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IMAGINE
Improved Methods for the Assessment of the Generic Impact of Noise in the Environment

IMAGINE – State of the Art

***Deliverable 2* of the IMAGINE project**

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EXECUTIVE SUMMARY

The state of the art in noise mapping and action planning in Europe has been assessed to provide the point of reference for the IMAGINE project. This state of the art document is the product of all work package leaders in the project.

Presently noise mapping in Europe is applied for different purposes like support to national noise policy, spatial planning, comparison between sources or comparison with other annoyances like air quality. Dependent on the goal and on the available data, different mapping techniques are used: definition of hot spots, development of exposed areas over time, simulation of future scenarios and comparison of measures.

A standard for data storage and presentation of the noise exposure does not exist, which results in incomparable maps. So standardization of storage and presentation is needed, although presentations may need to differ for different purposes. GIS-systems would be an appropriate platform for standardized data storage.

Databases, which have been developed in several countries, facilitate the mapping possibilities, scale and accuracy. In some countries geographic or traffic data are hardly available. The collection of data is very expensive which makes large-scale mapping hardly achievable if the data are not in stock.

Computation and measurement methods are compared, showing differences in methods and in assessed indicators. It turns out that there is little experience of predictions in full conformance with the directive and the details of the source models of Harmonoise.

The presentation methods of computed or measured data differ from single receiver points to ISO noise level contour lines, for the accuracy of which the grid size is determinative. Some software developers apply dynamic grid sizes (high grid point density for built up areas). The noise levels together with the population density determine the number of annoyed people. Population density maps are generally available, but data for the maps are collected in considerably different ways. Here standardization is also preferred.

Finally the noise maps will form the basis for action planning. Actions can be divided into source reduction and volume reduction. Source reduction is done in several ways: damping, shielding, maintenance or new techniques. Volume reduction aims at management of the traffic flow by restrictions, planning, intelligent infrastructure and land-use.

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INTRODUCTION

Noise mapping is not a new activity. Noise maps have been produced in many countries of the European community since the 1970-ies. For the purpose of the present State of the Art report it is intended to give an overview of the experience gathered in the different countries with respect to the production of noise maps. What were they used for, how were they produced, what methods and indicators have been used, what difficulties were encountered and how were these solved ?

A survey was made of the current and past experience with respect to Noise Mapping in the countries that are represented in the Imagine consortium; partners in Norway, Sweden, Poland, Germany, Hungary, Switzerland, France, Spain, Italy, Belgium, The Netherlands and the UK were requested to provide their input based on their own experience and from what they could gather referring to the state of Noise Mapping in their own countries. In addition to that, open knowledge that can be found on the web was included. The results of that survey are presented and discussed in the following chapter.

In the following sections, the information is presented in aggregated form; specific information on individual countries is presented only when this country represents a clear exception compared to the vast majority of the other countries.

The aim of this document is to determine the state of the art in noise mapping and action planning to provide the point of reference for the IMAGINE project. This document is the product of all work package leaders and other partners in the project. The scientific coordinator has coordinated the production of this document.

1 State of the art of noise mapping in European countries

The present chapter presents practical examples of noise mapping in a large variety of applications and interpretations, and discusses the pros and cons of the different options. In drafting this chapter, the consortium has used the Good Practice Guide on Noise Mapping produced by the EU working group on the Assessment of the Exposure to Noise [1]. It is not the intention to repeat what has been addressed in that document, but rather to complement it.

1.1 Noise maps, a definition

For the purpose of the present report, for the definition of a Noise Map reference is made to the Environmental Noise Directive [3]. According to this directive, a Strategic Noise Map is

> *“a map designed for the global assessment of noise exposure*
> *in a given area due to different noise sources or*
> *for overall predictions for such an area”.*

This definition is sufficiently broad to cover almost every attempt to indicate a specific location dependent noise situation on a topographic background. In the following sections, we will attempt to further distinguish various types of noise maps as they can be encountered in the countries that were included in the survey.

1.2 Sources to be covered

Noise maps exist for all kind of noise sources, although clearly road traffic noise maps are the most common. Noise maps for aircraft noise, indicating the noise situation around airports, are also quite common. More rare are specific railway noise maps and noise maps for industrial activities. For industrial plants, a clear distinction should be made between noise maps reflecting the situation inside the plant (usually for occupational health purposes) and outside the plant (for environmental noise purposes). Norway reports that noise maps have been produced for specific activities such as shooting ranges, building and construction sites, and sites for motor sports. This may be the case – although not reported specifically – in other countries.

A final, yet different type of noise maps, though not reported by any country, are the so-called inward zoning maps, applied e.g. for the representation and protection of quiet areas.

