfz/h.

geführt werden. Es sei angenommen, dass $n1$ bzw. $n2$ Anwohner in vergleichbarem Abstand an diesen Straßen wohnen und dass sie jeweils nur vom Lärm ihrer eigenen Straße beaufschlagt werden.

Um den Parameter k geeignet festlegen zu können, muss eine Entscheidung über die gewünschte Verkehrsverteilung in diesem einfachen Fall getroffen werden. Wenn an jeder der beiden Straßen nur eine Person wohnt, sollten wir dann den gesamten Verkehrsstrom N durch eine Straße lenken oder sollte der halbe Strom $N/2$ durch jede der beiden Straßen gelenkt werden?

Diese fast schon „moralische" Frage soll – sicher etwas axiomatisch – so beantwortet werden: Wenn keine andere Information vorliegt, gibt es keinen Grund, eine Person zugunsten einer anderen Person mehr zu belasten – der Fahrzeugstrom sollte auf beide Straßen aufgeteilt werden.

Sind zusätzliche Lärmminderungsmaßnahmen möglich – z. B. die Erhöhung der Schalldämmung der Gebäudefassaden – so kann es günstiger sein, den gesamten Verkehr durch eine der beiden Straßen zu lenken und dann diese Gebäude entsprechend zu verbessern.

Eine hilfreiche Grundlage zur Festlegung von Austauschbeziehungen zwischen unterschiedlichen Belastungsniveaus ergibt sich aus der in **Tabelle 1** dargestellten Beziehung zwischen Lärmbelastung einerseits und Beeinträchtigung des Wohnens andererseits.

Hieraus ergibt sich, dass mit einem einzigen Pegelanstieg um 10 dB aus einer in Ballungsräumen durchaus akzeptablen eine unakzeptabel hohe Belastung resultiert. Dies ist bei der Entscheidung zu berücksichtigen, wie viele mit einem bestimmten Pegel belastete Personen im Rahmen der Gesamtbewertung einer einzelnen Person mit einer um 10 dB höheren Belastung gleichgesetzt werden sollen.

Um den Einfluss der verwendeten Lärmbewertungsfunktion näher zu untersuchen, wird die NS-Funktion (11) auf das Szenario in Bild 7 angewendet.

Nach Definition soll der Planer die Verkehrsverteilung bevorzugen, die zum kleineren NS-Wert führt:

$$NS = n_1 \cdot 10^{k \cdot (L_1 - L_R)} + n_2 \cdot 10^{k \cdot (L2 - L_R)} + \ldots \qquad (12)$$

Um den Einfluss der Fahrzeugdichte zu isolieren, wird die von einer Straße verursachte Immission ausgedrückt durch

$$L_i = \overline{L}_i + 10 \cdot \log(N_i)\, dB \qquad (13)$$

Der Basispegel $\overline{L}_i$ ist der durch 1 Kfz/h verursachte Lärmindikator.

Durch Einsetzen von Gl. (13) in Gl. (12) ergibt sich

$$NS = 10^{-k \cdot L_R} \cdot \left(n_1 \cdot 10^{k \cdot \overline{L}_1} \cdot N_1^{10k} + n_2 \cdot 10^{k \cdot \overline{L}_2} \cdot N_2^{10k} + \ldots \right) \qquad (14)$$

Bild 8 zeigt die Abhängigkeit des verkehrsflussbedingten Pegelanteils 10 log(N_i) an den Wohnungen in Abhängigkeit von der Aufteilung des Fahrzeugstroms, wobei die Gesamtfahrzeugdichte 1 000 Kfz/h beträgt.

Das Ergebnis ist trivial: Bei Konzentration auf eine Straße verschwindet die Immission an der anderen Straße und bei Gleichverteilung ist der Pegel an beiden Straßen um 3 dB geringer als an der vorher maximal belasteten Straße.

Mit G. (14) ergibt sich die auf der Basis der Lärmbewertung „empfohlene" Verkehrsverteilung durch das Minimum dieser Lärmbewertungsfunktion

$$NS = n_1 \cdot 10^{k \cdot \overline{L}_1 + 10 \cdot k \cdot \log(N_1) - k \cdot L_R} + n_2 \cdot 10^{K \cdot \overline{L}_2 + 10 \cdot k \cdot \log(N - N_1) - k \cdot L_R} \qquad (15)$$

aus

$$\frac{\partial NS}{\partial N_1} = 0 \qquad (16)$$

Durch Differenzieren und Auflösung von Gl. (16) ergibt sich

$$N_1(NS_{\min}) = \frac{N}{\left(\frac{n_1 \cdot 10^{k \cdot \overline{L}_1}}{n_2 \cdot 10^{k \cdot \overline{L}_2}} \right)^{\frac{1}{10 \cdot k - 1}} + 1} \qquad (17)$$

L_{den} in dB(A)	Qualifizierung
50	komfortabel
60	typisch und akzeptabel in Ballungsräumen
70	hoch belastet und nicht akzeptabel, aber leider typisch für das Hauptstraßennetz in Ballungsräumen
80	extrem hohe Belastung, wohnen unakzeptabel beeinträchtigt
> 80	Wohnen ohne unakzeptable Gesundheitsrisiken nicht möglich

Tabelle 1. Qualifizierung von „Wohnen" für unterschiedliche Grade der Lärmbelastung.

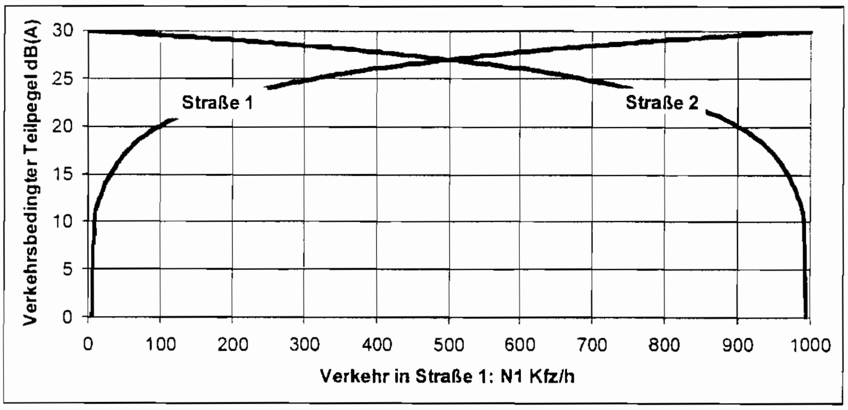

Bild 8. Verkehrsflussbedingter Pegelanteil an den Straßen 1 und 2.

Tabelle 2. Relation von Verdopplungsparameter *dL* und Parameter *k*.

dL in dB	*k*
10	0,03
5	0,06
3	0,10
1	0,30

Die von dieser Lärmbewertung empfohlene optimale Verteilung hängt somit vom Verhältnis n_1/n_2 der Anwohnerzahlen ab.

Der NS-Wert verdoppelt sich bei Erhöhung des Lärmindikators *dL*. **Tabelle** 2 zeigt die Beziehung dieses Verdopplungsparameters *dL* mit dem Exponentialparameter *k*.

Die **Bilder 9, 10** und **11** zeigen den nach Gl. (14) berechneten NS-Wert in Abhängigkeit von der Verkehrsverteilung auf den Straßen 1 und 2, wobei für den Parameter *k* die Werte 0,03 (Bild 9), 0,1 (Bild 10) und 0,3 (Bild 11) eingesetzt sind. Mit jedem Diagramm sind die beiden Fälle „Anwohner gleichverteilt" (500 – 500) und „Anwohner ungleich verteilt" (800 – 200) einbezogen. Die jeweils „empfohlene" Verkehrsverteilung ergibt sich als Minimum der zutreffenden Funktion.

Mit $k = 0{,}03$ (Bild 9) verdoppelt sich der NS-Wert alle 10 dB. Diese Bewertung wurde schon von *Glück* [13] vorgeschlagen, wobei dieser Ansatz damals mit der annähernden „Verdopplung" des Lautheitseindrucks beim Anstieg des A-bewerteten Pegels um 10 dB begründet wurde. Die Verwendung des HA-Konzepts nach *Miedema* [4] bzw. der mit Bild 1 dargestellte Ansatz (2) entspricht einer Verdopplung alle 8 dB und ist somit vergleichbar.

Dieses Konzept entspricht einer extrem schwachen Bewertung der Pegelhöhe relativ zur Betroffenenzahl. Nach dieser Bewertung darf ein Anwohner mit einer schon vorhandenen Belastung von 70 dB um X dB mehrbelastet werden, wenn nur zwei Anwohner mit vorhandener Belastung 60 dB um denselben Wert X dB entlastet werden. Berücksichtigt man den enormen Unterschied der Wohnqualität für diese beiden Fälle nach Tabelle 1, so ist kaum vorstellbar, dass dieses Lärmbewertungskonzept der gesellschaftlichen Meinung über eine faire Lastenverteilung entspricht.

Wie Bild 9 zeigt, ergibt sich das Minimum der Lärmbelastungsfunktion in beiden Fällen durch totale Bündelung des Verkehrs auf einer Straße. Für die Praxis bedeutet dies die Auslastung einer der beiden Straßen mit der technischen Maximalkapazität unabhängig von dem dort verursachten Pegel und auch ohne die Notwendigkeit, dort weitere Lärmminderungsmaßnahmen durchzuführen. Eine Optimierung unter Verwendung der Lärmbewertungsfunktion erübrigt sich – Konzentration führt stets zur Verringerung des NS-Werts. Das Minimum der Bewertungsgröße wird erreicht, wenn die Belastung der Anwohner an der weniger dicht bewohnten Straße soweit wie technisch möglich erhöht wird.

