DEVELOPMENT AND IMPLEMENTATION OF A DECISION SUPPORT SYSTEM FOR URBAN TRAFFIC NOISE REDUCTION MEASURES WITH MONETARY VALUES

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Abstract

The objective of this paper is to present the development and the implementation process of a sustainability assessment module for traffic as an instrument for urban transport policy.
Based on an overview of existing models describing transport emissions, exposure levels and several related environmental regulations (especially the new European noise regulation), this paper focuses on the noise problem as an important environmental problem in the cities. A model is developed to analyse the impacts on the inhabitants with respect to noise disturbance and its assessment in monetary values.

The cost effectiveness of noise reduction measures can be estimated and analysed by the depiction of environmental costs. The sustainable evaluation of measures which exclusively refers to the freight traffic, can be judged as well as similar measures that affect the commuter traffic as well as the total traffic. Noise reduction measures (e.g. detours affecting other network parts) can cause network effects in urban areas. Our model considers these instruments and network-specific properties of the various reduction measures for evaluating their effects on social welfare.

Keywords: Decision support system (DSS); Monetary environmental assessment; Urban traffic noise; Annoyance; Exposure; Sustainability assessment module
Topic area: H10 Urban Transport Policy Instruments

1 Introduction

Many cities suffer under environmental problems caused by passenger and freight traffic. Noise, air pollution and vibrations are three examples out of a long list of negative impacts of motorised traffic causing which nuisance and damage to property and human health in the cities. In the European Community and in its individual member states there are many laws and guidelines which are supposed to guarantee the protection of the environment; however, not all of them force cities to act.

The research presented in this paper was funded by the European Commission in context of a project which aims to improve the urban information flow between supply and demand side for city-logistic (*MOSCA – Decision Support System for Integrated Door-To-Door Delivery: Planning and Control in Logistic Chains, July 2001- June 2003*).

For a selected test site (Stuttgart, Germany) several traffic and noise reduction scenarios have been developed and subsequently assessed with health and property costs. How much the inhabitants are affected can be evaluated for each noise reduction measure. Instead of a vehicle-kilometre oriented estimation, our model provides an evaluation that starts directly at the affected people by using cost rates that have been calculated in advance. A high noise exposure leads to a higher damage to the properties and to higher health expenses. On the other side even measure costs must be considered when calculating noise reduction measures. Road closing for the HGV-traffic can for example cause detours. The cost calculation must also include these detours.

Noise reduction measures have a total-economic advantage which can be documented by monetary figures. This means that in combination with urban data and information about traffic volumes it is possible to calculate noise exposure levels with a "noise calculation software" and to graphically illustrate the result levels. The knowledge about inhabitants per house enables a monetary assessment.

As a result the paper gives an overview about all data which are necessary for the noise computation and the subsequent assessment. The monetary comparison of different noise reduction scenarios (status quo situation, speed limit in the total investigation area, access restriction for all HGV with a weight higher than 7.5t etc.) presented for the test site Stuttgart is a demonstration of the implemented module. In addition the implementation shows the meaning of the module as a transport policy instrument for local authorities. The assessment of noise exposure was calculated by pre-defined cost rates. Noise reduction which achieved by active or passive noise reduction measures can be easily displayed by this cost assessment method. The performance of noise reduction can be demonstrated by noise building maps or by calculated table sheets. Differences between scenarios can be displayed in form of ratios for each district of the city or for the whole investigation area . An access restriction for all HGV >7.5 t would for example lead to a cost reduction of almost 20 % compared to the status quo.

The results were calculated with the described model, so called City-SUSTAIN which is a **D**ecision **S**upport **S**ystem (DSS) for traffic noise reduction measures. The DSS is designed as an interface between existing software tools (e.g. noise computation and traffic tools) and the urban Geographical Information System (GIS)-input data. It is an appropriate tool for analysing the noise computation.

The remainder of this paper is organized as follows. The next section provides an overview about principles for the measurement and assessment of traffic noise (esp. definition and calculation methods). Section 4 describes the difference between emission and immission. Section 5 hints at the development and the implementation of the assessment model for traffic noise reduction measures. Additionally, this section displays he results of the application of these models tin the concerned area. Finally, section 6 concludes and gives prospects and recommendations for future research.

2 Principles for the measurement and assessment of traffic noise

2.1 Methodological background for the assessment of noise

The decisive for the assessment of road traffic noise is the perceived noise pressure level – the so-called assessment on the level of damage. Noise emissions of single vehicles are not relevant for the further examination. Besides an assessment will be performed on the basis of the noise immission (exposure) and not on the basis of noise emission. *The approach for the monetary assessment of the damage which can be due to traffic noise considers the local exposed population*. For this approach the noise level of each vehicle is not relevant.

2.2 Noise apperception

The human ear realizes sounds as information. Therefore, permanent sounds may sometimes not be realized . Characteristics like tones or changes in the sound level make us listen attentively. The faster the sound level changes, the more the sound will be interpreted as noise.

It is possible to differentiate between the following noise types:

- Continuous noise: The frequency and the sound level are continuous over a long time period.
- Increasing / decreasing noise: Cyclic sounds where the sound level increases drastically and decrease immediately afterwards.
- Pulse noise: Short and abrupt sounds.

Noise is not a physical unit, even though it can be percepted from the human ear. Therefore different persons react different to the same acoustic source.

VDI-guideline 2058 defines noise as an unaccepted sound that heckles, annoys or sanitary damage the human being. Noise can lead to nuisances of health, productivity and operational safety.

2.3 Measurement and calculation of noise

For the explanation of the measurement and the calculation of noise it is necessary to explain in a first step the physical background of acoustic noise.

Acoustic noise arises from vibrations in an elastic medium and disperses in form of a sinus curve in waveform. The frequency of the waveform can be used as an indicator for the level of a tone. The decisive units for the description of the acoustic noise are the frequency and the amplitude. The frequency, measured in Hertz (Hz), can easily be calculated by the reciprocal of the oscillation period *T*. A further method is the calculation with the wave length λ and the speed of the acoustic noise *c* which is in air about 340m/s.

$$f = \frac{1}{T} = \frac{c}{\lambda}$$

The frequencies which the human ear is able to percept are between 20 Hz and 20.000 Hz. The frequencies between 1 and 5 kHz are realized louder compared to low and very high frequencies.

The measuring unit for the description of sound effects on the human being is the sound pressure *p(t)*. The swinging material of an acoustic source leads to a so called “long distance area” - a rotatory compression and expansion of the air molecule which lead to areas with overpressure and under pressure. These areas are necessary for the dispersion of the air acoustic noise. Therefore, acoustic noise can also be interpreted as changes in air pressure which can be documented in Pa (Pascal) or mbar (millibar).

The noise pressure can differ between its amplitude and thus noise pressure can be also described by the root mean square (compare [MAUE et al., 1999]):

$$\tilde{p} = \frac{\hat{p}}{\sqrt{2}}$$

Two further measuring units are the oscillation speed of the molecule and the acoustic noise intensity as an indicator for the transported sound energy.

2.4 Measuring unit for loudness

The introduction of the logarithmic unit for the acoustic noise pressure is based on Graham Bell. Bell is defined as the decade logarithm as a proportion of two similar measurements. The noise pressure L_p results in Decibel (dB) and has the following equation:

$$L_p = 10 \cdot \lg\left(\frac{p^2}{p_0^2}\right) \text{dB}$$

The variable *p* is the measured noise pressure (in Pa) and p_0 the hearing threshold level $(2 \cdot 10^{-5}\,\mathrm{Pa})$.