1.3 Different noise maps for different purposes

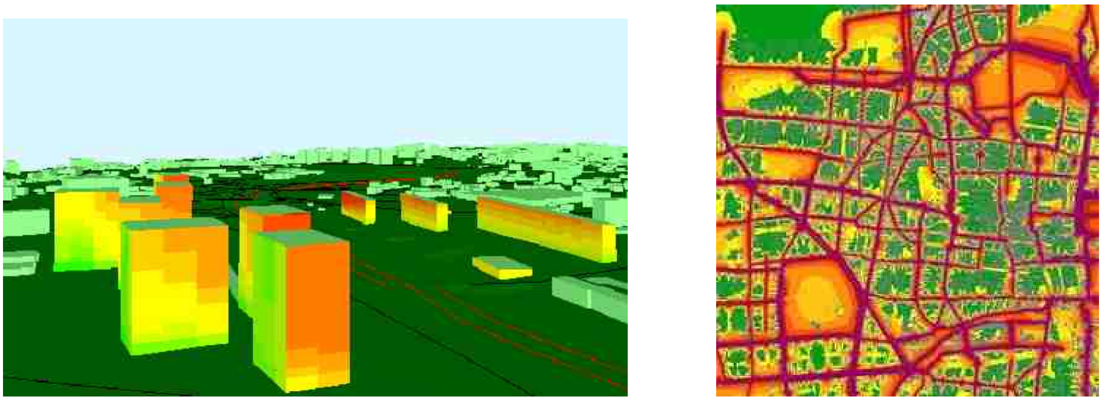
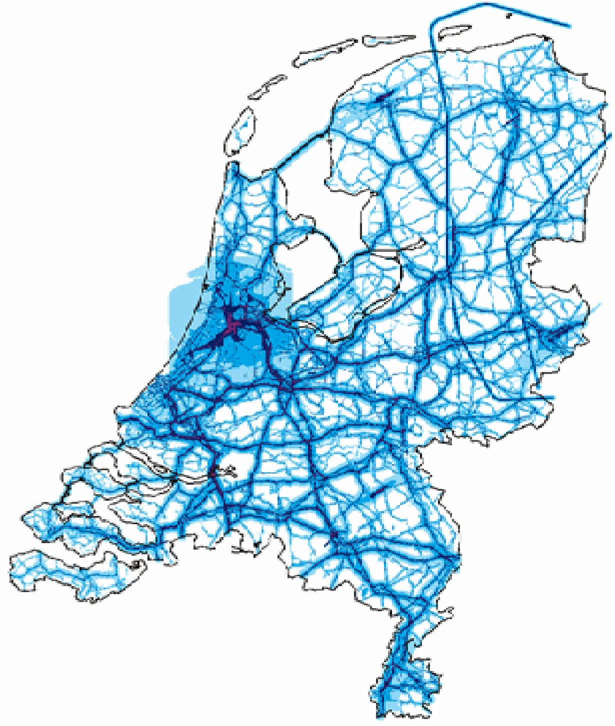


Figure 1: Large spread in presentation and reporting techniques. Left: Noise exposure per building level; Right: the city of The Hague in the Netherlands (both rail and road noise), scale 1:30.000.

Noise maps are produced for different purposes, of which the most common is the identification of hot spots or critical areas. Hot spots can be defined as locations with a relative maximum value of the surrounding sound level, or as locations where a specific limit value is exceeded.

A second important purpose of noise maps is to help monitor a certain development in time, and to compare this development with a desired goal. Many countries produce a national noise map in order to assess the total number of annoyed people, and to monitor the development of that number against a political goal (e.g. that this number should not increase in time). Obviously, this requires regular updates of the noise maps and comparison between different moments in time.



Figuur 2 Cumulative noise (road, rail, industrial and aircraft noise) in the Netherlands. These maps are produced annualy (source National Environmental Assessment Agency)

Closely related to this application is the simulation and representation of certain future scenarios, answering the what-if question. Noise maps are useful instruments to demonstrate the expected efficiency of certain political measures or to compare the effectiveness of alternative mitigation options.

Mapping type	Purpose
Hot spots	Indication of local maxima
Development in time	Comparison with desired goal
Future scenarios	Monitoring developments versus political goals
Impact studies	Compliance with permit restrictions
Comparison of different sources	Definition of priority actions
Comparison of the same source in different areas	Definition of priority actions
Multi-purpose maps	Integrated environmental mangagement

Table 1: Summary of mapping types and purposes.

Sometimes maps are used to monitor the behavior of an industrial enterprise or of a group of enterprises. This is the case when the industrial activity is subject to an environmental permit, which usually sets an upper limit to – among others – the noise produced in the nearest sensitive area. Noise maps are then used to demonstrate and monitor compliance with the permit restrictions.