Mit $k = 0{,}1$ (Bild 10) führt die Verdopplung der Zahl der Fahrzeuge zum selben Anstieg des NS-Werts wie die Verdopplung der Zahl der Anwohner. Nur bei exakt gleich vielen Anwohnern – ein in der Praxis auszuschließender Fall – hat die Verkehrsverteilung keinen Einfluss auf das Ergebnis. In allen anderen Fällen gilt dasselbe wie oben ausgeführt, d. h. die Bewertung empfiehlt die totale Bündelung auf einer Straße – und auch hier ohne Begrenzung der absoluten Belastung der

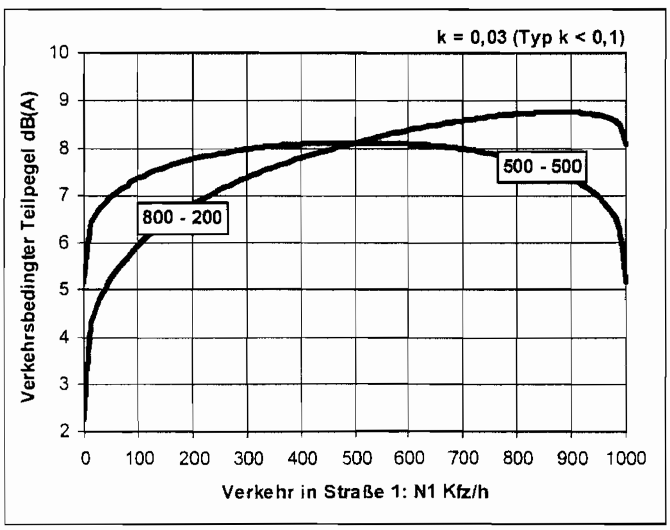

Bild 9. NS-Wert mit $k = 0{,}03$ (Verdopplung 10 dB).

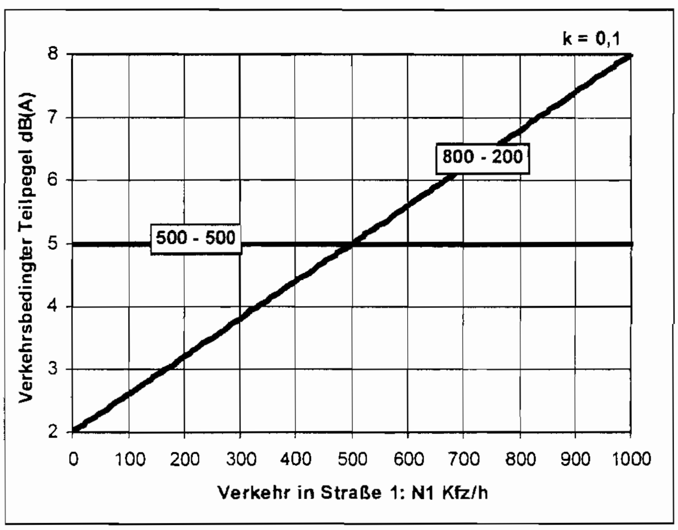

Bild 10. NS-Wert mit $k = 0{,}1$ (Verdopplung 3 dB).

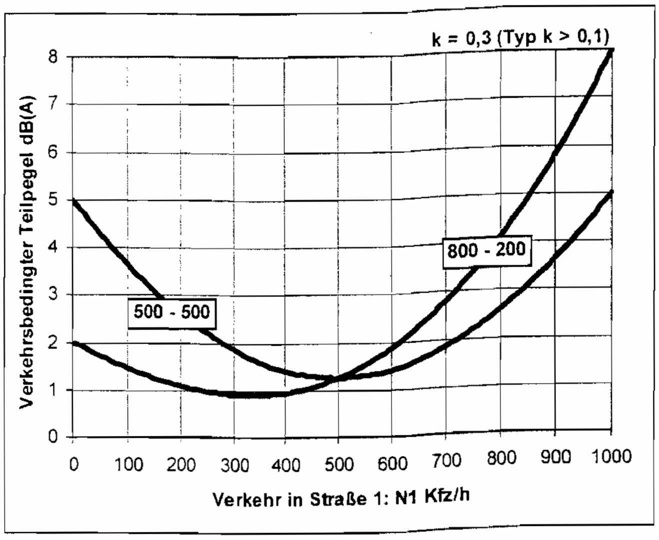

Bild 11. NS-Wert mit $k = 0,3$ (Verdopplung 1 dB).

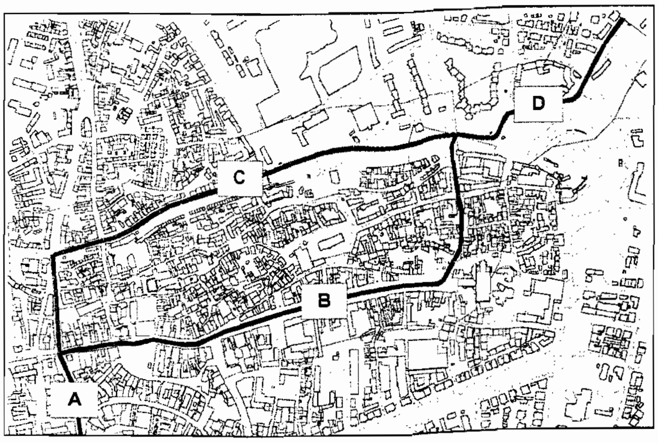

Bild 12. Das untersuchte Szenario mit der alternativen Verkehrsführung über Straße B oder C.

dort lebenden Anwohner und ohne die Notwendigkeit zusätzlicher Maßnahmen.
Nur im Fall $k = 0,3$ (wie generell für $k > 0,1$) ergibt sich ein Minimum der Lärmbewertungsfunktion bei einer Verkehrsaufteilung, die vom Verhältnis der Anwohnerzahl abhängt. Aufgrund des steilen Anstiegs der Lärmbewertungsfunktion bei hohen Pegeln können die Anwohner an keiner Straße beliebig belastet werden, ohne dass der NS-Wert wieder ansteigt.
Aus diesen Ergebnissen kann folgendes abgeleitet werden:
– Die Exponentialfunktion (11) ist ein akzeptabler Ansatz zur Lärmbewertung, weil sie eine progressiv ansteigende Gewichtung hoher Belastungen sicherstellt. Pegelanstiege bei hohem Ausgangspegel werden mehr gewichtet als Pegelanstiege bei niedrigem Ausgangspegel.
– Parameter $k \leq 0,1$ (oder Verdopplungsparameter über 3 dB) sind nicht akzeptabel, weil in diesem Fall die Lärmbewertung die technisch maximale Verkehrsbündelung ohne die Notwendigkeit von Lärmminderungsmaßnahmen und ohne Berücksichtigung der absoluten Lärmbelastung für die betroffenen Anwohner empfiehlt.
– Nur mit einem Parameter $k > 0,1$ wird eine Verteilung der Verkehrsflüsse empfohlen, die sich zwar am Verhältnis der Anwohnerzahlen orientiert, aber keine beliebig hohe Lärmbelastung durch Totalbündelung zulässt. Verkehrsbündelung, die über ein vom konkreten Wert für k abhängiges Maß hinausgeht, ist mit diesem Ansatz nur möglich, wenn für die Anwohner dieser mehrbelasteten Straße geeignete Lärmminderungsmaßnahmen einbezogen werden.
Da das letztgenannte Konzept dem entspricht, was umweltbewusste Verwaltungen im Einzelfall auch ohne formale Anwendung einer Lärmbewertung tun würden, spiegelt dieses den gesellschaftlichen Willen über die Verteilung unvermeidlicher Belastungen am besten wieder. Es beschreibt deshalb die im Weiteren verfolgte Strategie.

5 Vorschlag einer Lärmbewertung

Unter Berücksichtigung der beschriebenen Zusammenhänge wird die folgende Funktion zur Lärmbewertung vorgeschlagen:

$$NS = \sum_i \begin{cases} n_i \cdot 10^{0,15 \cdot (L_{den,i} - 50 - dl + dL_{source})} & \text{mit } L_{den,i} \leq 65\,dB(A) \\ n_i \cdot 10^{0,30 \cdot (L_{den,i} - 57,5 - dl + dL_{source})} & \text{mit } L_{den,i} > 65\,dB(A) \end{cases} \quad (18)$$

mit

NS	Lärmbewertungsmaß (Noise Score)
n_i	Zahl der Personen im Gebäude bzw. der Wohnung i
$L_{den,i}$	Lärmindikator an der am stärksten belasteten Fassade des Gebäudes bzw. der Wohnung i
dl	Abweichung der Schalldämmung der Fassade des Gebäudes bzw. der Wohnung i vom Mittelwert der Schalldämmung der Fassaden aller Gebäude bzw. aller Wohnungen
dL_{source}	Korrektur, die der unterschiedlichen Belästigungswirkung der verschiedenen Lärmarten (Straße, Schiene, Flug und Industrie) Rechnung trägt.

Diese Konstruktion der Lärmbewertungsfunktion bezieht mit ein, dass bei Pegeln über 65 dB(A) gesundheitliche Risiken nicht mehr auszuschließen sind und die Wohnfunktion erheblich beeinträchtigt sein kann. Wenn die Schalldämmung aller Gebäude vergleichbar ist bzw. wenn keine Informationen darüber vorliegen, ergibt sich eine „optimale" Verkehrsverteilung, bei der höhere Verkehrsdichten an den weniger dicht besiedelten Straßen vorliegen. Das System erlaubt aufgrund des steilen Anstiegs der Funktion (18) nicht, die dort befindlichen Anwohner beliebig hoch zu belasten. Aber es führt immer zu einem minimalen NS-Wert, wenn der Verkehr auf wenige Straßen gebündelt wird und wenn dann an diesen Straßen zusätzliche Maßnahmen durchgeführt werden. Diese können auf die Verringerung der Emission (bessere Fahrbahnoberfläche) oder auf die Erhöhung der Fassadenschalldämmung ausgerichtet sein.

