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Decision support tool

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0 EXECUTIVE SUMMARY

The objective of QCity is to propose a range of measures and solutions with respect to noise in cities that can be integrated in the action plans that these cities (agglomerations) have to produce as a consequence of the EU Environmental Noise Directive (END). Noise maps can be used as a starting point for the design of measures that improve the noise climate. To evaluate the need for noise measures as well as the improvement that can be obtained with various measures, there is a need for a system that rates environmental noise based on noise maps. Such a rating system was described in a previous report by Miedema et al. [8].

The noise climate in a city can be mapped with a noise mapping tool. However, to realize effective noise abatement measures another kind of tool is needed. The development of such a tool, a **decision support system**, is described in this report. The tool helps its users to locate noise sources that have most impact on the noise climate in a city and it suggests possible effective noise abatement measures.

The methodology of the decision support system is presented and the implementation is discussed. The proof of concept of the decision support system for road noise is given; we have used the city of Amsterdam as an example. On the basis of a detailed noise map, for each road segment an indication is given for the amount of negative effect (e.g. number of people being highly annoyed per meter) it is causing. On the basis of the characteristics of the road segment, the system suggests possible noise mitigation measures. The effect of the measure chosen by the user, such as the application of silent road surface types or lowering speed limits, can be interactively explored with the system. It directly shows the impact of a measure after a measure has been applied though the interactive interface.

1 INTRODUCTION

Noise annoyance due to transportation is widespread in industrialized countries and in urban areas in developing countries. June 2002 the European Parliament and Council adopted the Environmental Noise Directive (END) [2]. END intends to provide a common basis for dealing with noise problems across the EU. One of its main objectives is to monitor the environmental problem by requiring the authorities in Member States to draw up strategic noise maps for major roads, railways, airports and agglomerations, using harmonised noise metrics L_{den} (day-evening-night level) and L_{night} (night equivalent level). These maps will be used to design action plans to manage environmental noise and its health effects, including noise annoyance. To meet this main objective and others, a number of projects started at national and EU level; including the project Quiet City Transport (QCity), as part of the EU Sixth Framework Programme.

This report focuses on the proof of concept of a so called **decision support system.** This decision support system helps planners to locate the noise sources that have most impact and to think of noise abatement measures that are most (cost) effective. This system can be applied to any city in general, but in this report it has been applied to the city of Amsterdam (The Netherlands) for road traffic noise. Using a road traffic noise map of the city of Amsterdam the impact of each road traffic noise source can be quantified; in particular the number of highly annoyed per meter can be calculated for each road segment. Based on this noise impact quantification, the decision support system then suggests a short list with the most (cost) effective noise abatement measures. The user/planner can then select a measure and evaluate its effect.

This report is organised as follows. In Section 2 the various steps of the decision support system are described. In particular the quantification of the impact of noise sources is discussed in more detail. Also the methods used to estimate the effects of possible noise abatement measures are elaborated. Section 3 describes the software and its design. In Section 4 an example of the quantification of the impact of road traffic noise sources is given for the city of Amsterdam. The number of highly annoyed (*HA*) per meter is calculated for each road segment. Furthermore examples of possible noise measures and their (estimated) effect are shown. Finally in Section 5 we summarize our findings and conclude.

2 THE DECISION SUPPORT SYSTEM

2.1 NOISE MAPPING AND NOISE RATING

Several methods and software tools for noise mapping exist and have been used for noise mapping various cities, see e.g. Refs. [4] and [9]. One of those noise mapping tools is Urbis [3], developed by TNO.

Urbis calculates the noise emissions on the basis of digital road maps, where traffic volume, speed and road surface type are attributes of road segments. Further input for noise transmission calculations is digital maps of land use from which the surface type may be derived, and maps of buildings and other objects (e.g. noise screens). Meteorological, ground, object and screen attenuation, and first order reflections close to noise sources are included in the modelling of noise transmissions. The noise immissions are calculated for receptor points at a height of 4 meter on a 25 x 25 meter grid, supplemented with receptors close to the noise sources and receptors at the façades of buildings with direct sight on a noise source. A 3×3 meter noise grid is derived by interpolation from the calculated noise levels at these receptors. The A-weighted equivalent noise levels (L_{Aeq}) are calculated for the day, evening and night, and combined to a map for the day-evening-night noise levels (L_{den}).

An application of Urbis in the case of Amsterdam can be found in another QCity report by Polinder et al. [9]. The Urbis instrument is suited for environmental surveys. For dealing with very local noise issues we have developed a **decision support system** in the framework of the QCity project as described in this report

The effects of various noise measures (e.g. lowering speed limits, silent road surface types) can be explored interactively with the system. The software is constructed in a modular way such that it can be linked to a traffic model, so that the effect of traffic measures can also be evaluated. Also the used noise model can easily be replaced by other detailed noise models.

Directly after a noise abatement measure has been applied through the interactive interface the updated noise impact indicators (e.g. annoyance) as well as detailed noise contour maps may be displayed. For further details about interactive noise maps we refer to Borst et al. [1]. An example of a noise map for the central part of Amsterdam produced by Urbis is shown in Figure 1.

Figure 1 shows the road traffic noise levels, L_{den} in dB(A), for the city of Amsterdam. The structure of several major roads can be seen clearly. The blue and purple areas indicate a high noise level as is explained by the legend at the bottom of the figure.

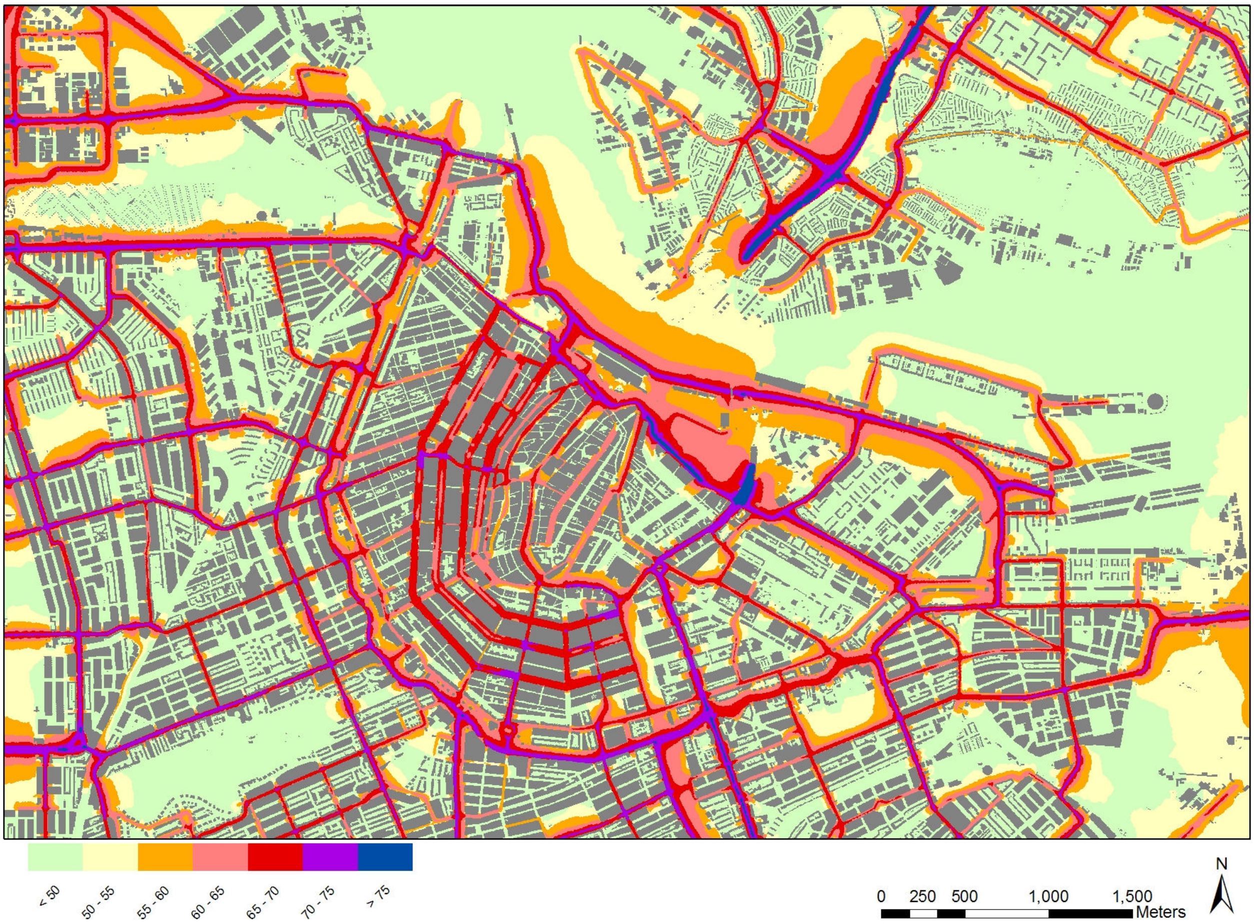

Figure 1: Road traffic noise map for the city centre of Amsterdam. The values for the noise levels, L_{den} in dB(A), are represented by the various colours.