The hearing threshold level L_0 can be calculated by the following equation:

$$L_0 = 10 \cdot \lg\left(\frac{\left(2 \cdot 10^{-5}\,\mathrm{Pa}\right)^2}{\left(2 \cdot 10^{-5}\,\mathrm{Pa}\right)^2}\right)\mathrm{dB} = 10 \cdot \lg(1)\,\mathrm{dB} = 0\,\mathrm{dB}$$

It is also possible to calculate the noise pressure which is the threshold of noise pain of the human ear:

$$L_0 = 10 \cdot \lg\left(\frac{(20\,\mathrm{Pa})^2}{\left(2 \cdot 10^{-5}\,\mathrm{Pa}\right)^2}\right)\mathrm{dB} = 10 \cdot \lg\left(10^{12}\right)\mathrm{dB} = 120\,\mathrm{dB}$$

The unit decibel has two advantages:

- On the one hand it is possible to operate with small numerical values for calculations and comparisons.
- On the other hand the reaction of the human ear to the noise pressure is nearly logarithmic (cp. [Maue et al. 1999]).

The summation and averaging of different noise pressure levels are important mathematic operations for the calculation of alternative noise pressure levels which can be used for an assessment (cp. Chapter 4). Therefore, the equations for the summation and the averaging are illustrated below.

Summation

The summation of different noise levels L_1 and L_2 are indicated in the following formula:

$$L_1 + L_2 = 10 \cdot \lg\left(\frac{p_1^2}{p_0^2}\right) + 10 \cdot \lg\left(\frac{p_2^2}{p_0^2}\right) = 10 \cdot \lg\left(\frac{p_1^2}{p_0^2} + \frac{p_2^2}{p_0^2}\right) = 10 \cdot \lg\left(10^{0,1 \cdot L_1} + 10^{0,1 \cdot L_2}\right)\mathrm{dB}$$

The summation of two equal noise levels L_1 and L_2 are indicated as follows:

$$L + L = 10 \cdot \lg\left(2 \cdot 10^{0,1 \cdot L}\right) = 10 \cdot \lg\left(10^{0,1 \cdot L}\right) + 10 \cdot \lg(2) = 10 \cdot 0,1 \cdot L + 10 \cdot 0,3 = L + 3\,\mathrm{dB}$$

The addition of two equal noise sources leads to an increase of 3 dB (cp. [Maue et al. 1999]).

With a multiplication (*n* equal noise sources) the result of the noise level addition can be calculated by the following formula:

$$L_{res} = L + 10 \cdot \lg(n)\,\mathrm{dB}$$

The following table shows the results of a multiplication of *n* equal noise sources.

Table 1: Multiplication of equal noise sources and the belonging noise level increase

n equal noise sources	**10 lg(n)**	**Increase of noise level**
2	3,0103	3 dB
4	6,0206	6 dB
10	10	10 dB
100	20	20 dB
1000	30	30 dB

Averaging

Sometimes it is necessary to calculate an average noise level, especially if different noise levels for different time periods are available and an alternative value is needed for a monetary assessment (cp. Chapter 4.5). Due to the logarithmic characteristics of noise levels, the averaging must be also calculated by a special logarithmic operation.

The following formula shows the averaging calculated for punctual measurements:

$$L_m = 10 \cdot lg\left(\frac{1}{n}\sum_{i=1}^{n} 10^{0,1 \cdot L_i}\right) dB$$

3 Noise emission and immission

The road traffic causes sounds with frequencies between 20 Hz and 5 kHz. Actually, the low frequencies are mainly caused by the sound of engines, whereas the high frequencies are possibly mainly effected by the interaction between wheel and road.

For the evaluation of acoustic noise, it is important to differentiate between noise emission and noise immission (exposure). The point of interest for the evaluation of the noise emission is the source of the noise, where the acoustic noise level or the emission noise pressure level can be measured. For the evaluation of the noise immission the impact of noise is relevant (e.g. the impact on persons, animals etc.)

The measuring unit for the average noise immission is the level of evaluation. According to DIN guideline 45 645-2 the evaluation level is an important index for the description of noise immission. As a consequence it is possible to compare different sounds with each other or with according limit values independent from their type and their source.

Another indicator for the measurement of the noise immission is the maximum noise pressure level. During the evaluation period all maximum noise level values will be used as measuring unit.

3.1 Noise measurement

In most cases the noise has been measured with local installed sound level meters. A further option is the personal measurement by a microphone which is affixed at a body. In our module, the noise level can be measured either at the immission point, where the impact occurs, or at the emission point, where the sound arises. The measurement at the immission point helps to facilitate compliance with the immission regulations, whereas the measuring of the emission is needed to control single aggregates and to plan noise protection measures.

The regulation for the German noise protection on roads of the year 1990 (RLS-90) regulates that the traffic sound immission must be calculated on the basis of the traffic data.
Reasons for it are mainly the consideration of noise immission during the planning of new road infrastructure and the high effort for long time measurements in several cases.

The validity of the calculation methodology was confirmed for several roads with an extensive complexity. Relevant parameters for the calculation are for example information about the traffic (average daily traffic, share of heavy good vehicles etc.) and attributes for the infrastructure (number of lanes, type of roads, speed limit etc.).

For the free sound propagation the RLS-90 regulates that the average noise emission level for traffic sound must be calculated in 25m distance and in 4m height as illustrated in figure 1 (whereby the distance must be measured from the middle of the road).

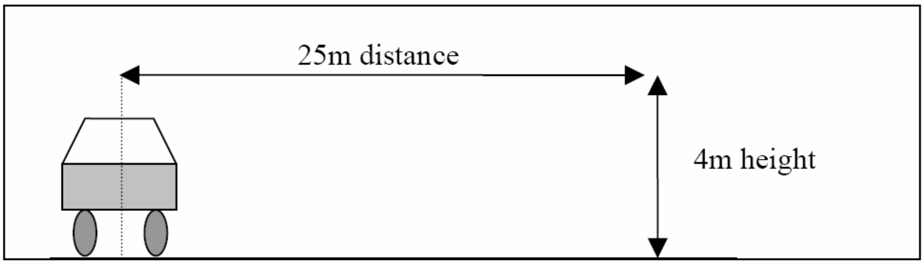

Figure 1: Outside measurement of emission after RLS-90, own illustration

In order to calculate the noise immission in residential areas the leading immission point is not defined , since it depends on each individual case.

Noise emissions for huge investigation areas can be calculated by the scheme presented in the German RLS-90 handbook. The calculation methodology can differ between countries. The new European noise regulation (2002/49/EG) tries to harmonise the different calculation methods on the European level. However, up to now there is no harmonised calculation method available.

The following parameters are relevant for the calculation of the noise emission level:

- average daily traffic,
- share of heavy good vehicles (HGV) and
- speeds.

Furthermore, the constructional parameters which describe the attributes of the roads (paving, gradient, type, number of lanes etc.), are also important.

However, even meteorological conditions have to be considered (e.g. higher sound values must be used for wet road surface, because of the sound of the wheel-road interaction).

Since the noise immission will be used to assess damage, the noise emission will not further be discussed. The calculation of the noise emission with the algorithms described in the RLS-90 builds the basis for the calculation of the transmission and the immission which will be assessed later on for a test case.