6 Praktische Anwendung

Bild 12 zeigt ein Szenario, bei dem beispielhaft unter Anwendung der Lärmbewertung verschiedene Alternativen einer Verkehrsführung untersucht worden sind. Es handelt sich um einen Teilbereich einer Großstadt, in dem der Verkehrsstrom von Straße A zu Straße D auf einer der Straßen B oder C konzentriert geführt oder auf diese Straßen verteilt werden kann. Insgesamt 3 167 Gebäude mit 16 067 Bewoh-

nern wurden in die Untersuchung einbezogen.
Tabelle 3 zeigt, in welchen Abständen von diesen Straßen wie viele Personen wohnen.
Im Ausgangszustand – Fall 1 – wird von einer mittleren effektiven Fassadendämmung (hier: Differenz Außenpegel - Innenpegel) von 30 dB ausgegangen. Der Verkehrsstrom von A nach D und umgekehrt beträgt 1 360 Kfz/h mit 5 % Lkw-Anteil tags, 1 170 Kfz/h und Lkw-Anteil 4 % abends und 250 Kfz/h mit 5 % Lkw-Anteil nachts.
Folgende drei Alternativen wurden untersucht:
– Szenario 1: je die Hälfte des Verkehrs durch die Straßen B und C.
– Szenario 2: nahezu der gesamte Verkehr durch Straße B.
– Szenario 3: nahezu der gesamte Verkehr durch Straße C.
Für alle drei Szenarien wurde für die Wohngebäude der auf die am stärksten betroffene Fassade und auf 4 m Höhe bezogene Lärmindikator L_{den} aus den Fassadenpegeln berechnet. Dann wurde mit Gl. (19) der NS-Wert für jedes Gebäude ermittelt und für das gesamte Gebiet summiert. Dasselbe Verfahren wurde dann unter Anwendung des „Highly-Annoyed-Konzepts" wiederholt. Dabei ist die Bewertungsgleichung nach *Borst* und *Miedema* [8] um eine Korrektur für die Abweichung der jeweiligen Fassadendämmung vom Mittelwert in ähnlicher Weise wie in Gl. (18) ergänzt worden.

Tabelle 3. Anzahl der Bewohner in der unmittelbaren Nähe der Straßen B und C.

Straße	Anwohner bis zum Maximalabstand		
	25 m	50 m	100 m
B	938	1 388	2 891
C	704	1 659	3 530

Tabelle 4. NS-Wert summiert über 16 067 Einwohner und jeweils auf 100 % auf Szenario 1 bezogen.

Methodik	Fall 1: Reff = 30 dB alle Gebäude			Fall 2: Reff = 40 dB für L_{den} > 70		
	B und C	B	C	B und C	B	C
NS (HA)	100	89	91	100	88	87
NS (Gl. 18)	100	148	175	100	148	34

Tabelle 5. Verteilung der Anwohner auf einzelne L_{den}-Intervalle.

L^*_{den}		B	C	B und C
min	max			
	60	14 191	14 256	13 626
60	62	300	207	279
62	64	276	487	327
64	66	64	56	128
66	68	73	162	551
68	70	425	75	291
70	72	262	234	532
72	74	246	316	237
74	76	201	245	67
76	78	30	30	30
78	80	0	0	0

$$\%HA = 9{,}87 \cdot 10^{-4}(L_i - dl - 42)^3 - 1{,}44 \cdot 10^{-2}(L_i - dl - 42)^2 + 0{,}51(L_i - dl - 42) \quad (19)$$

Die Absolutwerte der Bewertungsergebnisse *NS* hängen vom Umgriff ab und sind nicht relevant – es wurden deshalb die NS-Werte für Szenario 1 zu 100 % gesetzt und alle anderen Ergebnisse darauf bezogen. Die Ergebnisse dieser Bewertung zeigt **Tabelle 4**.
Im Fall 1 – gleiche Fassadendämmung von 30 dB für alle Wohnungen vorausgesetzt – ergibt sich mit dem HA-Konzept die Empfehlung, den gesamten Verkehr über die Straße B zu leiten, während bei Gleichverteilung auf beide Straßen der höchste NS-Wert und damit die ungünstigste Beurteilung produziert wird. Bei Anwendung der vorgeschlagenen Bewertung nach Gl. (18) wird in diesem Fall eindeutig die Aufteilung des Verkehrs bevorzugt.
Tabelle 5 zeigt dass die mit dem HA-Konzept empfohlene Lösung bei 201 Anwohner Pegel im oberen Intervall 74 dB(A) bis 76 dB(A) verursacht, während mit dem vorgeschlagenen Konzept nach Gl. (18) nur 67 Anwohner mit diesem Pegel belastet werden (30 Anwohner mit Pegel 76 dB(A) bis 78 dB(A) leben in Gebäuden an den Straßen A und D – sie sind für diese Entscheidung nicht relevant). Damit ergibt sich wieder die bereits oben diskutierte Entscheidung, ob die Bündelung auf Straße B bevorzugt werden sollte, obwohl dreimal soviel Personen mit einem Pegel im höchsten Intervall wie bei Gleichverteilung belastet werden, nur weil mit niedrigeren Pegeln (z. B. im Intervall 70 dB(A) bis 72 dB(A)) nur ca. halb so viele belastet werden. Nach dem oben diskutierten ist dies folgendermaßen zu beantworten: Solange die Anwohner mit hoher Lärmexposition nicht besser geschützt werden, ist es nicht sinnvoll, den Verkehr auf einer Straße zu bündeln.
In einem weiteren Schritt wurde für die Wohngebäude, bei denen L_{den} > 70 dB(A) ist, eine um 10 dB verbesserte Fassadenschalldämmung vorausgesetzt (Fall 2) und dann das gesamte Prozedere wiederholt. Tabelle 4 zeigt, dass bei Einbeziehung dieser Maßnahme auch der vorgeschlagene Bewertungsansatz nach Gl. (18) die Bündelung empfiehlt – allerdings wesentlich eindeutiger und ausschließlich auf die Straße C bezogen. Der HA-Ansatz ergibt dagegen – nicht überraschend aufgrund der schwachen Bewertung hoher Pegel und der dadurch bedingten Unschärfe – sowohl bei Verkehrsbündelung auf B wie auch auf C fast denselben niedrigen NS-Wert, obwohl nach der Expositionsverteilung in diesem Fall (Tabelle 5) bei Bündelung auf B wesentlich mehr Personen mit dem höchsten auftretenden Pegel im Intervall 68 dB(A) bis 70 dB(A) belastet werden.
Auch diese Ergebnisse zeigen, dass die zur Lärmbewertung

Tabelle 6. Verteilung der 16 067 Einwohner auf L^*_{den}-Intervalle, wobei für Wohnungen mit einem außen anliegenden L_{den} über 70 dB(A) eine um 10 dB verbesserte Fassadenschalldämmung angenommen und entsprechend den Gln. (18) und (19) berücksichtigt ist ($L^*_{den} = L_{den} - dI$).

L^*_{den}		B	C	B und C
min	max			
	60	14191	14256	13626
60	62	562	441	811
62	64	522	803	564
64	66	265	301	195
66	68	103	192	581
68	70	425	75	291
70	72	0	0	0

üblicherweise herangezogenen Funktionen des Anteils der erheblich Belästigten (HA – Highly Annoyed) den Pegel der Geräuschexposition in Wohnbereichen extrem schwach gewichten. Auch die Anwendung im Sinne einer empirischen Näherung kann nicht empfohlen werden, wenn Lärmminderungsprogramme die Verbesserung in den höchstbelasteten Bereichen priorisieren sollen.

Ein System zur Lärmbewertung sollte unter Berücksichtigung der beschriebenen Prinzipien so einfach und transparent wie möglich aufgebaut sein, um einen Konsens über die damit erarbeiteten Lärmminderungsstrategien herbeiführen zu können. Die Einbeziehung unterschiedlicher, die Urteile der Menschen über ihr Wohnumfeld beeinflussender Sachverhalte, wie z. B. in [19] vorgeschlagen, macht ein Bewertungssystem technokratisch und erschwert die praktische Anwendung. Die Entscheidung über mögliche Verbesserungsmaßnahmen ist immer ein Kompromiss und es sind in den meisten Fällen zahlreiche nichtakustische Aspekte einzubeziehen. Es sollte aber nicht versucht werden, alle diese Faktoren im Lärmbewertungssystem zu berücksichtigen. Selbst wenn nachgewiesen werden könnte, dass die Nähe eines ruhigen Parks die Belästigung durch den Lärm an der eigenen Wohnung vermindert, so ist es doch kaum möglich, dafür eine Korrektur in der Bewertungsformel anzuwenden – dies wäre nämlich im Umkehrschluss eine Entscheidung darüber, um wie viel der Pegel in einem Wohngebiet erhöht werden kann, wenn in der Nähe solch ein Park eingerichtet wird. Wenn derartige Austauschbeziehungen für die einbezogenen Parameter nicht quantifiziert werden können, wird das Bewertungssystem in vielen Fällen zu nicht akzeptablen Lösungen führen.

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VBUS und RLS-90

Wie unterscheidet sich die „Vorläufige Berechnungsmethode für den Umgebungslärm an Straßen (VBUS)" von den „Richtlinien für den Lärmschutz an Straßen (RLS-90)"?

Wolfram Bartolomaeus, Lars Schade

Einführung

Die EG-Umgebungslärmrichtlinie 2002/49/EG [1] verfolgt das Ziel, die Belastung durch Umgebungslärm europaweit einheitlich zu erfassen sowie schädliche Auswirkungen durch Umgebungslärm zu verhindern, ihnen vorzubeugen oder sie zu mindern. Zu diesem Zweck sind im 5-Jahres-Turnus Lärmkarten zur Dokumentation der Belastung zu erstellen. Für Gebiete, in denen Lärmprobleme und Lärmauswirkungen vorliegen, sind Lärmaktionspläne zur Minderung der Belastung aufzustellen und ebenfalls im 5-Jahres-Turnus zu aktualisieren. Darüber hinaus sollen ruhige Gebiete vor einer Verlärmung geschützt werden.