Noise impact indicators are an effective aid to compare various noise abatement scenarios [1]. To evaluate the necessity of noise abatement measures and to determine the improvement that may be obtained with noise abatement measures, it is necessary to have a system to rate environmental noise. Such a rating system based on noise maps has been presented in a previous report by Miedema et al. [8]. One of the four indicators, which together constitute the environmental noise rating system, is the percentage highly annoyed people (*%HA*).

The *%HA* is defined as the percentage of responses exceeding the cut-off of 72 on a 0-100 scale of annoyance, with 0 corresponding to no noise annoyance, and 100 to corresponding to an extreme noise annoyance. It can be calculated for various noise sources (aircraft, road traffic, railways). For example for road traffic noise, the *%HA* as a function of L_{den} may be expressed as the following polynomial (see Ref. [7])

$$\%HA = 9.868 \cdot 10^{-4} \left(L_{den} - 42\right)^3 - 1.436 \cdot 10^{-2} \left(L_{den} - 42\right)^2 + 0.512\left(L_{den} - 42\right). \qquad (1)$$

The numerical coefficients in Eq. (1) were determined in a fit to data from noise annoyance studies for road traffic noise. Here, as a noise exposure metric, the sound pressure level L_{den} has been used. It is defined in terms of the sound pressure levels during daytime, evening, and night. Its precise definition is

$$L_{den} = 10\log\left[(12/24)10^{LD/10} + (4/24)10^{(LE+5)/10} + (8/24)10^{(LN+10)/10}\right]. \quad (2)$$

Here *LD*, *LE*, and *LN* are the A-weighted equivalent sound pressure levels for the day (7-19h), evening (19-23h), and night (23-7h) respectively determined over the year.

Borst et al. [1] showed how this can be used to calculate the number of highly annoyed people, and how this indicator can be used to compare different noise abatement strategies. Figure 2 shows an example of this for the city of Amsterdam, see Polinder et al. [9]; the various noise abatement strategies labelled with *s1*, *s2*, etc. can be found in this report.

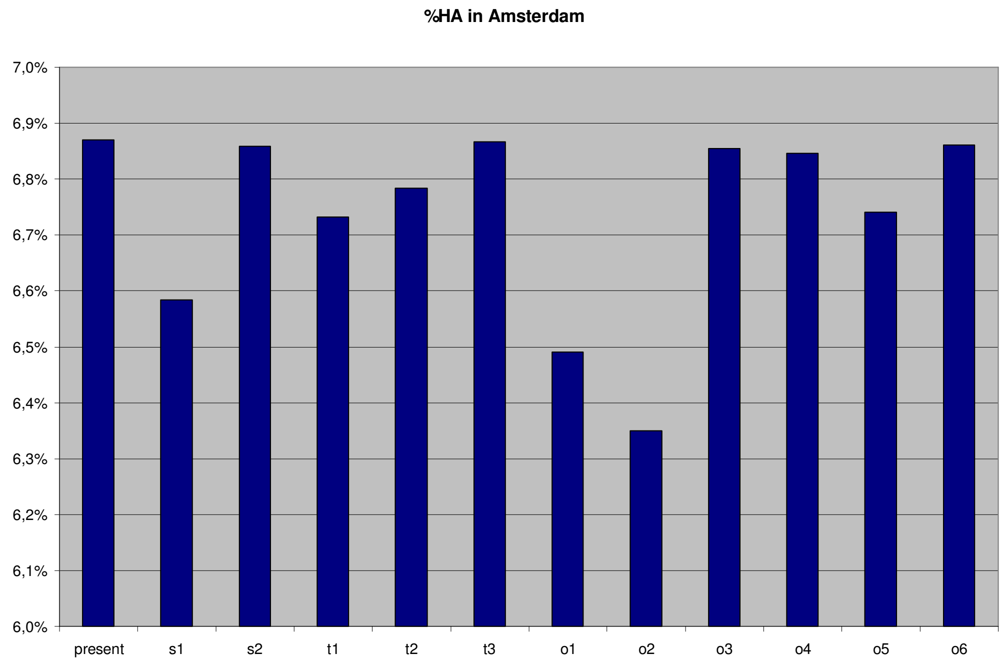

Figure 2: Expected percentage of people highly annoyed (*%HA*) due to road traffic noise in Amsterdam according to the various noise abatement scenarios.

2.2 CONCEPT OF THE DECISION SUPPORT SYSTEM

Applying a noise mapping tool, such as Urbis, one can gain an insight into the (global) noise climate in a city or urban area. However, to realize effective noise actions one needs another kind of tool. Such a tool, a decision support system, has been developed by TNO in the framework of the QCity project.

This decision support system helps its users to locate noise sources that have most impact and it helps to estimate the effect of noise abatement measures. So far, in this proof of concept of the decision support system, only noise due to road traffic is taken into account. Furthermore, the system is not completely automated; instead some input of the user has remained a part of the loop. This will become clear shortly.

The working of the decision support system basically consists of the following five steps:

1. The impact of each noise source is quantified,

2. The user selects the noise sources to which noise abatement measures are applied,
3. The decision support system suggests a shortlist of possible effective noise abatement measures; see also the QCity datasheets showing various noise measures applied to the city of Amsterdam,
4. The user selects noise abatement measure,
5. The effect of the selected noise abatement measure is evaluated.

The first and the third step are the most important ones in the construction of the decision support system. These two steps will be discussed in more detail in Sections 2.3-2.5 respectively.

We note again that we have not fully automated the decision support system. It has become an interactive system in which the user decides to which noise sources abatement measures are applied. Supported with a shortlist with possible effective noise abatement measurers, as suggested by the decision support system, the user also decides which measures are applied to the selected noise sources.

2.3 QUANTIFICATION OF THE IMPACT OF NOISE SOURCES

Here we elaborate on the quantification of the impact of noise sources. In particular we will consider the number of highly annoyed (*HA*) people as a result of road traffic noise as the appropriate noise impact indicator; and then we will determine the *HA* per road segment. Here the road segments are identified as the noise sources. To be more specific, the quantification scheme for the impact of noise sources is as follows:

1. Define receptors on each façade of each dwelling,
2. Calculate the noise load on each receptor, and store the noise load contribution per road segment,
3. For each dwelling, determine the receptor with the highest noise load,
4. Calculate the percentage of highly annoyed ($\%HA$) people for each dwelling, using the receptor noise load values,
5. Assign the contribution to HA to each road segment (weighted by the noise energy contribution of the road segments),
6. Sum the HA contributions for each road segment.

Figure 3 visualizes in a schematic way a location at which the noise impact can be quantified according to the previous scheme.

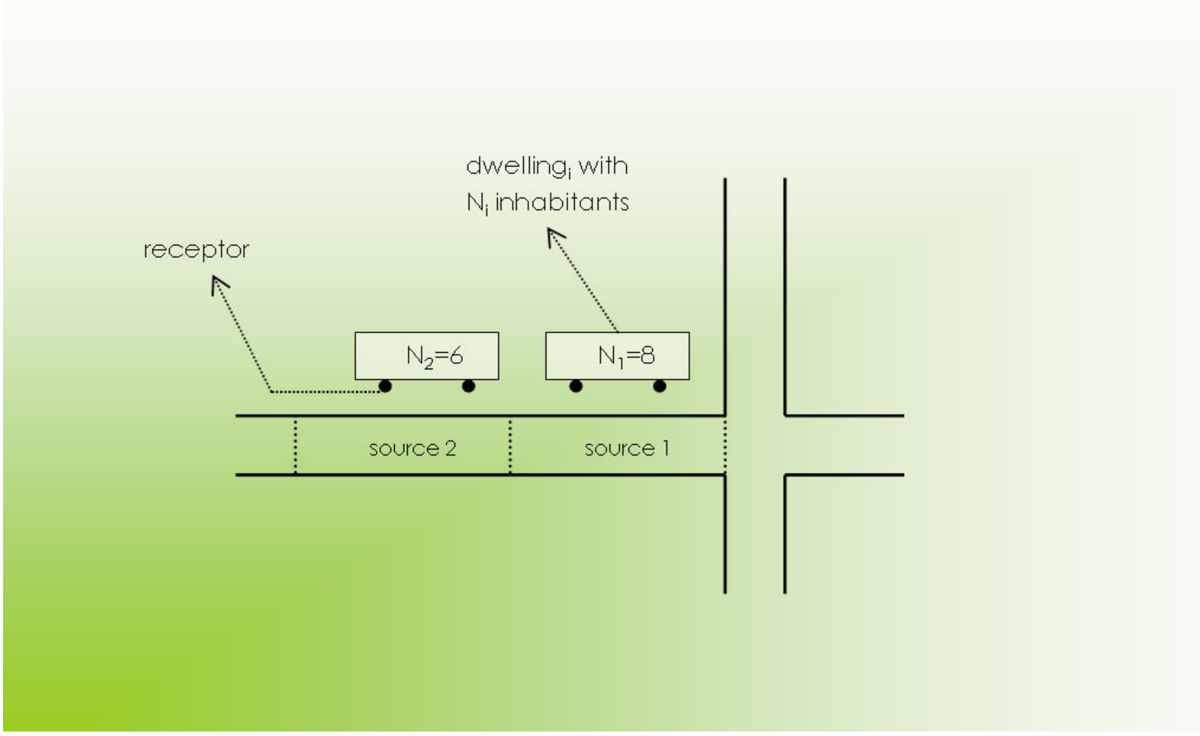

Figure 3: Schematic overview to illustrate the quantification of the noise impact.