3.2 Immission: Measuring on the level of concerned inhabitants

The focus of this paper is the evaluation of the road traffic noise in urban areas and the monetary assessment of the impacts on the exposed population. Therefore, it is necessary to have a deeper look on the emitted noise level which is exposed to population.

The main part of the German population feels annoyed by road traffic noise. Noise can cause health risk and problems, even when the acoustic noise intensity is much lower than the threshold of noise pain.

Normally it is unusual that the permanent noise level caused by road traffic exceeds the critical value of 80 dB(A). Therefore, it can be assumed that traffic noise will not lead to ear damages based on excessive metabolism demand of the acuesthesia. The impacts on human beings are of a physical and mental manner and can be reflected by sleep disturbance, loss of concentration and communication disturbance. Moreover long time noise can cause diseases (cp. [Krell 1990]).

The German Environmental Agency (Umweltbundesamt) has been analysing the noise annoyance of the German population by an online survey since the beginning of the year 2002. First results , could be drawn end of July 2002 with 8771 participants. 40% of these persons stated that they are highly or super highly annoyed because of the road traffic noise, as illustrated in figure 2 (cp. [UBA 2002]).

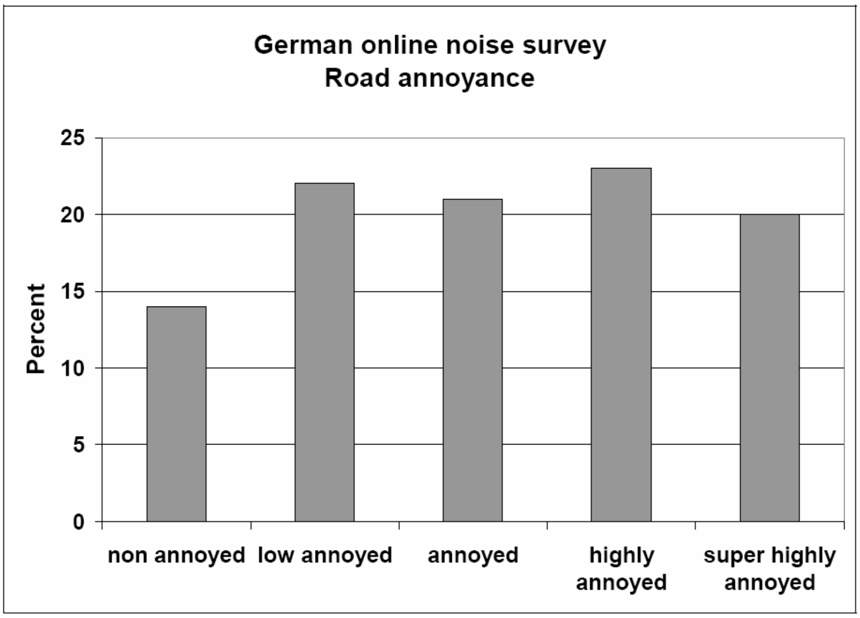

Figure 2: Noise annoyance in Germany, (cp. [UBA 2002])

3.3 Annoyance of traffic noise

According to Paracelsus[1] all substance are toxic. Only the dose of the substance determines its toxical impact. With regard to this thesis the following question comes up:

"Which is the evaluation level for noise turning out into annoyance in terms of health risk?"

Klosterkötter[2] worked out maximum values for residential areas for the German "Bundesimmissionsschutzgesetz, 1976" (German Environmental Law), where all negative impacts of noise are considered.

The main negative impacts of noise are:

- Sleep disturbance,
- communication disturbance and
- general annoyance.

For road noise immission the "Bundesimmissionsschutzgesetz" and several related guidelines (e.g. for Germany DIN, VDI) set up several guidelines for road construction and for the construction of noise protection (e.g. noise protection walls).

At the moment the noise evaluation level for traffic noise is[3] divided in two evaluation time ranges „Day" (06am-10pm) and „Night" (10pm-6am).

In order to sleep undisturbed, the average noise level at a lightly opened window should not exceed a value of 35 dB(A). During the day the average noise level value should not disturb communications and annoy the affected inhabitants.

Examinations showed that a noise level of 40 dB(A) in closed buildings is during the day an optimal orientation value. Based on the absorption of noise through the building facade and

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[1] Swiss doctor, philosopher und nature researcher, 1493-1541

[2] Prof. Dr. Klosterkötter, chairman of the German working group for noise protection (Deutscher Arbeitsring für Lärmbekämpfung), 1966-1977

[3] With the new European guideline (2002/49/EC) on environmental noise the evaluation time ranges will be more detailed with an additional time range fort he evening. The new noise evaluation time ranges will be from 06am-06pm (day), 06pm-10pm (evening) and from 10pm-06am (night).

windows *Klosterkötter* documented for the German Bundesimmissions-schutzgesetz an maximum value of 55 dB(A) for outside (cp. [Krell 1990]). As a consequence values of 55 dB(A) during the day and 45 dB(A) for the night time were set up for active noise protection; for passive noise protection respectively 65 dB(A) during the day and 55 dB(A)during the night.

These orientation values were updated for Germany in the actual valid traffic noise protection guidelines (16. BImSchV) from 12th June 1990. The current valid values are presented in Table 2.

Table 2: Maximum immission noise levels according to the German 16. BImSchV. 1990

	Day / Night
Village- / mixed zone	64 / 54
Residential zone	59 / 49
Residential zone and small urban area	59 / 49
Sensible areas (sanatoria etc.)	57 / 47
Health risk	> 65 / > 55
Sleep disturbance	- / 45

The real and measurable noise pressure level emitted from the HGV is in fact higher than the allowed guided values. Concerning the emissions, the road traffic sounds can often reach a maximum noise emission level of 96 dB (maximum value for HGV). The average noise level is much lower. It is about 80 dB and thus far under the threshold noise level of pain, but also over the guided values.

A Noise-Expertise from the German Environmental Agency (Umweltbundesamt) in cooperation with "*Stiftung Warentest*" (German quality check institution) documented the diversion of the evaluation level. The figures are indicated in Table 3. According to this expertise a huge part of the German population is annoyed with a health-risk noise compared to the maximum values form the 16. Bundesimmissionsschutzgesetz (German Environmental law) (cp. Table 2): during the day 58,1% and for the night time 70,8% of the German population.

If the maximum level is exceeded, noise reduction measures will be required. The "Bundesimmissionschutzgesetz" regulates how noise reduction measures must be realized.

Table 3: Diversion of the annoyance, (cp. [Lärmgutachten 2001])

Evaluation noise level in dB(A)	**Part (Day) in %**	**Part (Night) in %**
< 45	0,1	1,7
45 - 50	0,1	7,4
50,1 - 55	4,3	20,1
55,1 - 60	11,9	35,1
60,1 - 65	25,6	25,5
65,1 - 70	34,7	9,0
70,1 - 75	18,5	1,0
75,1 - 80	4,2	0,2
> 80	0,7	0
Sum	**100**	**100**

4 Development and implementation of a methodology for the assessment of traffic noise reduction measures

4.1 Software calculation of immission levels

In huge investigation areas it is not possible to obtain a measurement for the noise evaluation levels for all relevant points. In these cases the calculations can be done by modern software instruments.