Die Umsetzung der Umgebungslärmrichtlinie in nationales Recht erfolgte durch das Gesetz „zur Umsetzung der EG-Richtlinie über die Bewertung und Bekämpfung von Umgebungslärm" vom 24. Juni 2005 [2]. Dieses Gesetz besteht im Wesentlichen aus einer Änderung des Bundes-Immissionsschutzgesetzes vom 26. September 2002 [3], in das nach § 47 ein sechster Teil „Lärmminderungsplanung" eingefügt wurde. Auf der Grundlage dieses Gesetzes (siehe Verordnungsermächtigung in § 47f BImSchG) ist weiterhin die „Verordnung über die Lärmkartierung" – 34. Verordnung zum Bundes-Immissionsschutzgesetz (34. BImSchV) vom 6. März 2006 [8] erlassen worden. Nach § 5 Abs. 1 der 34. BImSchV werden die Berechnungsverfahren durch die Bundesregierung durch Veröffentlichung im Bundesanzeiger konkretisiert.

Die Richtlinie eröffnet den Mitgliedstaaten bis zum Vorliegen europaweit harmonisierter Verfahren nach Artikel 6 Abs. 2 zwei unterschiedliche Vorgehensweisen: entweder die Verwendung sog. „Interimsmethoden" oder die Weiterverwendung angepasster nationaler Verfahren. Bei den Interimsverfahren handelt es sich um folgende Methoden:

- für Industrie- und Gewerbelärm: DIN ISO 9613-2 „Akustik – Dämpfung des Schalls bei der Ausbreitung im Freien – Teil 2: Allgemeines Berechnungsverfahren" [4];
- für Fluglärm: ECAC.CEAC Doc. 29 „Report on Standard Method of Computing Noise Contours around Civil Airports" [5];
- für Straßenverkehrslärm: die französische Berechnungsmethode „NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB)" [6];
- für Eisenbahnlärm: die niederländische Berechnungsmethode, veröffentlicht in „Reken- en Meetvoorschrift Railverkeerslawaai '96" [7].

In Hinblick darauf, dass es sich bei den genannten Verfahren nur um vorläufige Bewertungsmethoden handelt, bis die Kommission im Verfahren nach Artikel 13 Abs. 2 der Richtlinie gemeinsame Bewertungsmethoden im Wege einer Überprüfung des Anhangs II festgelegt hat, hat die Bundesregierung beschlossen, die nationalen Verfahren weiter zu verwenden und an die Erfordernisse der Richtlinie anzupassen. Die Anpassung bezieht sich zum Einen auf die Vorgaben des Anhangs II sowie zum Anderen auf die Forderung der Richtlinie nach einer „Gleichwertigkeit" der Ergebnisse im Verhältnis zu den oben genannten Interimsverfahren.

Im Einzelnen wurden folgende Berechnungsvorschriften erarbeitet:

- für Industrie- und Gewerbelärm die VBUI (Vorläufige Berechnungsmethode für den Umgebungslärm durch Industrie und Gewerbe) auf Basis der TA Lärm [9];
- für Fluglärm die VBUF (Vorläufige Berechnungsmethode für den Umgebungslärm an Flugplätzen) auf Basis der AzB [10] und des DES [11];
- für Straßenverkehrslärm die VBUS (Vorläufige Berechnungsmethode für den Umgebungslärm an Straßen) auf Basis der RLS-90 [12];
- für Eisenbahnlärm die VBUSch (Vorläufige Berechnungsmethode für den Umgebungslärm an Schienenwegen) auf Basis der Schall03 [13].

Im Folgenden soll ausschließlich der Bereich des Straßenverkehrs betrachtet werden.

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Wie unterscheiden sich VBUS und RLS-90?

Bei der Erstellung der VBUS wurde der Grundsatz verfolgt, die Unterschiede zu den RLS-90 möglichst gering zu halten. Änderungen gegenüber den RLS-90 wurden daher nur vorgenommen, wenn sie laut Umgebungslärmrichtlinie erforderlich waren oder im Sinne einer Präzisierung der RLS-90 sinnvoll erschienen. Im Folgenden sind alle Änderungen aufgeführt und kurz erläutert.

Lärmindizes

Die wichtigste Änderung der VBUS gegenüber den RLS-90 ergibt sich aus der notwendigen Einführung neuer Lärmindizes. Im Anhang I der Umgebungslärmrichtlinie wird der Tag-Abend-Nacht-Pegel L_{DEN} definiert:

$$L_{DEN} = 10\lg\frac{1}{24}\left(12\cdot 10^{\frac{L_{Day}}{10}} + 4\cdot 10^{\frac{L_{Evening}+5}{10}} + 8\cdot 10^{\frac{L_{Night}+10}{10}}\right)$$

Die einzelnen Pegel L_{Day}, $L_{Evening}$ und L_{Night} sind als A-bewertete äquivalente Dauerschallpegel gemäß ISO 1996-2 [14] definiert, wobei der Beurteilungszeitraum ein Jahr beträgt und die Bestimmung des Langzeitmittelungspegels an allen Kalendertagen in den entsprechenden Zeiträumen des Tages vorgenommen wird.

In Deutschland hat man sich bei der

THE ASSESSMENT OF NOISE TAKING INTO ACCOUNT NOISE LEVELS AND PEOPLE ANNOYED

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SUMMARY

Numerous research on annoyance caused by noise improved our knowledge and understanding of peoples reactions. With our computerized methods to determine the noise levels for large scale scenarios and as a consequence of the European Directive about Environmental Noise this knowledge can be transformed into assessment methods allowing the relative scaling of different noise mitigation measures. A thorough review showed that ranking of noise exposures was always based on exposure – effect relations where the number of highly annoyed persons was used to quantify complex situations with spatial varying noise exposures.

It will be shown that this concept fails. If noise exposures change, we must sum up an annoyance quantity for all persons concerned and not only count the number of persons above a threshold. It is postulated that the relative weighting of different grades of annoyance is a political decision and should be defined taking into account the communities opinion about the best acceptable distribution of unavoidable hazards. Looking to the expressions used to calculate a single number result for assessing noise scenarios, it will be shown that the “Highly Annoyed” expression causes an extremely weak weighting of noise levels – the consequences are unacceptable.

On the basis of these findings a new assessment expression was developed and used for decision-making in the planning phase for simple and complex scenarios. This method can easily be extended to inclose different noise types and it may help to find effective and “fair” noise mitigation measures acceptable for all people concerned.

1 INTRODUCTION

Strategic noise mapping is a core activity addressed by the Directive 2002/49/EC /1/ to achieve comparable information about the noise situation in Europe. These noise maps are not only a means to produce coloured presentations of the noise distribution in a city. The digital model of agglomerations and environment with all relevant noise sources is an effective noise information system for the city administration and the public.

The map of noise levels shows the spatial distribution of noise. With the conflict map the regions are shown where given limiting values are exceeded. On the basis of an assessment of the noise situation action plans shall be developed with an optimal combination of measures to reduce the harmful effects.

An effective system to assess large scale noise problems must include the noise indicators (e.g. as defined by END) and the population exposed. Each decision-making whether the noise impact is significant or not needs at the end a ranking of different scenarios and this is a single number rating procedure. If we want to reduce the harmful effects of noise on people and decide about pros and cons among different scenarios, we are oblighed to define the necessary reduction of exposure if the number of persons exposed is raised.

Different concepts to calculate a Noise Score (NS) have been published:

Concept 1 – a linear relation (Lärmkennziffer LKZ)

$$NS = \sum_i n_i \cdot (L_i - L_R) \qquad (1)$$

n_i number of persons in group i, L_i Exposure level of group i, L_R limiting or reference value

Concept 2 – percentage of highly annoyed people (%HA Highly Annoyed)

$$\%HA = 9{,}87 \cdot 10^{-4}(L_i - 42)^3 - 1{,}44 \cdot 10^{-2}(L_i - 42)^2 + 0{,}51(L_i - 42)$$

$$NS = \sum_i n_i \cdot \frac{\%HA}{100} \qquad (2)$$

(This equation proposed by Miedema et al. /4/ for road noise approximates the result of many studies and questionnaires)

Concept 3 – Exponential increase

$$NS = \sum_i n_i \cdot 10^{k \cdot (L_i - L_R)} \qquad (3)$$

Parameter k defines the slope of the evaluation curve.

The general approach was to find the dependency of annoyance or any other examined hazard from the relevant noise indicator. Using an appropriate scaling of the effect and summing up the quantity for a regarded population gives the single number quantity that can be used to quantify and rank noise scenarios.

In most cases the number of highly annoyed persons HA was used as such a single number score. T.J. Schultz /2/ published a relation between the percentage of a population expressing high annoyance for the different noise types and the A-weighted day-night average sound level. Some years later Kryter /3/ compared the percentage of respondents being highly annoyed by different noise types. Many others used the number of heavy annoyed persons to express the reaction to noise.

Miedema and Vos /4/ summarized 45 surveys and extracted comparable curves representing the percentage of highly annoyed persons (%HA) as a function of DNL for aircraft, road traffic and railway noise (equation (2)). Miedema takes these functions not only as an information about the number of highly annoyed persons caused by a given exposure, but recommends to use this number to compare planning concepts with respect to the noise impact on the community.

Many other groups followed this idea to use the %HA function to derive a single number rating or a "Noise Score" for decision-making in community planning – the publications /5/, /6/, /7/ and /8/ are cited representative for many others.

A comprehensive review about the research on dose – effect relations and acoustic ratings was published in /9/ and /10/. It proves that ratings are generally based on counting the number of annoyed persons. Even attempts to standardize assessment methods /11,12/ use the same approach.