In Figure 3 noise receptors have been defined at the façades of the buildings. The roads are divided into various road segments, i.e. the noise sources, using dotted lines (in reality all roads are split up in 50 meter segments). The noise load for each receptor can be calculated and the noise energy contribution from each noise source is known. The number of inhabitant is known for each dwelling$_i$, N_i. Applying the road traffic noise dose-effect relation, Eq. (1), the number of *HA* can be calculated for dwelling$_i$ and can be assigned to each noise source, weighted by the noise energy contribution of the noise sources to dwelling$_i$. Finally for each noise source the number of *HA* can be obtained by summing the contributions from each dwelling$_i$.

Once the noise impact (in this report the number of *HA*) is known for each noise source, the decision support system can estimate the effect of possible noise abatement measures and suggest a shortlist of them to the user, see Sections 2.4-2.5. We remark again that in the above quantification scheme *HA* was used for evaluating the noise impact but in principle the scheme could be generalized to use other noise impact indicators as well.

2.4 Possible noise abatement measures

If a road segment in a city causes high annoyance, there may be several possibilities for achieving lower noise levels and reducing the annoyance. In this proof of concept of the decision support system we restrict ourselves to the following three categories of noise abatement measures:

1. Noise barrier near the road,
2. Modification of traffic flow (speeds and intensities of various vehicle types),

3. Modification of road surface.

In principle, these three categories correspond to an infinite number of measures, as there are an infinite number of possibilities for choosing continuous variables such as the height of a barrier. We have chosen to restrict ourselves to a *finite list* of practical measures, *i.e.* measures that can be applied reasonably in a city:

1. Noise barrier of 3 m at the edge of the road,
2. Noise barrier of 5 m at the edge of the road,
3. Driving speed reduction of 20 km/h (e.g. 120 → 100 km/h or 50 → 30 km/h),
4. Prohibition of heavy vehicles (trucks) in the street,
5. Modification of road surface: cobbles → dense asphalt,
6. Modification of road surface: dense asphalt → porous asphalt,
7. Modification of road surface: dense asphalt → double-layer porous asphalt,
8. Modification of road surface: dense asphalt → thin top layer asphalt,
9. Modification of road surface: porous asphalt → double-layer porous asphalt.

We consider noise barriers (measures 1 and 2) only for roads with driving speeds of 70 km/h or higher. We assume that there is no noise barrier in the original situation.

We note that not all parameters that influence the feasibility of noise abatement measures at a specific location in a city have been taken into account by the decision support system.

For example, the system may suggest the application of double-layer porous asphalt as the best measure (In terms of noise level reduction). However, in practice such a measure is not always applied in central parts of a city.

2.5 DETERMINATION OF MOST EFFECTIVE NOISE ABATEMENT MEASURES

We have developed a simple calculation model to calculate estimates of the expected noise reductions for the nine measures indicated in the previous section. With this model, the measures can be ranked in increasing order of expected noise reduction. From the ranked list, the most effective measures can be selected.

A noise barrier (measures 1 and 2) has an effect on *sound propagation* from the source to the receivers. In Section 2.5.1 we describe the model that we use for the noise reduction due to a noise barrier.

The other measures (measures 3 – 9) correspond to a modification of the traffic parameters or the road surface. These measures have an effect only on the *sound emission* of the source. We neglect here the small effect that a modification of the road surface has on the sound propagation. Consequently, the noise reduction for these measures is equal to the emission reduction. In Section 2.5.2 we describe the model that we use for the noise reduction for measures 3 – 9.

The models described in the next sections are based on the Dutch calculation method for road traffic noise, see Refs. [6] and [11], which is more or less similar to the International standard ISO 9613-2, see Ref. [5].

2.5.1 A noise barrier near the road

In this section we describe a model for calculating the noise reduction due to a noise barrier near a road segment.

The input parameters of the model are (see Figure 4):

- $\mathbf{r}_s = (x_s, y_s, z_s)$ coordinates of midpoint of the road segment, with $z_s = 0$,
- $\mathbf{r}_{r,i} = (x_{r,i}, y_{r,i}, z_{r,i})$ coordinates of relevant receivers, $i = 1, \ldots, N$,

  (We assume $z_{r,i} = 4$ m, except behind buildings, see below),
- $\mathbf{r}_{t,i} = (x_{t,i}, y_{t,i}, z_{t,i})$ coordinates of the barrier top,
- For receivers behind buildings:

  $\mathbf{r}_{b,i} = (x_{b,i}, y_{b,i}, z_{b,i})$ coordinates of the diffraction edge of the dominant or nearest building,

  $z_{rooftop}$ average height of roof tops in the built-up area,
- $L_{i,j}$ received sound levels due to the road segment (for eight octave bands $j = 1, \ldots, 8$).

The eight octave bands that we consider are 63 Hz ($j = 1$), …, 8 kHz ($j = 8$).

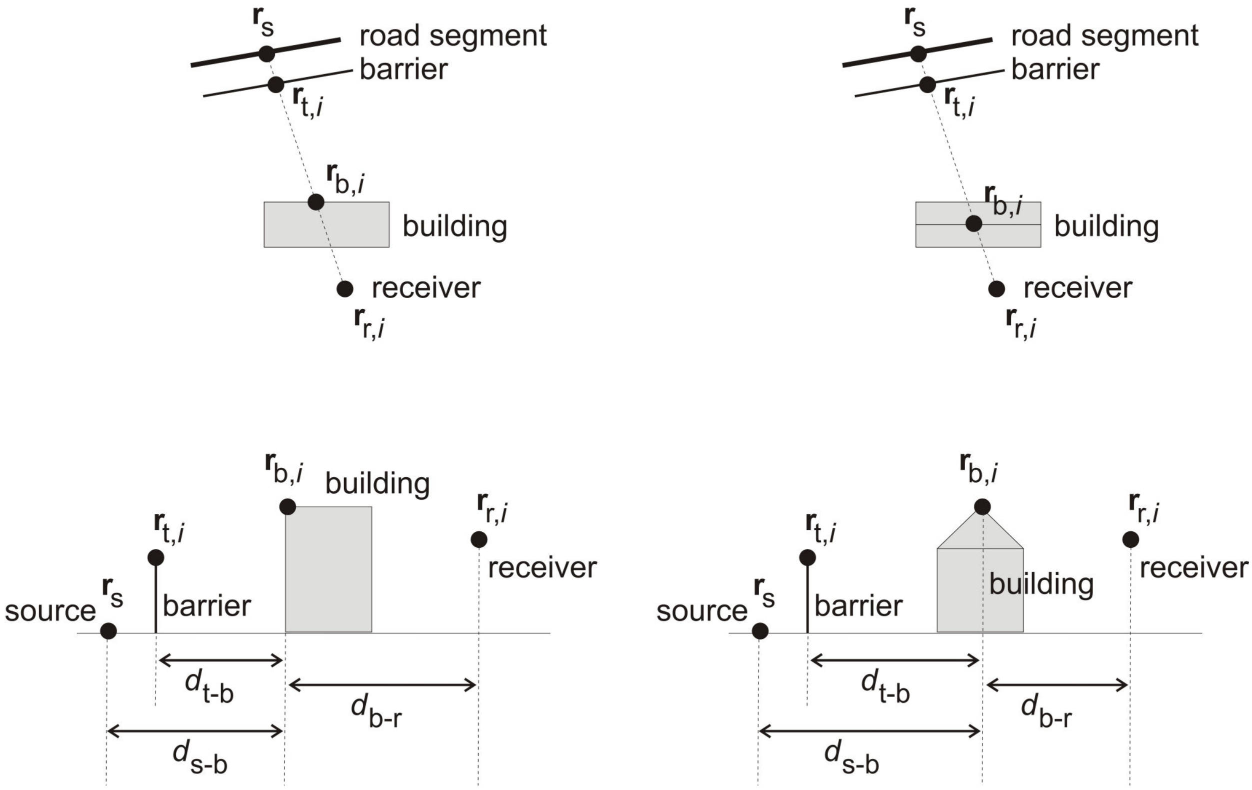

Figure 4: Top view and side view of the geometry with a building with a flat roof (left) and a louver roof (right).

We consider two cases:

- the case *without* a building between the source and the receiver,

- the case *with* a building between the source and the receiver (see Figure 4).

In the case *without* a building, the noise barrier causes a sound reduction for receiver *i* and octave band *j* that is given by

$$A_{ij} = A_{screen}(\mathbf{r}_s, \mathbf{r}_t, \mathbf{r}_r) \ . \tag{3}$$

Here, the index *i* is omitted in $\mathbf{r}_{t,i}$ and $\mathbf{r}_{r,I}$; and A_{screen} is a function that is specified at the end of this section.

In the case *with* a building, we follow the Dutch calculation scheme SKM2 [6] for sound levels in built-up areas. Taking into account the double screening by the barrier and the building we find

$$A_{ij} = A_{screen}(\mathbf{r}_s, \mathbf{r}_t, \mathbf{r}_r) - A_{screen}(\mathbf{r}_s, \mathbf{r}_b, \mathbf{r}_r) + A_{screen}(\mathbf{r}_t, \mathbf{r}_b, \mathbf{r}_r) \ , \tag{4}$$

with modified receiver height $z_i = z_{rooftop} + 3$ m, where $z_{rooftop}$ is the average height of roof tops in the built-up area (this area contains the building shown in Figure 4 and possibly other buildings near the receiver).