The most software instruments for the calculation of the noise exposure need the traffic data. It is necessary to build the average hourly traffic density *M* in vehicles per hour (veh/h) for all days of the investigated year, divided into two time periods day (06am to 10pm) and night (10pm to 06am). Additionally the corresponding HGV-parts p (in percent) must be included. In case that only the average daily traffic (ADT) is known, *M* and *p* can be calculated by parameters depending on the road type which are documented in the RLS-90. Table 4 contains a list of parameters for an in-town road (cp. [Krell 1990]).

Table 4: Calculation of the hourly traffic loads from the ADT (cp. [RLS 1990])

	Day (06am-10pm)		**Night (10pm-06am)**	
	M (veh / h)	p (%)	M (veh / h)	p (%)
urban (in-town streets)	0,06 DTV	10	0,011 DTV	3

In most cases the required traffic data are available at the environmental agencies or the traffic planning departments of the city administrative.
Currently there is no equivalent standard concerning the used software instruments for the traffic load data.

For the implementation (cp. Chapter 4.6) of the developed methodology for the assessment of noise reduction measures presented in this chapter, traffic loads for the city of Stuttgart were used, provided by the transport assignment model VISUM. VISUM is an information and planning instrument to analyse the traffic network and prognosis of traffic loads, developed by PTV AG (Karlsruhe).

In the next step with the available traffic loads the noise exposure of the inhabitants can be calculated. A functional and usable software instrument for modelling the noise immission values is the software SoundPLAN developed by Braunstein and Berndt GmbH (Backnang).
Due to an announcement of the developer, SoundPLAN is the worldwide leading product in the field of noise exposure analysing software.

The traffic loads must be modified and in a next step imported in SoundPLAN.

4.2 Method for the assessment of damages caused by traffic noise

For the assessment of noise reduction measures which will be described for a concrete test site later on, a model based on a database (MS-Access), so called City-SUSTAIN was developed. The structure of the database is not visible for the user. Figure 3 shows some of these user interfaces. Several functions for the data management and the data analysing are connected with the different buttons.

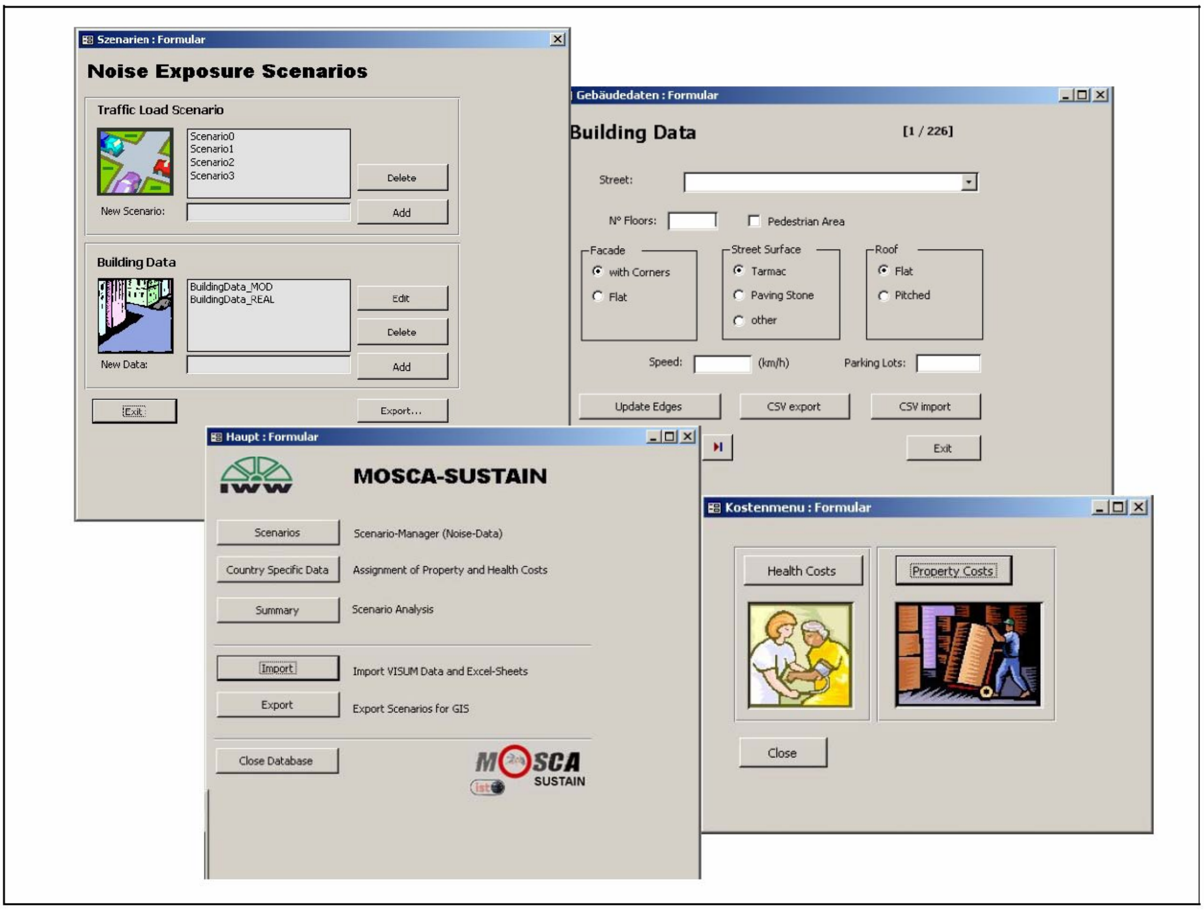

Figure 3: City-SUSTAIN user interfaces

The database is an interface between software instruments which deliver on the one hand the traffic load data and on the other hand the results of the noise immission calculation.
The modifying, migration and editing of the data can be indicated in an intermediate step within the different modules of the database.

Additionally, the database contains monetary assessment modules for the monetary assessment of the calculated noise immission values for different noise reduction scenarios.

4.3 Input parameter

The traffic loads for the investigation in the city of Stuttgart (used for the demonstration of the developed module) were illustrated by the software VISUM in hourly loads, divided in the time of day. Altogether the values were differentiated in values for day (06am to 06pm), evening (06pm to 10pm) and night (10pm to 06am). The loads were indicated by each link.
In a first step the loads for the different time segments must be added up and afterwards combined to a total day value.

VISUM also provides the coordinates of the links and the affiliated length of the links for the subsequent calculation and depiction of the noise immission.

A link represents a road section from one road crossing to the next. (cp. Figure 4).