In Germany there began a discussion about a suitable method to assess noise in city planning 1975 /13/. The present author focused on the problems when the number of annoyed persons is used to quantify a noise situation using a single number rating /14,15/. These questions are also dealt with in the standardisation project VDI 3722-2 /16/ that started 1990 and which has still not been finalised.

The techniques of noise mapping /17,18/ and computer supported evaluation of large scenarios boost the need for a methodology of noise scoring. Based on research and publications mentioned above a systematic approach is presented here to link the annoyance concept with the highly annoyed quantification. The consequences of the definition of a noise score expression based on traffic flow distribution minimizing it will be discussed and from these results a methodology is proposed. The application to an existing scenario confirms the practicability of this approach.

2 The Highly Annoyed Concept (HA)

From questionnaires the relation between a noise indicator – in case of figure 1 this is the Day-Night-Level L_{dn} – and the percentage of highly annoyed persons in a population exposed can be derived.

Such %HA curves are shown in figure 1.

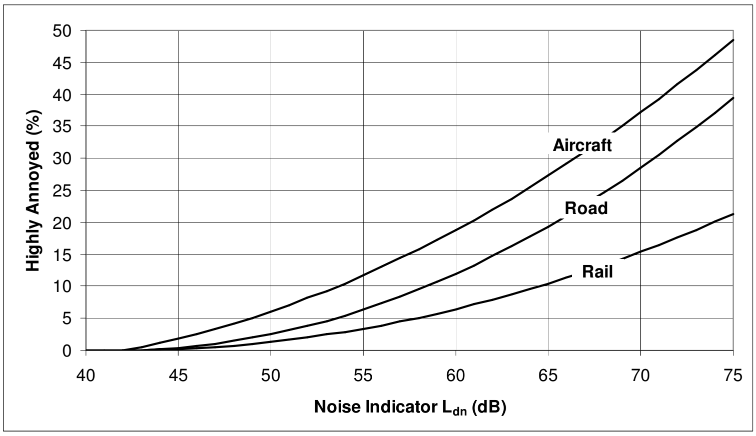


Figure 1 - Percentage of highly annoyed (%HA) for different noise types /4/

Using these functions (Figure 1), the probability to be highly annoyed can be determined for each person with known noise exposure. The result is the number of highly annoyed persons in a population. Generally (e.g. in /4/) this number is recommended to decide about the best strategy in planning scenarios where noise is an issue.

In reality it is a fiction that counting up people who declare to be highly annoyed would be a fair assessment of the populations exposure. Such a metric counts direct or indirect only how many persons cross the line between two categories of annoyance, but it neglects that for all the other people the annoyance raises also with increasing exposure. This is easily understood taking into account the complete curves – figure 1 shows for practical reasons only the lower part of the whole diagram, because in real field surveys we cannot include scenarios where more than 50% of the population is highly annoyed.

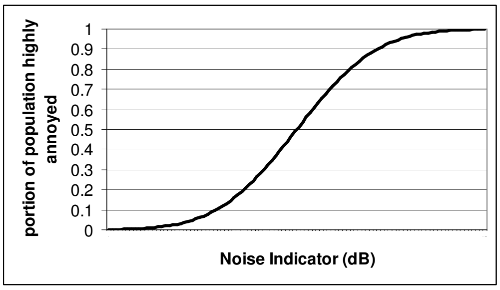


Figure 2 – Portion of exposed population highly annoyed

Figure 2 shows the complete HA-curve – it is obvious that the percentage cannot exceed 100% and therefore the curve must converge against this value. If we take the relation behind this curve to rank a noise situation, an increase of x decibels at medium range levels gives more additional highly annoyed persons than the same increase at high levels. It would be a fatal consequence to conclude that people living in noisy areas suffer less than those in more silent areas if the level is increased by a certain amount.

3 RELATION ANNOYANCE (AE) - HIGHLY ANNOYED (HA)

The following summarizes some ideas how people react on noise and the consequences for the assessment and ranking of noise problems. Using this very simple model of a population reacting on noise the relation between “annoyance curves” (AE) and “highly annoyed curves” (%HA) shall be investigated.

Assuming that we would apply a noise indicator which is a perfect measure to quantify the noise exposure and we would ask people living with defined exposure about the grade of annoyance caused by this, we get the relation of annoyance versus exposure. Many of such studies have been undertaken, and different scales have been used to qualify this grade of annoyance. Let's assume that the persons included in the survey use a simple 0 – 10 scale where the number correspond to judgements like "slightly annoying", "annoying", "highly annoying" and others.

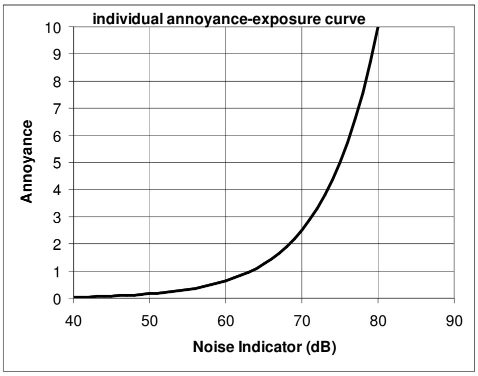


Figure 3 - Annoyance-exposure relation of an individual person (AE-curve) –scaling assumed

At this moment we take this 0 – 10 scale attached to the above mentioned judgements as a given hypothesis – we will see later that this more or less arbitrary assignment has tremendous consequences.

To fit our curve into the frame built by the scales of noise indicator and of annoyance judgement we can use the following experiences:

- most studies show that there is no significant annoyance reaction below 40 dB(A) – this defines the lower limit of our scale
- living at and above 80 dB(A) is nearly impossible – this defines where the slope of the assessment curve should converge at infinity
- the increase of annoyance with a given increase of noise level is larger at higher levels – the second derivative of the curve should be positive everywhere

The exponential expression

$$A(L) = c \cdot 10^{k \cdot (L - L_0)} \quad (4)$$

with

A quantity to express annoyance (selected scaling)
L noise indicator (e.g. L_{DEN})
L_0 reference value of noise indicator
k factor to be adjusted (0,03 <= k <= 0,3)

shall be used to represent the AE curve.

c is a factor used to calibrate the curve . If we assume that the annoyance quantity should be A_{cal} with a noise indicator L_{cal}, c is

$$c = A_{cal} \cdot 10^{-k \cdot (L_{cal} - L_0)} \quad (5)$$

where k defines the doubling parameter q – if an increase of the level L by q doubles the value of the annoyance A, k is

$$k = \frac{\lg(2)}{q} \tag{6}$$

The shown curve (Figure 3) was calculated with k=0,06. This means that doubling the annoyance quantity with each level increase of 5 dB – and setting c equal 0,04. So, an annoyance value of 10 corresponds with a noise indicator of 80 dB).

In our model different persons are different sensitive against noise – the AE-curves will therefore be distributed along the x–axis. To study the relation between AE-curves and HA-curves, we take the AE-curve (Figure 3) as the mean reaction for a certain noise type (e. g. railway noise) and assume the individual curves of all persons included in the survey to be normal distributed. Such a distribution is defined by its mean value and a standard deviation or variance. (The assumption of a normal distribution is somewhat arbitrary, but not prerequisite for the following). The curves in figure 4 shall be representative for the reaction of 9 persons on varying noise exposure.

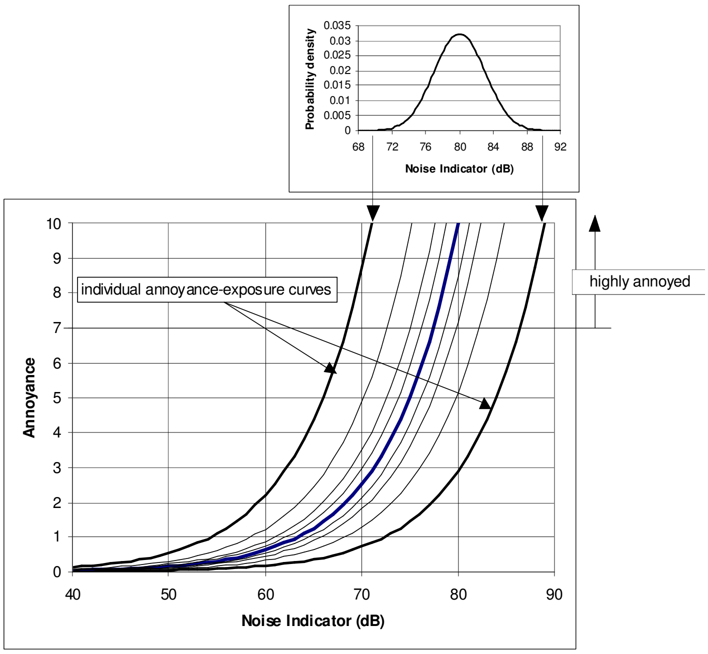


Figure 4 - Dispersion (approximated by a normal distribution) of individual AE-curves

Now, we define the annoyance threshold that should possibly not be exceeded – this may be the lower edge of the category "Highly annoyed". Miedema and Vos /4/ concluded from many studies that this annoyance quantity is 72 on a 0-100 scale.

Using this model of dispersed individual AE-curves, we are now able to understand the relation between the type of curves shown in figures 1 and 3. Based on the "threshold-annoyance" of

$$A_T = 7{,}2 \tag{7}$$

on our 0-10 scale the portion of a population exposed to a noise indicator of L' being "highly annoyed" can be written

$$w(L') = 1 - \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot \int_{-\infty}^{L'} e^{-\frac{(L-L_m)^2}{2\sigma^2}} dL \tag{8}$$

where

$$\mathrm{L_m} = \frac{1}{\mathrm{k}} \cdot \lg\left(\frac{\mathrm{A_T}}{\mathrm{c}}\right) + \mathrm{L_0} \tag{9}$$

From substitution of (7) and (9) in (8) the noise indicator that corresponds to the lower edge of the HA-category can be determined.