The spectra A_{ij} correspond to a broadband sound reduction

$$A_i = L_i - L_i' \ , \tag{5}$$

with

$$L_i = 10\log\left(\sum_{j=1}^{8} 10^{L_{ij}/10}\right),$$

$$L_i' = 10\log\left(\sum_{j=1}^{8} 10^{(L_{ij}-A_{ij})/10}\right). \tag{6}$$

The average sound reduction is calculated by weighted averaging over all receivers,

$$A_{av} = \sum_{i=1}^{N} w_i A_i \,, \tag{7}$$

with normalized weights

$$w_i = \frac{10^{L_i/10}}{\sum_{i=1}^{N} 10^{L_i/10}}. \tag{8}$$

The function $A_{screen}(\mathbf{r}_s, \mathbf{r}_t, \mathbf{r}_r)$, used in Eq. (3) and Eq. (4), is defined as

$$A_{screen}(\mathbf{r}_s, \mathbf{r}_t, \mathbf{r}_r) = 10\log\left(\frac{f_{j,oct}}{10}\Delta r + 3\right), \tag{9}$$

see also Figure 5. In Eq. (9) the centre frequency of octave band j is called $f_{j,oct}$, and

$$\Delta r = \begin{cases} r_{total} - r_{direct} & \text{if } z_e > z_s + \dfrac{d_{s\text{-}t}}{d_{s\text{-}t} + d_{t\text{-}r}}(z_r - z_s) \\ r_{direct} - r_{total} & \text{otherwise} \end{cases},$$

$$z_e = z_t - \frac{d_{s\text{-}t} d_{t\text{-}r}}{26(d_{s\text{-}t} + d_{t\text{-}r})},$$

$$r_{direct} = \sqrt{(d_{s\text{-}t} + d_{t\text{-}r})^2 + (z_r - z_s)^2}\,,$$

$$r_{total} = \sqrt{{d_{s\text{-}t}}^2 + (z_e - z_s)^2} + \sqrt{{d_{t\text{-}r}}^2 + (z_e - z_r)^2}\,. \tag{10}$$

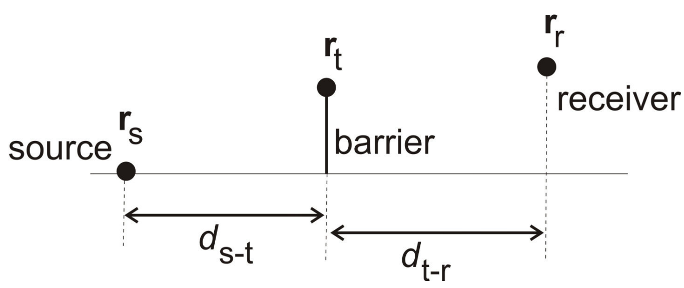

Figure 5: Geometry used for the definition of the screening attenuation.

2.5.2 Modification of the traffic flow or the road surface type

In this section we describe a model for calculating the noise reduction due to a modification of the traffic flow parameters (reduction of driving speeds or prohibition of heavy vehicles) or a modification of the road surface.

A modification of the traffic flow or the road surface causes a modification of the sound emission spectrum of the road segment under consideration. To calculate the sound emission, we follow the Dutch model for road traffic noise [11], which employs the following expression for the sound power level spectrum per unit length:

$$L_{E,j,m} = 10\log\left(\frac{Q_m}{v_m}\right) + a_{j,m} + \beta_{j,m}\log\left(\frac{v_m}{v_{0,m}}\right) + C_{j,m}\,. \tag{11}$$

Where

j is an octave band index (j = 1, …, 8) ,

m is a vehicle category index, m = 1, 2, 3 for light, medium heavy, and heavy vehicles, respectively,

Q_m is the traffic intensity of vehicle type m (number of vehicles per hour),

v_m is the mean driving speed of vehicles of type m (km/h),

$v_{0,m}$ is the reference speed: 80 km/h for m = 1 and 70 km/h for m = 2,3 ,

$a_{j,m}$ is a numerical coefficient (see Table 1 in Appendix A),

$\beta_{j,m}$ is a numerical coefficient (see Table 2 in Appendix A),

$C_{j,m}$ is the road surface emission correction, given by

$$C_{j,m} = \Delta L_{j,m} + b_m \log\left(\frac{v_m}{v_{0,m}}\right). \tag{12}$$

Where

$\Delta L_{j,m}$ is a numerical coefficient (see Table 3 and Table 4 in Appendix A),

b_m is a numerical coefficient (see Table 3 and Table 4 in Appendix A).

We consider five types of road surface:

- Dense asphalt,
- Cobbles,
- Porous asphalt,
- Double-layer porous asphalt,
- Thin top layer asphalt.

The total emission spectrum is calculated by summation over the three vehicle types:

$$L_{E,j} = 10\log\left(\sum_{m=1}^{3} 10^{L_{E,j,m}/10}\right). \tag{13}$$

The broadband emission level is calculated by summation over the eight octave bands:

$$L_E = 10\log\left(\sum_{j=1}^{8} 10^{L_{E,j}/10}\right). \tag{14}$$

The sound reduction A follows from the difference between the emission level L_E' in the new situation and the emission level L_E in the original situation:

$$A = L_E - L_E'. \tag{15}$$

2.6 USER SELECTION OF NOISE ABATEMENT MEASURE

The decision support system has not been fully automated; instead it has become an interactive system in which the user can decide to which sources noise abatement measures have to be applied (step 2 of the system).

Also, the type of abatement measure is selected by the user from a short list with possible measures presented by the decision support system (step 4 of the system). The system may for example suggest replacing the current road surface type by "double-layer porous asphalt" as the most effective measure and "reducing the maximum speed with 20 km/h" as the second best measure. For example in view of the costs, the user is free to select this second best measure and evaluate its effect.

2.7 EVALUATING THE EFFECT OF THE SELECTED MEASURE

During the last step of the decision support system the effect of the selected noise measurer is evaluated. Firstly a new noise map for the new situation is made. Secondly, using the new noise map, the new distribution of the number of *HA* per metre road segment is calculated. The total change in the number of *HA* can also be calculated.

We note that the assignment of the number of *HA* to the road segments has been done in a noise-energy weighted way. Therefore, the number of *HA* for other road segments, close to the road segment to which a noise measure has been applied, may also have changed.

3 SOFTWARE

In the previous section the various steps of the decision support system were discussed in detail, in this section the software developed for the decision support system and its design will be discussed.

The software developed for the decision support system consists of several modules. The modular design is based on advanced software systems currently present at TNO (Urbis / Urban Strategy). The systems architecture and the individual modules of the system will be discussed now.

3.1 DESIGN OF THE DECISION SUPPORT SYSTEM

The design of the decision support system is shown diagrammatically below in Figure 6.

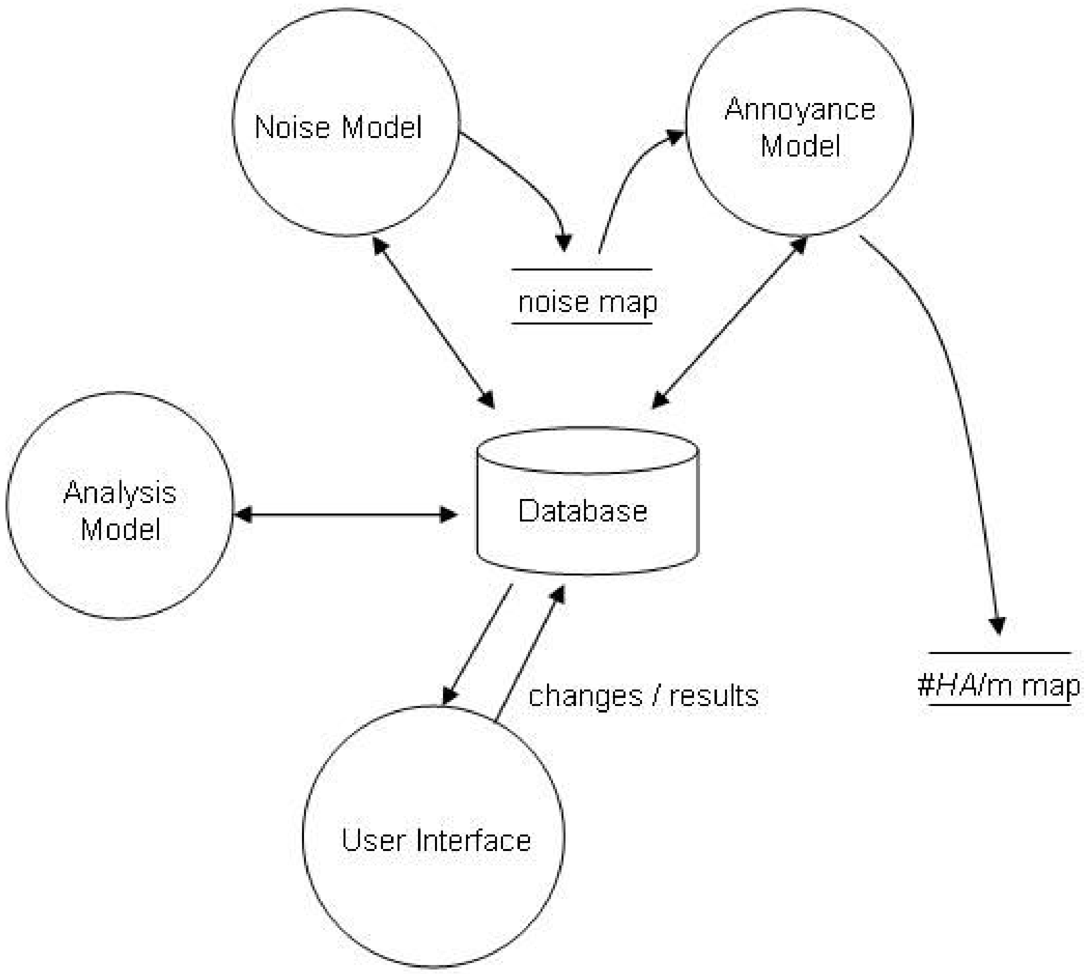

Figure 6: Graphical display of the design of the decision support system; see also the flowchart displayed in Figure 7 which illustrates the sequence of operation of the various modules.