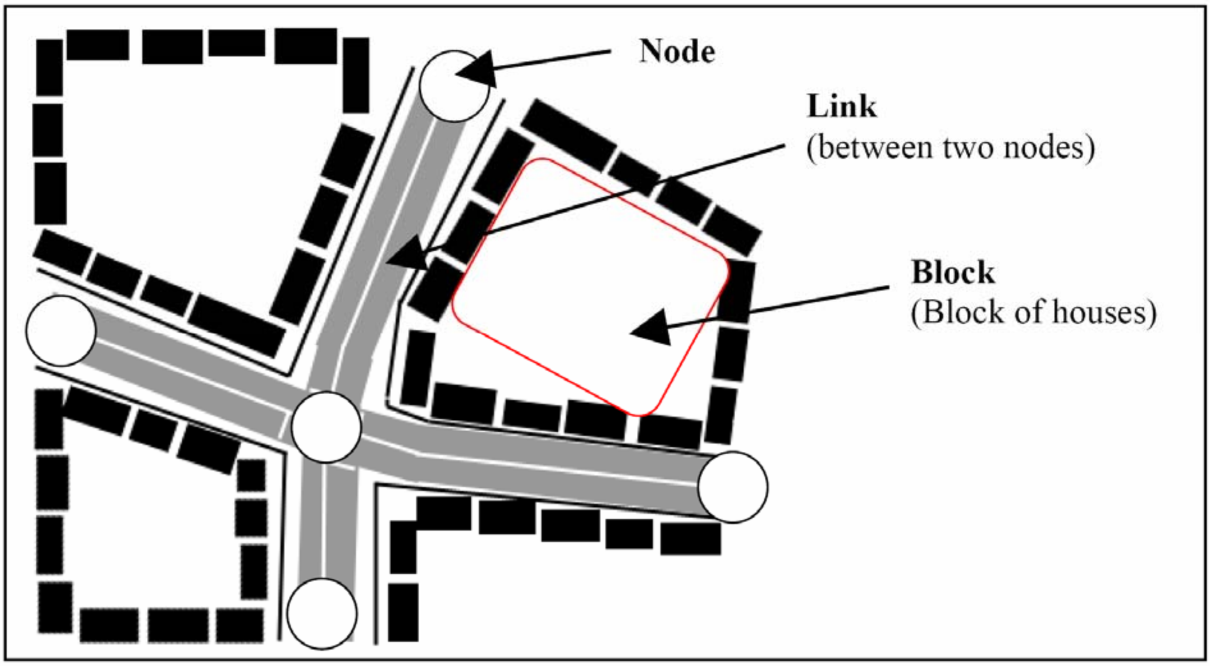

Figure 4: Presentation of the investigation method, own depiction

Further relevant input parameters are the number of inhabitants of each block of houses which can be imported into the database from a GIS[4] (used from the city of Stuttgart), and the characteristic parameters of the links which can either be detected by a site inspection or be imported from an urban GIS.

Necessary data for the description of the links are paving, character of the facade of buildings, type of the roof and average height of the buildings along the link.

For the description of the height of the building the number of floors is sufficient which can be assumed with 2,80m (cp. [Schmedding 2002]).

4.4 Function of the database

In order to assess the traffic noise it is important to consider the reduction of the value of the property and the health impact on the side of the exposed population The traffic load data from the traffic assignment model (here VISUM) is edited and converted so that the data of the daily traffic loads per link can be imported into SoundPLAN by an interface. The results based on the calculation of the noise immission values in SoundPLAN can be re-imported into the database City-SUSTAIN.

The noise immission values are connected with the population data and the corresponding information per link. Thus it is possible to assess the noise exposure in a monetary way.

The costs can be illustrated in costs per block of houses or as a sum for the whole investigation area.

For the decision about the implementation of a noise reduction measure it is possible to implement different scenarios into the database in order to compare their impact on cost reduction *(*cp. [Schmedding 2002]).

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[4] GIS = **G**eographical **I**nformation **S**ystem

Possible noise reduction measures are for example:

- Detour of the HGV-traffic,
- reduction of traffic loads,
- speed limits,
- noise reducing paving or
- noise protection windows, noise protection walls.

It is not possible to document the noise reduction measures themselves. However, the impacts of the chosen noise reduction measures which noise emission and other relevant input parameter have for the noise exposure calculation, can be analysed by the monetary assessment module (included in the City-SUSTAIN module).

As an additional function it is possible to present the calculated noise costs graphically (comparison in absolute or relative figures) for the different traffic scenarios (with different impact on the noise immission). The following figure enables an overview about all modules and functions of the database (including the external interfaces to urban GIS and SoundPLAN – a software for the computation of noise exposures).

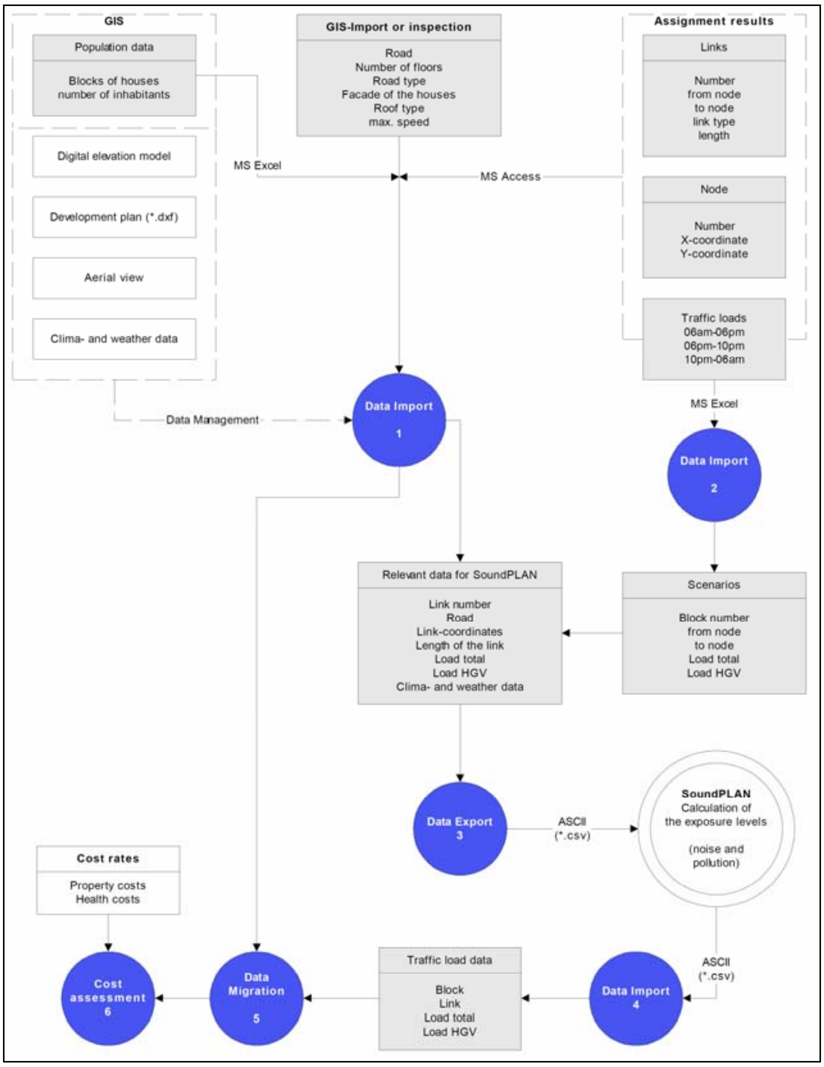


Figure 5: Overview of the modules and functions

4.5 Cost assessment

For the monetary assessment of the affected inhabitants the databases uses property costs based on the loss of rental prices and health costs based on an increasing of health risk with reference to the current noise levels.

4.5.1 Property costs based on traffic noise

The effects of the road traffic noise on the property costs are evaluated by the following studies: [Weinberger et al. 1991], [Borjans 1983] and [Pommerehne 1986]. These studies assume that each db(A) leads to a certain decrease of property value. Table 5 gives an overview of these decrease rates.