The diagram figure 2 is the result of integrating the probability density function (8) with parameter settings as described.

This model for the reaction of people on noise has enormous consequences for the necessary single number rating procedure. The derivation of the %HA-curve from the individual AE-curves proofs that this %HA-curve is not suitable to rank the increase of noise exposures for a population, because its slope is nothing but a measure of the distribution of the individual AE-curves. As it is shown in figures 3 or 4 in accordance with experience, the annoyance increases continuously with level for each person (where we use the word “level” as default for a well adapted noise indicator that correlates with annoyance). If the value of the indicator grows, the annoyance of all people exposed will increase.

Figure 5 helps to understand the relation AE – HA curves. These 9 curves shall be representative for the reaction of 9 persons on noise exposure. The horizontal line with annoyance quantity of 7,2 is the lower edge of the category “Highly annoyed”. If we want to know the HA-value at a certain level, we draw a vertical line and count the intersecting points of this vertical line with all AE-curves above this 7,2-threshold-line or the intersecting points of AE-curves at AE=7,2 left from this vertical line – it defines the number of persons that are above the threshold at this level. At level L1 we get for our population of 9 persons two such intersecting points and therefore

$$\mathrm{HA(L_1)} = \frac{2}{9} \cdot 100\,\% = 22{,}2\,\% \tag{10}$$

In the same way HA(L_2) is determined to be 89 % (8/9 * 100 %).

If we want to characterize the increase of annoyance using the HA-curve, we conclude that the harm by noise was increased by a factor of 4 (22 % -> 88 %). We counted the number of persons that crossed the threshold level for the HA-category. But, we neglected completely in our ranking system that all the other persons are more annoyed at level L2 than at level L1. This is shown in the diagram for person x – the annoyance quantity rises from 1.3 to 4.9, but this worsening of the situation is not included in the ranking system. Also a further increase of the annoyance of the 2 persons heavily annoyed at level L1 is not considered when the level is increased to L2.

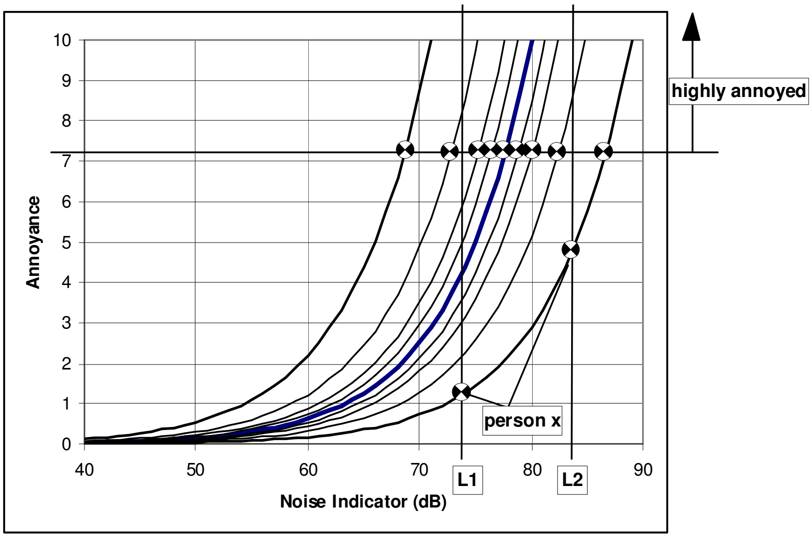


Figure 5 - Increase of AE and HA when the level is increased

We have to evaluate the increase of annoyance for all 9 persons in figure 6 caused by a level increase from L1 to L2 as it has been shown for person x. The increase in number of highly annoyed persons has nothing to do with this increase of annoyance. This can easily be proven: If we use AE-curves with a steeper slope keeping the intersecting points of these curves with the lower limit of the HA-section (horizontal line at AE = 7,2) constant, we will get the same increase of HA. But, for any of these 9 persons the increase of annoyance is larger caused by the steeper curve.

From these observations can be concluded that only the AE-curves can be used to characterize the increase of annoyance when the levels are increased. Unfortunately, there is no scientific way to relate a scaling like the one above to the qualifications of annoyance that we use in questionnaires. This is different with the %HA curves – the scale with values 0 % - 100 % can be related to the noise exposures completely based on such questionnaires and the resulting curve is based on scientific evidence. But, unfortunately, it is methodically not applicable to rank noise exposures.

This is the dilemma developing a Noise Scoring System – as it is shown in figure 6, the relation between noise indicator and noise score is partly scientifically based, partly a political decision.

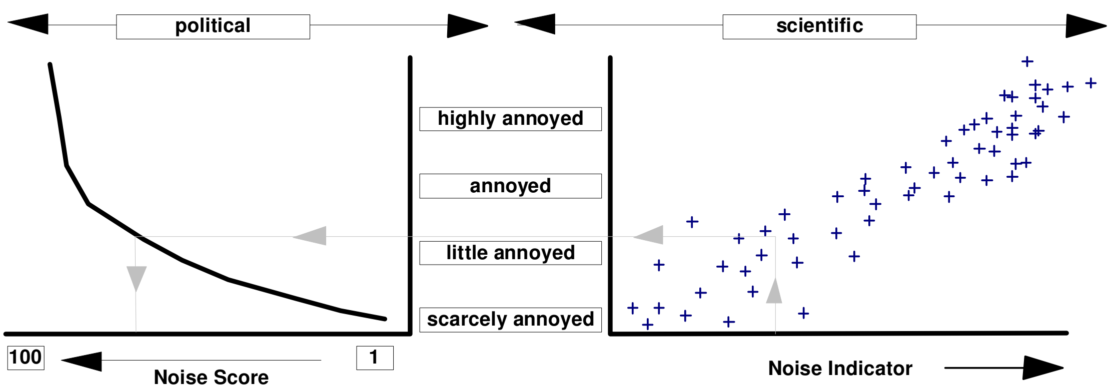


Figure 6 - Scientific and political parts of the relation between noise indicator and noise score

From questionnaires with people exposed to noise in their living environment we can derive diagrams of the type shown on the right side of figure 6. But, how we rank these verbal qualifications of different annoyance levels in relation to each other is a political decision that cannot be based on scientific evidence. There is no methodology to derive for how many “little annoyed” persons we must reduce the noise exposure by X dB(A) to justify the level increase with X dB(A) for one “highly annoyed” person.

We use the result of psycho-acoustic research and social questionnaires only as a basis to decide about this relation shown on the left side of figure 6 – but at the end we can use a function or curve relating the noise indicator directly with the noise score without the need of annoyance qualifications.

The derived relation between AE-curves and HA-curve show, that the HA-curve is nothing but a measure of the dispersion of the individual AE-curves – some people react later than others if the exposure is increased.

4 INFLUENCE OF SCORING ON DISTRIBUTION OF TRAFFIC FLOWS

A Noise Scoring System allows to sum up the noise scores of all persons concerned and to receive a single number to qualify a scenario. The best suited noise mitigation measure can then be found by minimizing the noise score for a given scenario.

With respect to the enormous consequences of the function relating the noise indicator to the noise score it is necessary to investigate carefully the consequences of such a definition. If an exponential expression is used

$$NS = \sum_i n_i \cdot 10^{K \cdot (L_i - L_R)} \qquad (11)$$

the influence of the parameter K on the optimization process should be known.

This influence has been investigated using the simple traffic flow system shown in figure 7. The traffic flow with N cars/hour is splitted up into two roads with flows N1 and N2. It is assumed that n1 and n2 residents are living with comparable mean distance at roads 1 and 2. The noise produced by road 1 does not influence the residents at road 2 and vice versa.

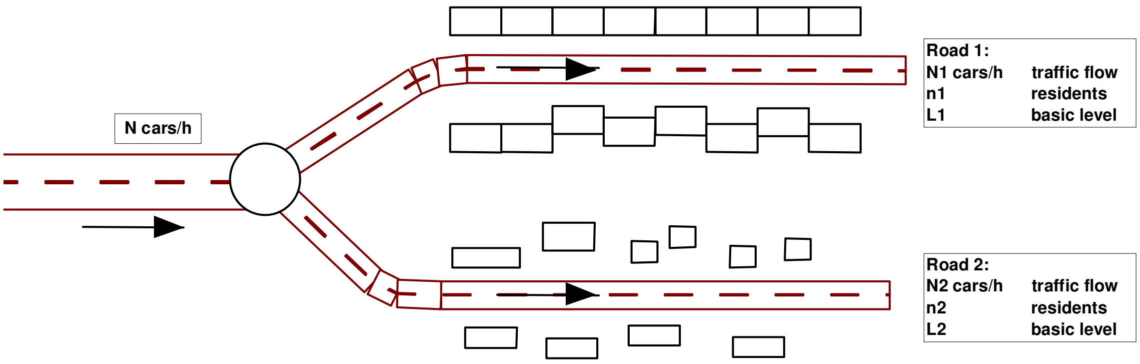


Figure 7 - A road with traffic flow N cars/h is splitted up in two roads

To select the parameter K in equation (11) we must decide about the “wanted” outcome of a decision in the simplest possible case. If there is one resident living at each of the two roads – should we channel the traffic N completely through one of the two roads or should we split it in two flows N/2 each?

From a social point of view the following is stated as a kind of postulate:

If no other information governs the decision, there is no reason to expose one person more to reduce the noise for the other person – the traffic flow should be splitted up into two equal flows.

If it is possible to apply additional measures, e.g. to improve the sound insulation of dwellings, it is better to concentrate the traffic on one of the two roads and to improve the sound insulation at this one dwelling.

A further help in the decision about the best acceptable parameter K in equation (11) is our knowledge about the relation noise indicator versus annoyance as it is shown in the diagram to the right in figure 7 or if we take into account the influence of noise exposure in living environments on quality of life as it is indicated in table 1.