The decision support system consists of five major parts. The central part in the system is the database, see Figure 6. This database holds all the GIS data the models need in order to perform their calculation. We remark that the noise map and the #*HA*/m (noise *impact*) map, as shown in Figure 6, are actually data in the Database that can be displayed in the User Interface. The sequence of operation of the various modules is discussed in an example in Section 3.7 and visualized in Figure 7 in this section.

Initially the Noise Model will calculate the noise map of the city using GIS data on the location of buildings, height of buildings, traffic data, etc. Based on this noise map, the Annoyance Model will calculate the number of *HA* people for each road segment due to the noise contribution from that particular road segment. Then a noise *impact* map is calculated. This map shows the number of *HA* for each noise source (i.e. road segment) in a city.

When a noise source on the noise impact map is selected in the User Interface, the Analysis Model will calculate a list with possible effective noise measures. When applying one of the suggested noise abatement measures, the User Interface will send the changes to the database and will activate a recalculation of the noise map and the noise *impact* map.

3.2 THE NOISE MODEL

The noise model implements the Dutch calculation method for calculating noise caused by road traffic as described in Section 2. In order to be able to designate the number of *HA* to each road segment in a later stage, the model stores intermediate results in the database.

The noise model will generate the noise map, which shows the road traffic noise levels throughout the city. The Annoyance model will use the intermediate results and generated a noise *impact* map, showing the number of *HA* people for each road segment.

3.3 THE ANNOYANCE MODEL

The Annoyance Model calculates the number of *HA* people per metre for each road segment as described in Section 2. After the Noise Model has calculated the noise map of the city, the Annoyance Model will calculate the number of *HA* people in a dwelling. This calculation is based on the noise load of the receptor having the largest noise load for that dwelling.

The Annoyance Model then uses the intermediate data, generated by the noise model, to distribute the number of *HA* people to individual road segments, weighted by amount of noise energy received from that particular road segment.

3.4 THE USER INTERFACE

A User Interface is designed for the decision support tool. This User Interface contains GIS functionality. The noise map or the noise *impact* map for a city is displayed in a viewer window and the user is allowed to select individual noise sources on the noise *impact* map.

When selecting a noise source on the noise *impact* map, the system will provide the user with a list of possible effective noise abatement measures. This list will be provided by the Analysis Model as discussed in the next section.

The user of the decision support system can select and apply one of the suggested noise measures and initiate a recalculation of the noise map and the noise *impact* map.

3.5 THE ANALYSIS MODEL

The Analysis Model contains a set of noise abatement measures and noise calculating rules as described in more detail in Sections 2.4 and 2.5

Based on the specific noise source selected by the user, the Analysis Model determines the most effective noise abatement measure by evaluating the estimated effect of each possible measure.

A list with possible effective measures ranked according to its effect (in terms of the noise level reduction) is than returned to the User Interface of the decision support system.

3.6 THE DATABASE

The central part of the decision support system is the Database. The Database contains (geographical) objects with several attributes. For example, one of the objects may be buildings, having attributes like position, height, inhabitants, etc. Other objects are for example roads, noise barriers, etc.

The various modules of the system share the same objects that are stored in the Database. When one module changes an object in the Database, other modules may initiate new calculations to take into account the changes. Furthermore, the output of one module (written to the Database) serves as input for other modules (loaded from the Database).

Intermediate steps of the performed calculations may be stored in the Database and used in a later stage. For example the noise energy contribution of noise sources to a receptor may be stored for all receptors by the Noise Model. In a later stage the Annoyance Model can use this information to assign the number of *HA* people to each noise source.

In the current implementation of the decision support system, the Database is an Oracle database. Oracle 's spatial extension aids its users in dealing with geographic data. Also, the use of an Oracle database guarantees the scalability of the system in the future.

3.7 THE COMMUNICATION FRAMEWORK

In addition to the Database, the several Models and the User Interface, the decision support system consists of a Communication Framework. The operation of the Models and the User Interface are coordinated by the Communication Framework.

Each time one of the Models or the User Interface writes data to the Database, an event is sent through the Communication Framework. These events inform the several modules of the decision support system that (some) data in the Database has changed. The Models and the User Interface are "subscribed" to events that are relevant for them. After they have received these events the relevant new data is loaded from the Database and new calculations will be performed.

Example

In the remaining part of this section the working of the Communication Framework and the sequence of operation of the various modules of the decision support system are illustrated by an example. The starting point of the example is a noise *impact* map for a city displaying the initial noise climate.

Based on the noise *impact* map the user of the system wants to select the noise source which has most impact; apply the most effective measure and evaluate its effect. The various steps are listed below and displayed in Figure 7, which shows the sequence of operation of the various modules of the system for this example.

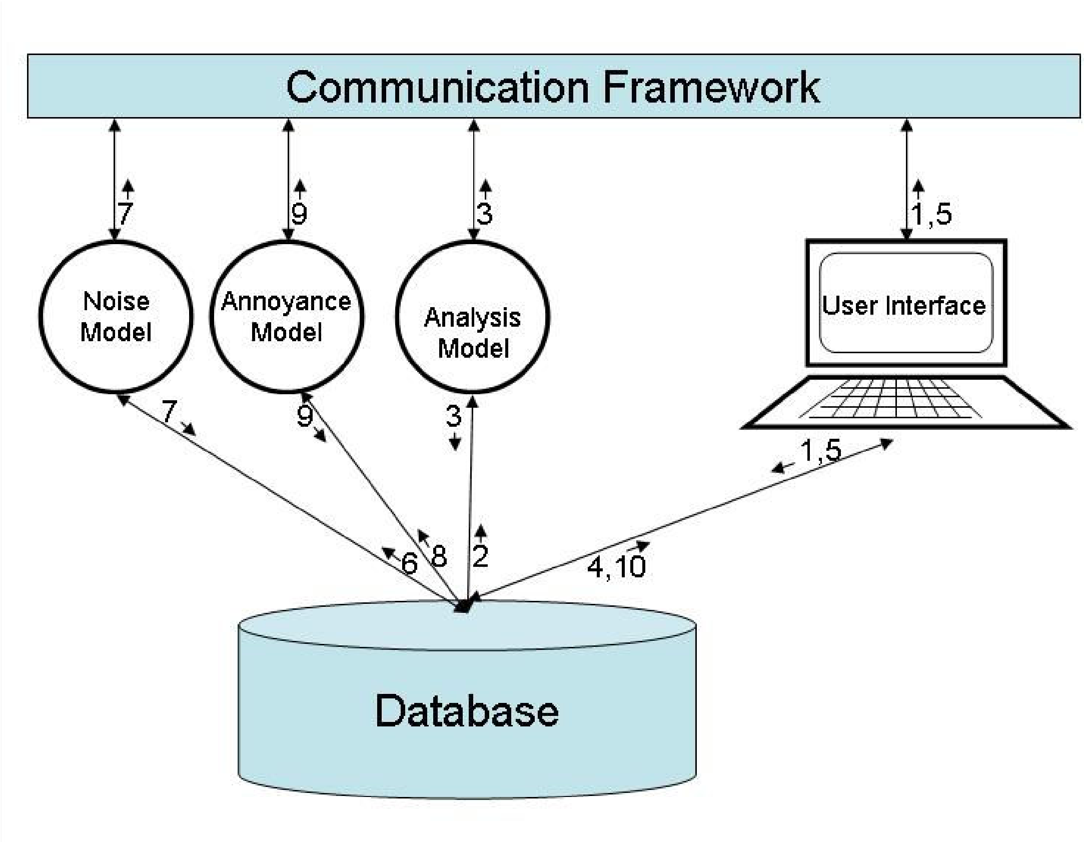

Figure 7 Flowchart: sequence of operation of the various modules of the decision support system; the numbers refer to the various steps of the example in the text.

1. Noise source having most impact is selected in User Interface; selection is written to Database; new event is sent through Communication Framework.
2. Analysis Model receives event; new data is loaded from Database; new calculation (evaluation effective measures) is started.