Table 5: Results of empirical studies for noise, (cp. [Weinberger et al. 1991], [ECOPLAN 2000])

in Europe:		**in comparison to:**	
[Borjans 1983]	0,5% per dB(A)	US studies (average)	0,42% per dB(A)
[Pommerehne 1986]	1,26% per dB(A)	Swiss study 2000 (ECOPLAN)	0,9% per dB(A)
Eu studies (average)	0,88% per dB(A)		

The older average value of 0,88% / dB(A), provided by [Borjans 1983] and [Pommerehne 1986], was confirmed by [ECOPLAN 2000, S. K-6] for the year 2000 in the framework of a hedonic pricing analysis for the city of Zurich (Swiss) with 0,9% per dB(A).

A property cost depreciation of 0,88% / dB(A) (average value of studies [Borjans 1983] and [Pommerehne 1986]) can be used.

Table 6 shows the monthly rent difference per person for each band provided by [Weinberger et al. 1991]. The monthly rent difference of 0,88% / dB(A) indicates the average value of the two studies.

Table 6: Monthly payment for a reduction of noise (cp. [Weinberger et al. 1991, S. 115])

dB(A)	**Monthly rent difference**		
	1,26%/ dB	**0,5%/ dB**	**0,88%/ dB**
Study	[Pommerehne 1986]	[Borjans 1983]	Average
<45	- €	- €	- €
45- <50	3,05 €	1,21 €	2,13 €
50- <55	9,16 €	3,64 €	6,40 €
55- <60	15,27 €	6,06 €	10,67 €
60- <65	21,38 €	8,48 €	14,93 €
65- <70	27,49 €	10,91 €	19,20 €
70- <75	33,60 €	13,33 €	23,46 €
75- <80	39,70 €	15,75 €	27,73 €

For the monetary assessment of a noise control and/or a noise reduction measure, the average values which represented in Table 6, are divided into five classes. Table 7 gives an overview of the five classes which assign in each case the monthly payment to every affected inhabitant. The monthly payment means that each resident which who has to tolerate traffic with 55 dB(A) is ready to spend 8,53 € per month for a calmer living.

Table 7: Monthly payment with a noise-conditioned rent difference of 0,88% per decibel

dB(A)	<45	45- <50	50- <60	60- <70	<70
Monthly rent difference 0,88%/ dB	- €	2,13 €	8,53 €	17,06 €	25,60 €

The monthly payment determined by [Weinberger et al. 1991] and presented in Table 7 can also be used for a property assessment in the year 2001, as the rent and the income rise approximately equally by 30 per cent in each case between the years 1991 and 2001.

4.5.2 Health costs based on traffic noise

Noise can lead to miscellaneous health problems. Health problems which caused by transport noise, are for example:

- Impairment of the aural acuity.
- Negative influence on the vegetative nervous system (e.g. high blood pressure, heart cycle complaints, disturbance of the digesting organs).
- Aggravation of risk for is chemic heart illnesses - comprehensive term for disease pictures, with which the coronary sclerosis (lack of blood circulation of arteries) is predominant the actual disease cause e.g.: Angina pectoris, cardiac infarct, heartbeat disturbances, sudden heart death.

The connection between traffic noise and ischemic heart illnesses is statistically verified by [UBA 2000]. According to data of UBA 3 % of all cardiac infarcts in Germany can be assigned to noise disturbance.

According to [UBA 2000] loads over 65 dB(A) during the day and 50 dB(A) at night cause increases of cardiac infarct risk and/or ischemic heart illnesses.

Starting point of the study of [Weinberger et al. 1991] is the estimation of the high blood pressure which caused by the road traffic noise. A direct comparison of the number of persons with high blood pressures in a low-noise area with the number of illnesses in an extremely high loaded area, [Weinberger et al. 1991] could acquire 3 % and/or 12 % of the hypertonia illnesses which due to the road traffic noise.

This three per cent value means that only loads of more than 70 dB(A) are relevant. [Weinberger et al. 1991] stated that a load beginning at 50 dB(A) also causes noise illnesses. 12 % of the hypertonia illnesses can be traced back to the road traffic noise, in case that loads starting at 50 dB(A) are considered (cp. [Weinberger et al. 1991, S. 96]).

According to UBA loads beginning at 65 dB(A) are dangerous. Figure 6 shows exemplary the part of the German population that is effected by a road traffic noise of more than 65 dB(A) during the day. 13 million people are exposed to an increased health risk (cp. [UBA 2000]).

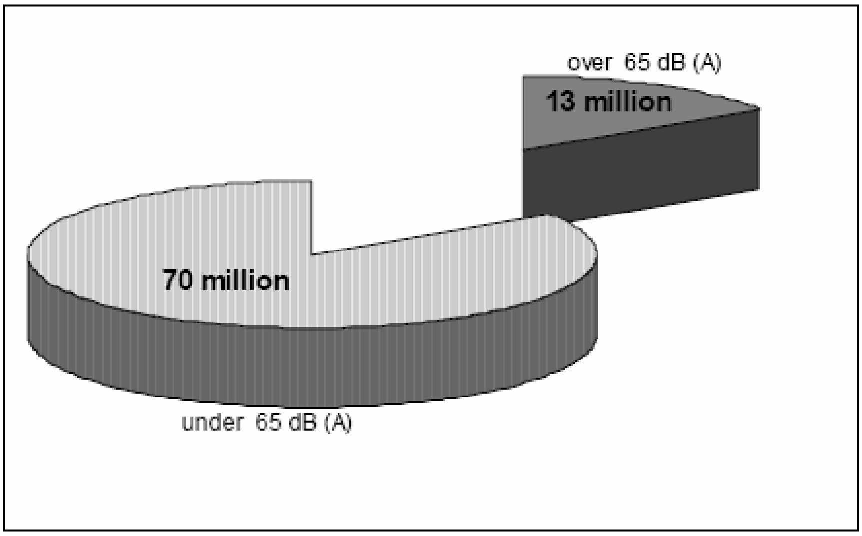


Figure 6: German population, affected by road traffic noise more than65 dB(A) (cp. [UBA 2000])

The following table shows the health costs for the year 2000 which can be ascribed to the traffic noise.

Table 8: Overall economic costs of the heart cycle illnesses of the year 2000; Sources: [Weinberger et al. 1991], [Bickel et al. 1994][5]

Overall economic costs of heart cycle illness of the year 2000		
Total costs	**Traffic-conditioned part**	
	3%	12%
22.243.497.646 €	667.304.929 €	2.669.219.718 €

In order to be able to prove the annual health costs per loaded person, the values for 3 % and/or 12 %, represented in Table 8, must be related to the population which is also effected by 65 dB(A).

A cost splitting leads to 52 € (3% traffic-caused portion of the costs of heart cycle illnesses) and/or 208 € (with 12%) per person, who is affected by road traffic noise.