Table 1 - Qualification of living environments in dependence of noise exposures

L_{den} dB(A)	**qualification**
50	comfortable
60	typical and acceptable in agglomerations with main roads
70	high exposure not acceptable, but typical for ring- and main roads
80	very high noise exposure, living extremely disturbed, not acceptable
>> 80	living without unacceptable high risc of noise induced deseases not possible

From these judgements about the influence of noise we can see that only one, maximal two steps of 10 dB are necessary to transform an acceptable into a non-acceptable living environment.

In order to investigate the influence of the selected noise scoring function we apply the exponential NS-function from equation (11) on the scenario in figure 7.

Using this function, the planner will prefer a distribution that minimizes the noise score

$$NS = n_1 \cdot 10^{K \cdot (L_1 - L_R)} + n_2 \cdot 10^{K \cdot (L_2 - L_R)} + ... \qquad (12)$$

To isolate the influence of the parameter "traffic flow" we write the noise indicator as

$$L_i = \overline{L}_i + 10 \cdot \log(N_i)\, dB \qquad (13)$$

The basic level $\overline{L}_i$ is the value of the noise indicator that would theoretically be produced by a traffic flow of 1 car/h.

Merging (13) into (12), we get the total noise score

$$NS = 10^{-K \cdot L_R} \cdot \left(n_1 \cdot 10^{K \cdot \overline{L}_1} \cdot N_1^{10K} + n_2 \cdot 10^{K \cdot \overline{L}_2} \cdot N_2^{10K} + ... \right) \qquad (14)$$

Figure 8 shows the noise indicator (resp. the flow dependent part 10 log(Ni)) at the dwellings in dependence of the splitting of the traffic flows, if the total traffic flow is assumed to be 1000 cars/h.

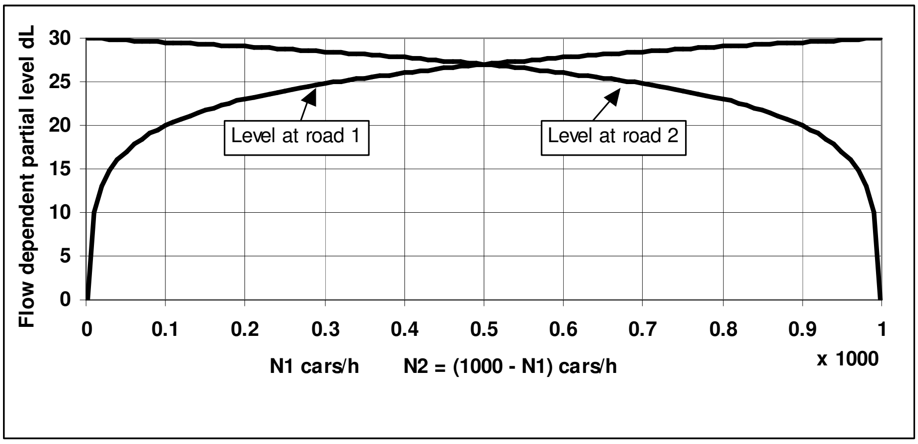


Figure 8 - Levels at road 1 and road 2 – dL is the flow dependent partial level 10 log(Ni) dB

The result based on this simple case is trivial – splitting-up the traffic flow into equal parts (N1 = 0.5 N) produces levels at both roads 3 dB less than the maximum level at the road with the total traffic concentrated on it.

Using expression (14), the optimum and “recommended” distribution will be found by minimizing the noise score NS

$$NS = n_1 \cdot 10^{K \cdot \overline{L}_1 + 10 \cdot K \cdot \log(N_1) - K \cdot L_R} + n_2 \cdot 10^{K \cdot \overline{L}_2 + 10 \cdot K \cdot \log(N - N_1) - K \cdot L_R} \qquad (15)$$

After rearranging this equation we obtain the traffic flow N_1 that produces the minimal noise score by

$$\frac{\partial NS}{\partial N_1} = 0 \qquad (16)$$

Solving this equation we get

$$N_1(NS_{min}) = \frac{N}{\left(\frac{n_1 \cdot 10^{K \cdot \overline{L}_1}}{n_2 \cdot 10^{K \cdot \overline{L}_2}}\right)^{\frac{1}{10 \cdot K - 1}} + 1} \qquad (17)$$

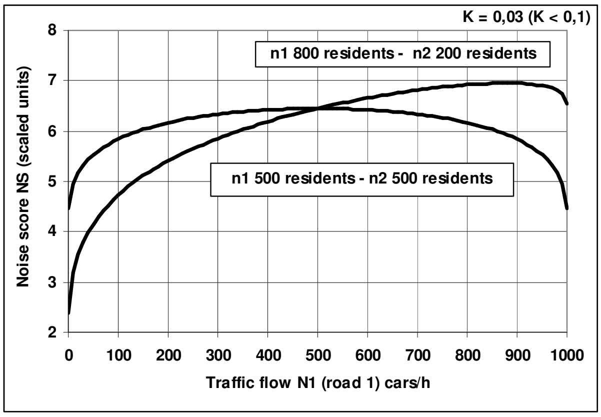
This result shows that the optimal traffic distribution depends on the relation n_1/n_2 of the number of people living along these roads.

The noise score NS is doubled when the noise indicator is increased by dL – table 2 shows the relation between this doubling parameter dL and the parameter K in the noise scoring equation (11).

Table 2 - Relation doubling parameter dL - parameter K

dL (dB)	K
10	0.03
5	0.06
3	0.10
1	0.30

Figures 10, 11 and 12 show the dependency between noise score NS and the traffic distribution on road 1 and road 2 with parameter K set to 0,03, 0,1 and 0,3. The best choice of distribution of traffic flows recommended in each case is given by the minimum of the curve.



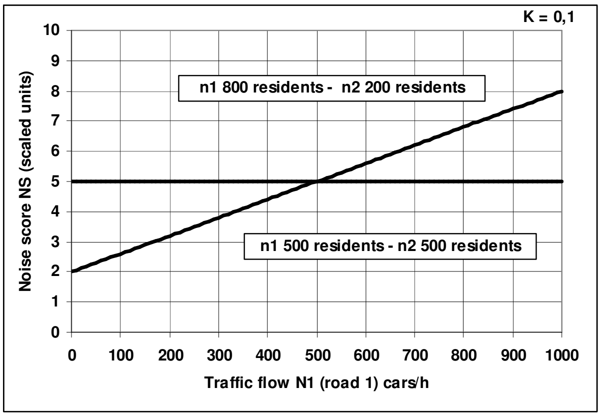


Figure 9 – Noise Score with K = 0.03 (HA-concept)

Figure 10 – Noise Score with K = 0.1

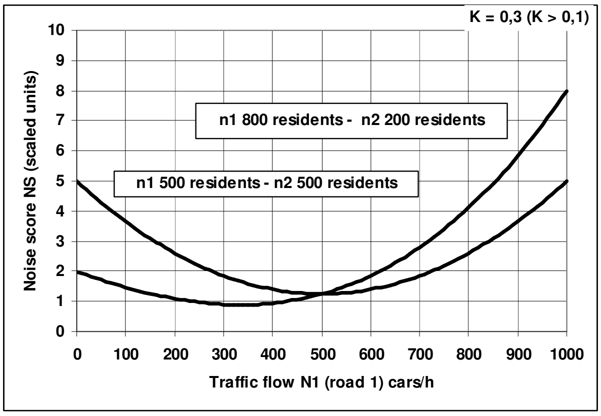


Figure 11 - Noise Score with K = 0.3

With K = 0,03 (Figure 9) the noise score NS doubles all 10 dB. This rating was used in /13/ and substantiated by the impression that the individual loudness doubles with a 10 dB increase of the A-weighted level. It is similar to the use of the %HA curves (figure 1), that produce a doubling of the noise score all 8 dB. This extremely weak dependency of the noise score from level recommends in all cases to bundle the traffic flows, even if the same number of residents live at roads 1 and 2. Figures 9 and 10 proof that a minimum of NS is always achieved if the traffic is completely (this means in reality to an extent allowed by the construction) bundled on the road with fewer residents. Traffic bundling is recommended even without any additional measures for the pitiable residents at the road less populated. The absolute exposure of these persons is not limited.

With K = 0,1 (figure 10) doubling the number of cars and doubling the number of inhabitants increases the noise score NS by the same amount. Only with equal distributed inhabitants the traffic distribution has no influence – in all other cases this scoring recommends to bundle the traffic on the road with the fewer residents – again without any limitation of their resulting noise exposure and without a need to protect them by additional measures.

Only in the case k= 0,3 (as it is true in all cases with k > 0,1) there is a minimum of the noise score that depends on the distribution of the traffic flows. This system does not allow to expose the residents at the road with smaller population to be exposed as much as possible. The steep increase of the noise score with level forbids to raise the exposure above an extent that depends on the distribution of the residents.

Based on these relations the following conclusions can be drawn:

- The exponential Noise Score Function (11) is an acceptable approach because it provides a progressive weighting of noise levels – a given increase of noise level is the worser the larger the noise levels in the existing situation are.
- Parameters K lower or equal 0.1 (or doubling parameters larger 3 dB) are not acceptable, because these values will instruct to concentrate the traffic as much as technically possible without any need to protect the exposed population.
- Only parameters K larger than 0.1 result in a distribution of traffic that depends on the distribution of residents. Bundling is not a consequence of exposure minimization, but of cost minimization if further noise mitigation measures to protect the most exposed residents are taken into account.

Authors proposing the "Highly-Annoyed-Concept" or any other system with weak weighting of levels often try to deal with the mentioned shortcomings by introducing a total maximum level of about 70 dB(A) and by recommending an optimization only where levels are lower. But this proves that the concept fails – it cannot be used in everyday situations in our cities where in many cases these levels are exceeded.