3. Analysis Model writes results of calculation (shortlist with effective measures) to Database; new event is sent through Communication Framework.
4. User Interface receives event; new data is loaded from Database; shortlist with effective measures is displayed in User Interface.
5. User of system selects effective measure (e.g. change of road surface type at selected location); selection is written to Database; new event is sent through Communication Framework.
6. Noise Model receives event; new data is loaded from Database; new noise calculation is started.
7. Noise Model writes results of calculation (new noise levels near selected location) to Database; new event is sent through Communication Framework.
8. Annoyance Model receives event; new data (updated noise levels) loaded from Database; new annoyance calculation is started.
9. Annoyance Model writes results of calculation (updated noise impact) to Database; new event is sent through Communication Framework.
10. User Interface receives event; new data is loaded from Database; updated noise *impact* map is displayed.

4 APPLICATION TO THE CITY OF AMSTERDAM

In the previous sections (the various steps of) the decision support system as well as its implementation have been described. In this section an example for the application of the system is given. We have applied the system to the city of Amsterdam.

4.1 DETERMINATION OF THE IMPACT OF ROAD TRAFFIC NOISE SOURCES

We start with quantifying the impact of road traffic noise source. For the city of Amsterdam for each road segment we have calculated the number of *HA* resulting from the noise contribution of that specific road segment, see Section 2.3. For the central part of Amsterdam the results of the performed calculation are depicted in Figure 8, which displays a screenshot of the graphical interface of the decision support system.

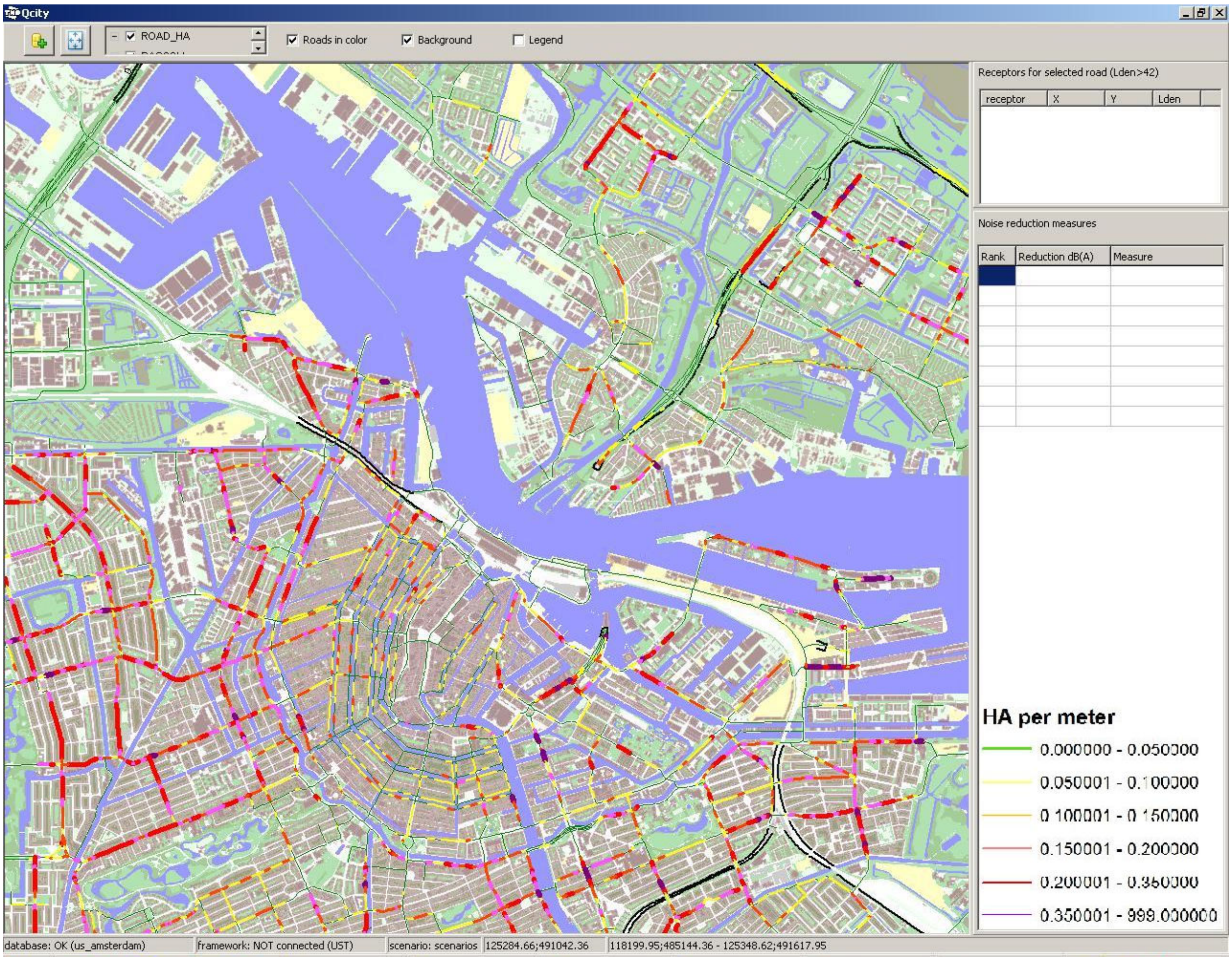

Figure 8: Screenshot of the graphical interface of the decision support system showing a road traffic noise *impact* map for the central part of Amsterdam.

The decision support system shows a noise *impact* map of the central part of Amsterdam. The map depicts the roads, buildings and ground use in Amsterdam; and the map show the noise impact of all noise sources, i.e. the number of *HA* per meter.

The number of *HA* per meter for various road segments, determined by the decision support system, is indicated by the colours of these segments as indicated by the legend in Figure 8. The green and yellow colours indicate a small noise impact, whereas the red and purple colours indicate a large noise impact. The noise impact map shows that the noise impact of roads in neighbourhoods adjacent to the city centre is often larger than the noise impact of roads in the city centre.

We note that the lower left corner of Figure 8 is equal to that of in Figure 1, which showed the noise levels throughout Amsterdam. Comparison of these maps (the noise *impact* map and the noise map) shows that road segments with a high noise level (blue and red coloured) do not necessarily have a large noise impact (number of *HA* per meter). Most likely this is caused by be the small number of dwellings close to those roads or a small number of inhabitants per dwelling for dwellings close to those roads.

Figure 9 shows another screenshot of the graphical interface of the decision support system. A zoomed-in picture for a specific location is Amsterdam is depicted. This figure clearly shows the contours of the buildings, the ground use and the pattern of the roads. The numbers attached to the road segments refer to the number of *HA* per meter for that road segment. In this case the user of the system has selected the road segment to which a noise measure has to be applied. The road segment with the largest noise impact in this region, 0.43 *HA* per meter, has been selected.

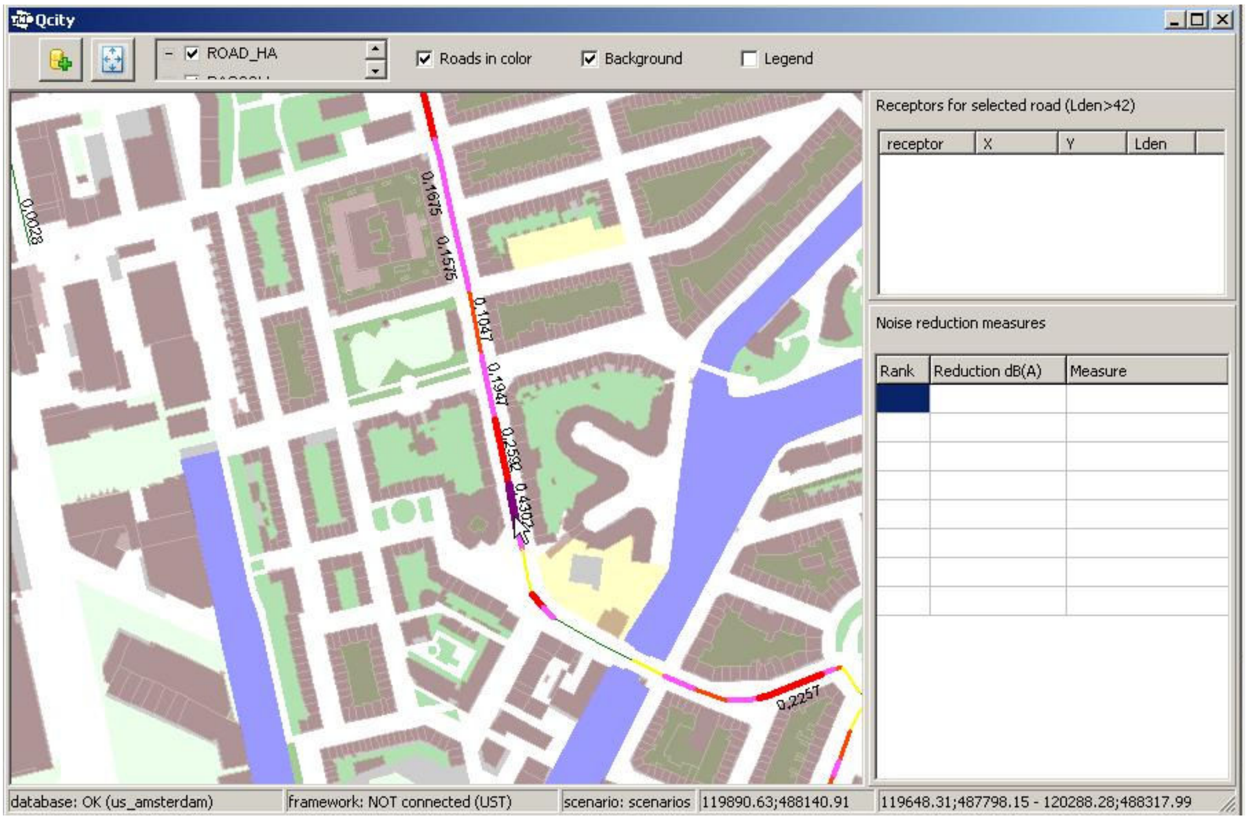

Figure 9: A zoomed in picture of the noise *impact* map for the central part of Amsterdam.