Neither the 3 % nor the 12 % value reflects the health costs which can be a result of a starting level from 65 dB(A). For this work a value of 8% was accepted. An annual amount of 130 € was set for the health costs for each person, who is affected by a road traffic noise of more than 65 dB(A).[6]

4.5.3 Demonstration of the evaluation concept

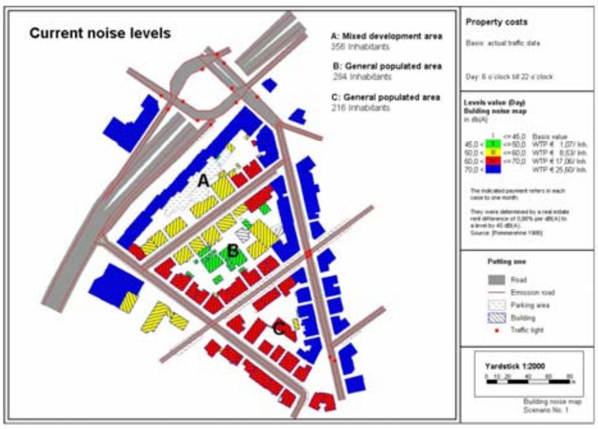
Figure 7 and Figure 8 depict the health and property costs for exemplarily three blocks of houses . The property and the health costs can be determined by building noise maps. Health impacts are accounted for each person, who is exposed to a level of 65 dB(A) or more. Property

[5] In consideration of an annual growth rate of 3 %.

[6] The amount of 130 € results from the average value of the two amounts: 52€ and 208€. It represents the 8% portion of the overall economic costs of the heart cycle illnesses put down on the number of persons who are affected by noise of more than 65 db(A).

impacts can be cut into several ranges. For each block side health and property impacts are proportionately seized.

Figure 7 shows the property impacts (blue: highest impact on the property value, green: lowest impact on the property value). Analogue to Figure 7, health impacts can be developed in Figure 8 (red: people, who live in one of the marked buildings are exposed with 65 dB(A) or more; hereby the health risk is increased).



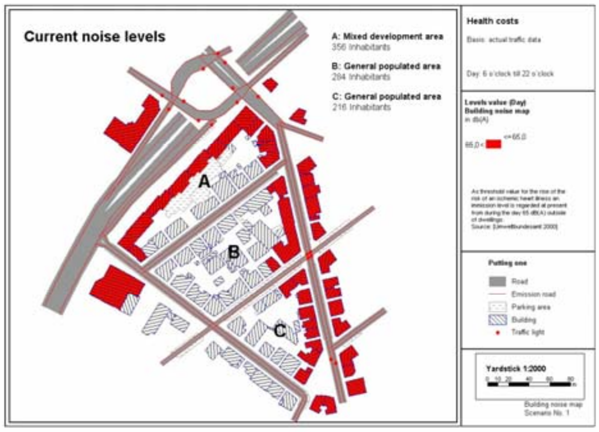


Figure 7: Exemplary calculation of property costs. Figure 8: Exemplary calculation of health costs

4.6 Implementation of the developed module in the city of Stuttgart

Stuttgart is the capital city of the German Federal State of "Baden-Wurttemberg" and is situated on the Neckar river. The city represents the centre of a region which today is the third most densely populated area (approx. 2,500,000 inhabitants) in the Federal Republic of Germany. The main business sectors are industry and technology.

Due to the unfavourable geographical situation (basin shaped valley) there are a lot of problems. Especially the high density utilisation of the urban road network causes environmental problems. The following figure (Figure 9) shows the area that is investigated by the actual traffic data (year 2003).

Traffic and urban data are imported into the City-SUSTAIN module where the data can be processed and other data (e.g. collected in several site inspections) can be added.

The data which is processed in City-SUSTAIN can be used for modelling and calculating social costs. The following figure shows a screenshot of the created geo-database model. This geo-database model contains all buildings (three dimensional: heights and all attributes related to the buildings) and all roads with the parameters which are necessary for noise computations (paving, speed limit etc.).

A DGM (Digital Geographical Model) is one of the most important additional urban data for noise computation. The DGM can be computed by contour lines which cities can normally provide from their GIS. The following figure shows the investigation area in combination with a contour line model.

Several scenarios are defined presuming changes on either the traffic volumes on the regarded road network or on other circumstances like for example a different paving.

Some of these changes are not reserved to the test area only but are also implemented in a broader extent in the city of Stuttgart. The following traffic scenarios (cp. Table 9) have been calculated by VISUM (MobilistNet) and the corresponding traffic matrices have been transferred into SoundPLAN:

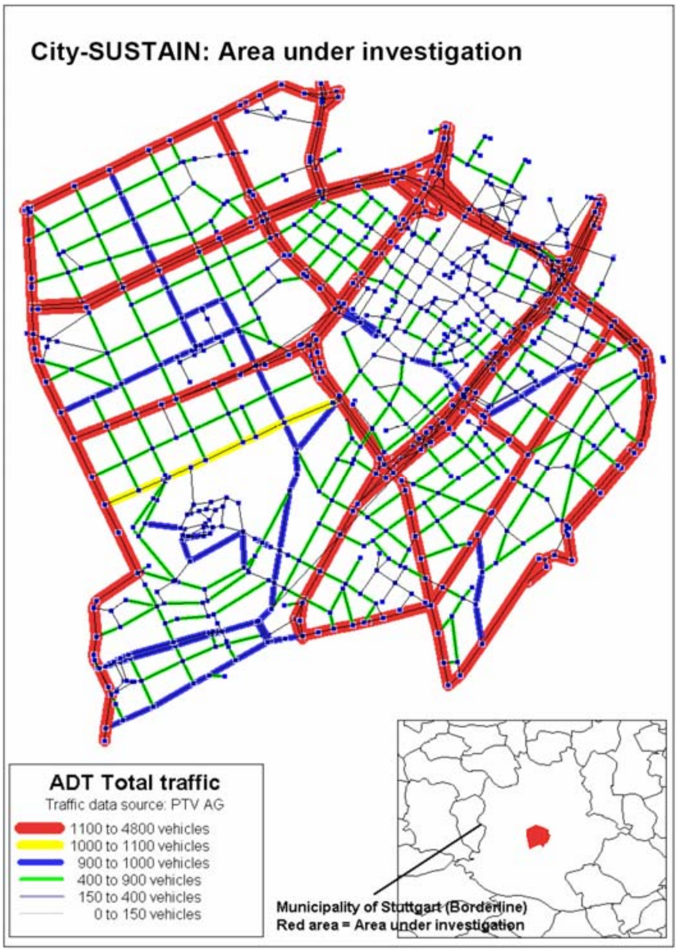


Figure 9: CITY-SUSTAIN - Area under investigation with the average daily traffic (ADT) situation (Traffic data source: VISUM, displayed in MapInfo, year 2003)

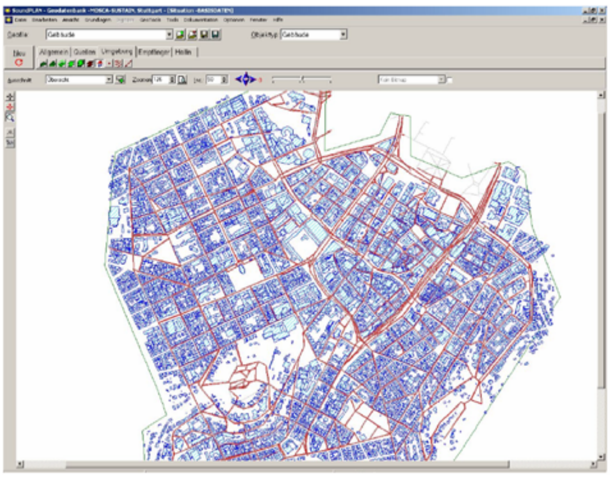


Figure 10: Investigation area modelled in the Geo-database of SoundPLAN: Basis for the noise computation

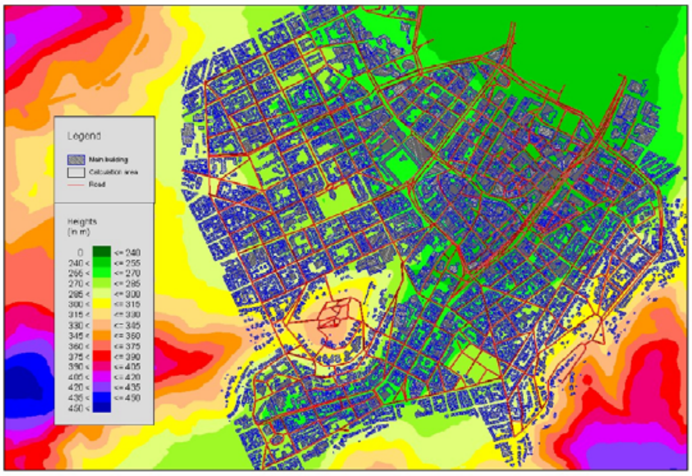


Figure 11: Digital Geographical Model with the area under investigation (calculated in SoundPLAN).