5 NOISE SCORING SYSTEM TO ASSESS SCENARIOS OF ANY COMPLEXITY

Based on the discussed dependencies and findings the following Noise Score is proposed:

$$NS = \sum_i \begin{cases} n_i \cdot 10^{0.15 \cdot \left(L_{den,i} - 50 - dI + dL_{source}\right)} & \text{with } L_{den,i} \le 65\,\mathrm{dB(A)} \\ n_i \cdot 10^{0.30 \cdot \left(L_{den,i} - 57.5 - dI + dL_{source}\right)} & \text{with } L_{den,i} > 65\,\mathrm{dB(A)} \end{cases} \tag{18}$$

with

NS	Noise Score
n_i	number of persons exposed with level $L_{den,I}$
$L_{den,j}$	Noise indicator at most exposed façade at dwelling i
dI	deviation of mean sound insulation of dwelling i from the mean insulation of all dwellings
dL_{source}	correction that accounts for different reaction versus noise from roads, railways, aircraft and industry

This Noise Score takes into account that above 65 dB(A) the risk of noise induced deseases cannot be neglected. If the sound insulation of the buildings is comparable, there is always an optimal traffic distribution where more traffic flow is accepted on roads with fewer exposed residents. It does not allow to expose these fewer residents as much as possible, because the NS-value increases exponentially with increasing level. But it recommends to bundle the traffic on roads with large capacity if additional measures like the acoustical improvement of the buildings for these highly exposed residents planned.

6 PRACTICAL APPLICATION

Figure 12 shows a scenario where the discussed Noise Scoring System has been applied. This scenario was extracted from a real city model with original buildings and inhabitants. Only the main roads A, B, C and D are considered. The traffic flow A-C and C-A is concentrated on road B or nearly equally distributed on roads B and C. There are 3167 buildings and 16067 inhabitants included in the survey. Table 3 shows the spatial distribution of residents.

Table 3 - Number of residents near roads B and C

Road	Max. distance from road		
	25 m	50 m	100 m
B	938	1388	2891
C	704	1659	3530

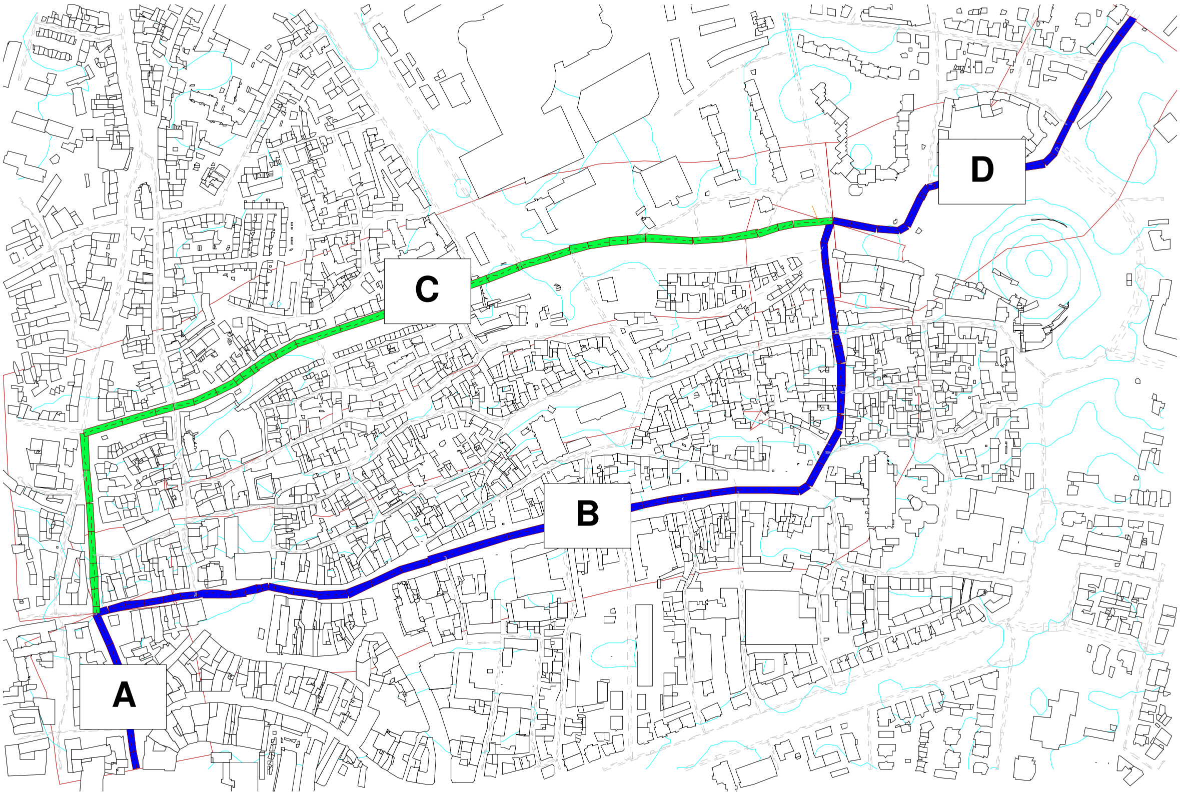


Figure 12 - Scenario where the Noise Scoring System has been applied – alternative routing B or C with main flow

It is assumed that the mean weighted sound reduction index of all buildings is 30 dB. The traffic flow A -> D and vice versa is 1360 veh/h and 5 % trucks day, 1170 veh/h and 4 % trucks evening and 250 veh/h and 5 % trucks night.

The following 3 scenarios have been evaluated:

- Scenario 1: half of traffic flow through road B and road C
- Scenario 2: nearly all traffic through road B
- Scenario 3: nearly all traffic through road C

For all three scenarios the noise indicator L_{den} was calculated at the most exposed façade and at a height 4 m above ground. Then NS was calculated in Case 1 (mean weighted sound reduction index of all building facades 30 dB) using expression (18) and – alternatively – based on the "Highly Annoyed Concept" (equation 2). This expression was used as proposed by Borst and Miedema /8/ including a correction for improved acoustical insulation of the building dl as it is defined above with equation (18).

$$\%HA = 9{,}87 \cdot 10^{-4}\left(L_i - dl - 42\right)^3 - 1{,}44 \cdot 10^{-2}\left(L_i - dl - 42\right)^2 + 0{,}51\left(L_i - dl - 42\right) \qquad (19)$$

The absolute values of the noise score NS for the whole scenario are not relevant. Therefore, the results for the scenario 1 with traffic flow equally distributed on roads B and C are used as reference 100 % in each case. The results of this evaluation are summarized in table 4.

Table 4 - Noise Score summed up for all 16067 residents and normalized in each case to 100% for scenario 1

Method	Case 1: R = 30 dB all buildings			Case 2: R = 40 dB for L_{DEN} > 70		
	B and C	B	C	B and C	B	C
NS (HA)	100	89	91	100	88	87
NS (equ. 18)	100	148	175	100	148	34

In case 1 (all buildings the same sound insulation) the Highly-Annoyed (HA) concept recommends to concentrate the traffic completely on road B, while by distributing it on both roads the largest noise score is produced. Applying the proposed expression (18) the distribution of the traffic on both roads is recommended.

Table 5 - Distribution of residents on L_{den}-intervals related to the most exposed façade (4m height)

Interval of L_{den}		B	C	B and C
min	max			
	60	14191	14256	13626
60	62	300	207	279
62	64	276	487	327
64	66	64	56	128
66	68	73	162	551
68	70	425	75	291
70	72	262	234	532
72	74	246	316	237
74	76	201	245	67
76	78	30	30	30
78	80	0	0	0

Table 5 shows that the solution proposed by the HA-concept produces 201 residents that are exposed with levels in the uppermost interval 74 – 76 dB(A), while with the solution recommended by equation (18) only 67 residents are exposed to these levels (30 residents in the level interval 76 – 78 dB(A) live in buildings facing roads A and D and are therefore not relevant for this decision). This is the basic decision: Should we prefer solution B with three times more people exposed with the highest level interval because at lower levels (e.g. 70 – 72 dB(A)) there are about half as many? The answer taking into account the discussion and the arguments above is clear: As long as these residents with high exposures are not better protected it is not allowed to bundle the traffic flow that way.

Now, an improved insulation of 40 dB for all facades with L_{den} larger than 70 dB(A) was taken into account (case 2) and the calculation was repeated. Table 6 shows, that the application of the proposed equation (18) recommends now strongly to bundle the traffic on road C, while again nearly the same noise score for bundling on road B or road C results if the HA-concept is applied.

Table 6 - Distribution of residents on L_{den}-intervals related to the most exposed façade (4m height) where the exceeding of 30 dB by the façade isolation is subtracted from the level outside

Interval of L_{den}		B	C	B and C
min	max			
	60	14191	14256	13626
60	62	562	441	811
62	64	522	803	564
64	66	265	301	195
66	68	103	192	581
68	70	425	75	291
70	72	0	0	0

Table 6 shows the distribution of exposures in that case – we have by far more residents in the uppermost level interval 68 – 70 dB(A) in case of bundling on road B than on road C. But even in this case the HA concept ranks bundling on B or C nearly equivalent.

From these results it can be concluded that the HA-concept is not only methodically wrong if noise scenarios shall be ranked. It even cannot be recommended to use the %HA-curve as an approximation when the highest noise exposures shall be reduced first.

Based on the detailed results of this investigation it is recommended to keep a ranking system for noise immissions as simple and transparent as possible and not to include different aspects as it was proposed in /19/. The decision among alternative possible noise mitigation plans is always a compromise where many additional non-acoustical aspects have to be taken into account. But it is a fiction that these influences can be included in the scoring system. Even if high noise levels at the façade are less annoying when a parc with low noise levels is somewhere nearby, it is hardly possible to quantify this effect for all possible configurations. Integrating it in the scoring system means to decide about the acceptable increase of noise levels at the facades when a parc is installed somewhere. If these exchange relations cannot be quantified, the formal construction of an expression will result in solutions that will not be acceptable in many cases.

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