4.2 SELECTION OF AN EFFECTIVE NOISE ABATEMENT MEASURE

Once the decision support system has quantified the noise impact of all noise sources and the user has selected a noise source to which a measure has to be applied, the system will determine possible noise abatement measures for the selected noise source.

Based on the characteristics of the selected noise source (road segment) the decision support system estimates the effect of possible noise abatement measures and presents an appropriate list of them to the user of the system. For details of this stage of the decision support system we refer to Section 2.4 and 2.5. Figure 10 shows the shortlist with noise measure that is proposed by the decision support system for the selected road segment. The probably most effective measure for this location would be changing the present road surface into double-layer porous asphalt. Figure 10 also shows the noise receptors that receive a significant contribution from the selected road segment. These receptors are depicted by the red coloured dots.

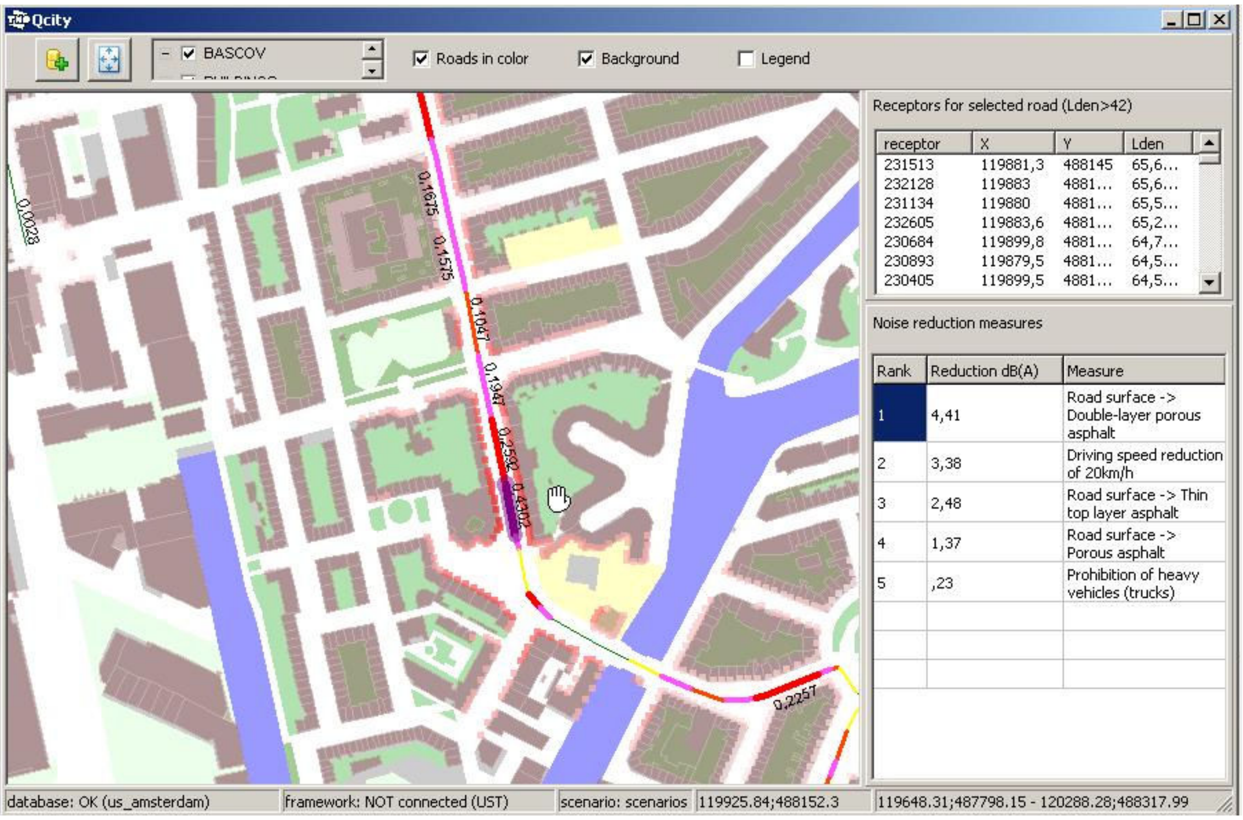

Figure 10: The noise *impact* map for the central part of Amsterdam and the estimated effect of possible noise abatement measures.

Switching off the back ground (buildings, water, green areas, etc.) makes the receptors receiving the most significant noise energy contributions from the selected road segment more visible. This is shown clearly in Figure 11. The darker the colour of the receptors the larger is the noise energy contribution to those receptors. Figure 11 clearly shows that receptors located directly along the selected road segments obtain a large noise energy contribution, but also receptors further away that are directly in the line of sight of the road segment obtain a relatively large noise energy contribution.

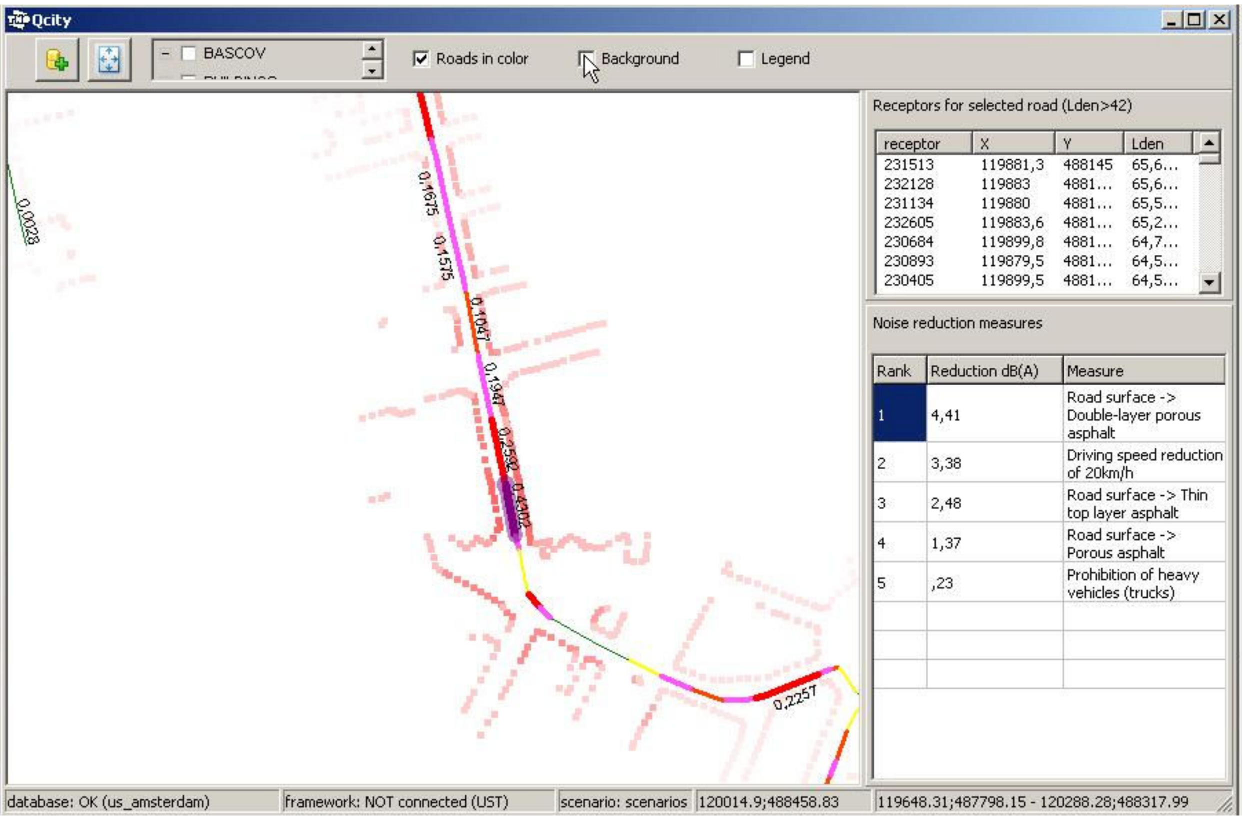

Figure 11: The receptors receiving the most significant noise energy contribution from the selected road segment.