Table 9: City-SUSTAIN traffic scenarios.

Scenario	Description	Remarks
Scenario 0	Current situation without any measures.	Used as reference for all other scenarios.
Scenario 1	Speed limit (30 km/h) In a huge area around the city centre the speed limit is implemented and the changes in the traffic flows of the test area are measured.	The aim is not to shift traffic from the main roads to the secondary roads. Effects in a broader range occur.
Scenario 2	Access restriction in the city centre for all HGV with more than 7.5 t (total weight).	Transit traffic will be shifted to the main roads. Transports which start or end in the test area have to be done by smaller vehicles. The factor used is 3,6 smaller vehicles for 1 HGV.
Scenario 3	Close down of one important main road for all HGV.	
Scenario 4	Passive noise reduction: Noise decreasing paving for the entire city (- 3dB).	This scenario was not calculated in VISUM because the measure does not influence the traffic flows.

All functions of the module City-SUSTAIN are working. The bi-directional interfaces between City-SUSTAIN and the noise computation software are completed and working.

With regard to the SoundPLAN software, several problems occurred during the implementation, however, most of them could be solved. There are still problems with the computation time. At the moment it takes a long time to calculate new scenarios. The noise calculation for one scenario, for example, takes about 30 hours.

Main results achieved

The assessments of the noise exposure were calculated by health and property costs. Noise reduction which achieved by active or passive noise reduction measures can be easily displayed by the cost assessment method described in chapter 4.5. The performance of noise reduction can be presented by noise building maps or by calculated table sheets. Differences between scenarios can be displayed in form of ratios for each part of the city or for the whole investigation area .

City-SUSTAIN can very exactly calculate the noise exposure for each house in the city centre of Stuttgart. Figure 12 shows the results of the test site implementation of City-SUSTAIN in Stuttgart. Each scenario is compared to the status quo situation (scenario 0). The differences in total noise costs (health and property costs) between the scenarios are illustrated in per cent.

Table 10 shows the total costs for each implemented scenario.

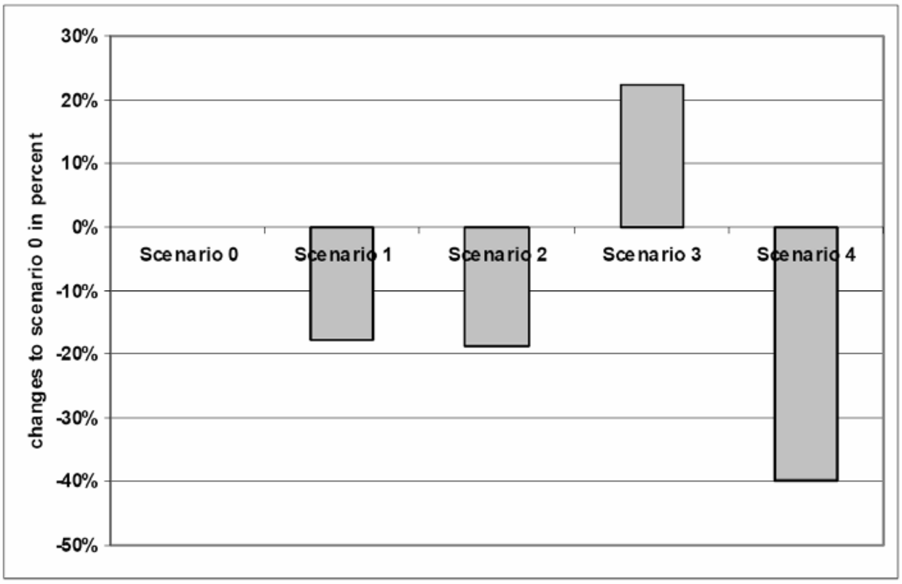


Figure 12: Results of the test site implementation of City-SUSTAIN in Stuttgart

Table 10: Results of the monetary assessment of different traffic scenarios with City-SUSTAIN

Scenario	Description	Absolute noise costs per year
Scenario 0 (Basis)	Current situation without any measures.	**1.296.000 Euro**
Scenario 1	Speed limit (30 km/h) In a huge area around the city centre the speed limit is implemented and the changes in the traffic flows of the test area are measured.	**1.068.000 Euro**
Scenario 2	Access restriction in the city centre for all HGV with more than 7.5 t (total weight).	**1.055.000 Euro**
Scenario 3	Close down of one important main road for all HGV.	**1.582.000 Euro**
Scenario 4	Passive noise reduction: Noise decreasing paving for the entire city (- 3dB). Note: This drastic effect heavily depends on high costs for infrastructure which are not considered at the moment	**635.000 Euro**

A short survey of the features of the City-SUSTAIN module is listed below:

- Data management (GIS-data etc.),
- Data modification (site inspection data),
- Scenario Management (Comparison between scenarios - graphical user interface),
- Noise exposure computation for different scenarios,
- Assessment with country specific cost rates (health and property costs) and
- Result management (in form of detailed tables or noise computation maps).

5 Conclusions

Particularly with regard to the new EC noise regulation (2002/49/EG) and the part of the assessment of noise reduction (part of the regulation) Stuttgart will use this module for a new noise abatement plan in the district "Zuffenhausen". The noise reduction measures which will be designed by the public and community will be assessed with City-SUSTAIN. The result will be a monetary noise evaluation of the exposed population. The developed database is a module which is able to manage all needed noise computation data, to modify and to export them to an external noise computation software. The module also allows the re-import of the noise computation results for an assessment with country specific data in a monetary way.

All needed functions for today and in the near future (cp. the new noise regulation concerning the assessment of noise abatement plans) are fulfilled with City-SUSTAIN.

The module can be used as a decision support system for urban traffic noise reduction measures. This is an important point in context *of* the growing environmental problems in the cities. The main approach of the presented instrument is the assessment of the concerned inhabitants with pre-defined cost rates and not the assessment of the vehicle emissions. The assessment of the exposed population with external costs expresses the economic damage which is very close to the reality.

As a conclusion the presented paper points at the development and implementation of an urban policy instrument for traffic and city planners. Noise reduction measures in cities can be easier evaluated using the described module. Up to now, it was only possible to compare the compilation costs of different reduction measures (e.g. sound insulating windows) . The sustainable effects can now be monetary assessed on economic, ecologic and social level.

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