4.3 EVALUATING THE EFFECT OF THE SELECTED NOISE ABATEMENT MEASURE

After selecting the probably most effective measure for the selected road segment, i.e. changing the road surface into double-layer porous asphalt, the system has recalculated the noise levels. The new noise map has been used to calculate the new noise *impact* map. The zoomed-in new noise *impact* map is shown in Figure 12.

Comparing with the initial situation we see that the noise impact of the road segment, to which the selected noise measure has been applied, has decreased sizably. In the initial situation the noise impact of the selected road segment was 0.43 *HA* per meter, whereas in the final situation the noise impact of this road segment has become 0.21 *HA* per meter, see Figure 12.

However, as mentioned before, due to the noise energy weighted assignment of the number of *HA* to the various noise sources, the noise impact of the road segments close to the selected one has increased somewhat. But of course in total there will be a reduction of the number of *HA*. In this example the total reduction of *HA* is 7 (rounded off).

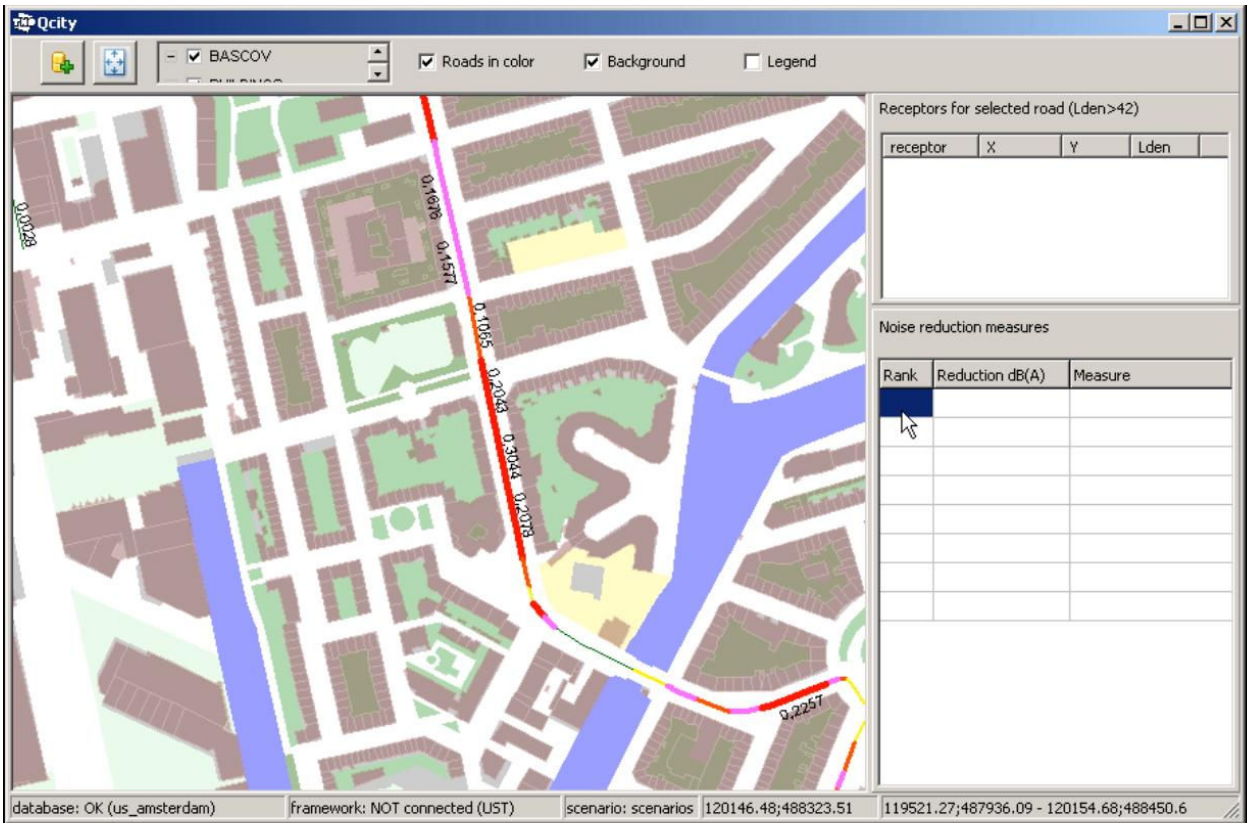

Figure 12: New results for the noise *impact* map after the selected noise abatement measure has been applied.

5 SUMMARY AND CONCLUSIONS

In this report we presented the proof of concept of a decision support system for noise abatement measures. The decision support system supports planners, which may not have detailed acoustic knowledge, to locate those noise sources that have most impact and to estimate what noise abatement measures are most effective for reducing the impact of those noise sources. The decision support system has been implemented in Urbis (TNO's tool for environmental surveys), but the concept of the decision support system can in principle be implemented in noise mapping tools in general. The system will be useful in action planning in the framework of the European Noise Directive (END).

In contrast of focusing on places in a city where relatively many people are harmfully affected by high noise levels ('hot spots') the decision support system focuses on noise sources that are responsible for a large number of people harmfully affected by noise, using the scientifically based quantity *%HA*. Doing so, the decision support system points towards those noise sources where lowering noise emissions has most effect on reducing the noise impact according to the impact indicator used. The noise impact indicator we use in this report is the number of highly annoyed people (*HA*), but in principle other noise impact indicators might have been used as well.

Results for the quantification of the impact of road traffic noise sources in the case of the city of Amsterdam are presented. In particular, the number of highly annoyed due to road traffic noise per meter for various road segments has been calculated and displayed in a map. This map provides insight in those areas where noise reduction has most effect on the number of people being highly annoyed.

The models that estimate the effect of possible noise abatement measures are based on the Dutch calculation method for road traffic noise. Specific road segments that have most noise impact, as pointed out by the system, can be selected by the user and the decision support system evaluates the most effective noise abatement measures for those locations. A ranked list with these measures is presented to the user of the system. The user can select one of the measures and evaluate its effect.

We have shown in this report that the decision support tool works successfully to locate road traffic noise sources that have most impact in terms of annoyance (*HA*) and to estimate which measures are effective to be applied to those sources.

The decision support system can be further developed in several directions in the near future. Other noise sources than road traffic (railway traffic and trams) could be implemented. Also, other noise impact indicators than *HA*, e.g. sleep disturbance, could be used in the system. An important step would be to extend the decision support system in such a way that it can also consider overall noise measures such as the application of silent tires or the introduction of car free city zones.

6 REFERENCES

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Appendix A

Table 1 and Table 2 contain the numerical coefficients that are used in Section 2.5.2 to calculate the noise emission in various octave bands, *j*, for various vehicle types, *m*.

Table 1: Emission coefficients $\alpha_{j,m}$ for various vehicle categories and various octave bands.

Octave band index *j*	$\alpha_{j,1}$	$\alpha_{j,2}$	$\alpha_{j,3}$
1	74.5	79.9	84.1
2	84.5	91.1	91.4
3	89.9	97.1	97.7
4	94.0	100.5	104.8
5	101.1	103.3	106.5
6	99.0	100.4	102.4
7	90.9	93.9	95.6
8	81.0	85.6	87.0

Table 2: Emission coefficients $\beta_{j,m}$ for various vehicle categories and various octave bands.

Octave band index *j*	$\beta_{j,1}$	$\beta_{j,2}$	$\beta_{j,3}$
1	-0.5	-0.2	9.8
2	24.6	16.6	11.4
3	27.6	2.5	2.6
4	26.1	26.6	23.2
5	26.8	22.3	20.8
6	22.5	16.6	15.0
7	22.2	16.2	12.4
8	11.7	-1.9	-3.1

Table 3 and Table 4 contain the numerical coefficients that are used in Section 2.5.2 to calculate the road surface type correction for various surface types (the reference surface type was dense asphalt) in various octave bands, *j*, and for various vehicle types, *m*.

Table 3: Surface type correction coefficients $\Delta L_{j,m}$ and b_m for m = 1.

	$\Delta L_{j,1}$								b_1
	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	
dense asphalt (0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
porous asphalt (1)	1.30	-3.70	-4.00	0.06	-2.27	-4.33	-3.32	0.17	-8.02
double-layer p.a. (2)	-0.67	-4.53	-5.23	-3.53	-4.93	-5.88	-5.24	-3.51	-5.41
thin top layer a. (11)	-1.11	-5.88	-5.59	-1.08	-3.80	-6.67	-5.10	-3.86	-7.24
bricks (9)	6.85	3.33	3.00	5.28	5.07	1.36	1.22	1.03	0.00

Table 4: Surface type correction coefficients $\Delta L_{j,m}$ and b_m for m = 2,3.

	$\Delta L_{j,2} = \Delta L_{j,3}$								$b_2 = b_3$
	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	
dense asphalt (0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
porous asphalt (1)	-1.60	-6.60	-4.26	-3.09	-4.65	-3.23	-3.39	-2.08	-6.05
double-layer p.a. (2)	-5.54	-6.99	-6.82	-6.23	-6.27	-5.90	-5.98	-6.03	1.02
thin top layer a. (11)	0.64	-4.14	-3.84	0.66	-2.05	-4.92	-3.35	-2.11	0.00
bricks (9)	6.85	3.33	3.00	5.28	5.07	1.36	1.22	1.03	0.00