Different noise maps, representing the contribution of different noise sources to the environmental noise level in the same area allow politicians to define priority actions with respect to the different sources. Alternatively comparison of the same sources in different areas or different countries gives insight in the European situation. This kind of application puts strict requirements on the presentation methods of the maps. On the other hand, different target groups may ask for different presentation of the noise data. This is described in paragraph 2.4.

In many countries, noise maps are used as a tool for spatial and urban planning purposes. In some countries, like e.g. in The Netherlands, noise maps can even be prohibitive with respect to certain urban developments; for example: it is not allowed to plan the construction of sensitive buildings within a prohibitive area within a given distance from an infrastructure link, the so-called noise zone, without at least investigating the precise acoustic situation.

Finally, multi-purpose maps occur, when environmental noise assessment is combined with a representation of e.g. air quality of traffic flows, allowing integrated environmental management by changing the input data to the map.

In France, noise maps are systematically produced for impact assessment, e.g. in case of planning a new road or railway infrastructures or in case of major changes to these. Impact assessment is also required before applying new airport traffic regulations. In principle, this is also true for major town and country planning operations (including new industrial or commercial activities). The permit for such operations requires compliance with legal limit values at existing or planned houses and other sensitive buildings. Such maps are published and used in the public debate preceding the final decisions. In many cases, people living in the vicinity of these planned operations will organize themselves in order to request noise exposure lower than the legal limits.

1.4 Noise Maps with different scales

The most common type of noise maps represent the noise situation in a complete city or a certain quarter of the city. The scale in this case ranges roughly from less than 1:25.000 to 1:50.000. Such maps usually represent road traffic noise, where only the roads with a certain minimum amount of traffic are included in the survey.

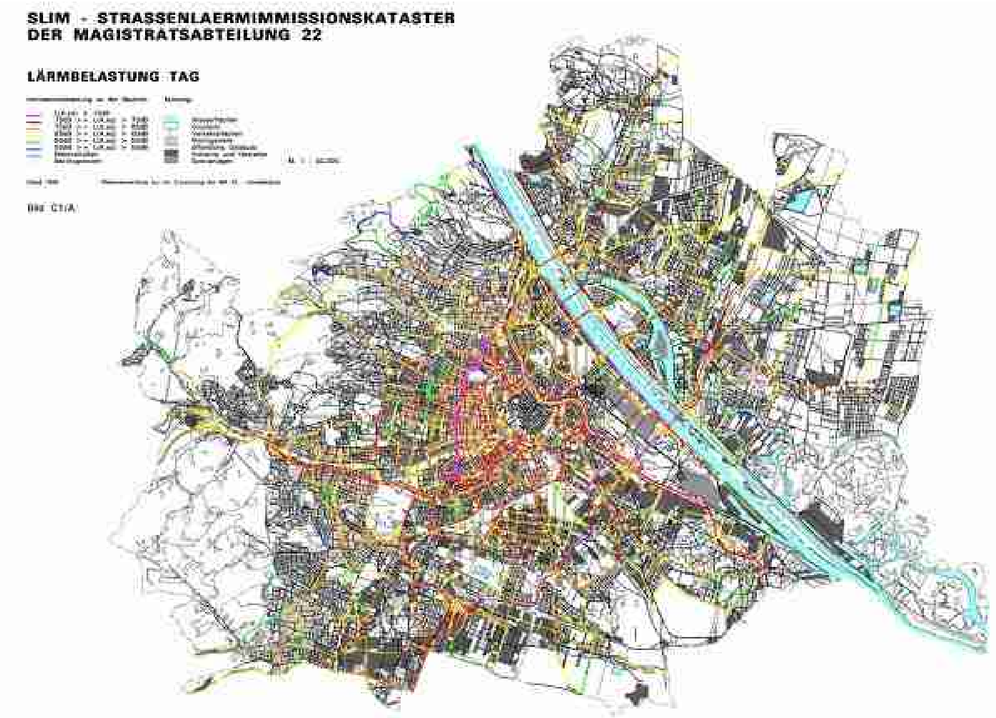


Figure 3: Vienna, Large scale road traffic noise Immission map. See for maps of European cities: http://www.xs4all.nl/~rigolett/ENGELS/maps/.

For extended industrial sites and airports, regional maps may be produced, showing the area around a city or even part of several cities. The scale of these maps is typically around 1:100.000 or more.

For national road and rail networks, maps are produced of the complete network in a country, with a typical scale ranging from 1:500.000 to 1:5.000.000, the length of the network under concern ranging from several thousands to several tens of thousand of kilometers. In these cases, only the main roads or railway lines are included.

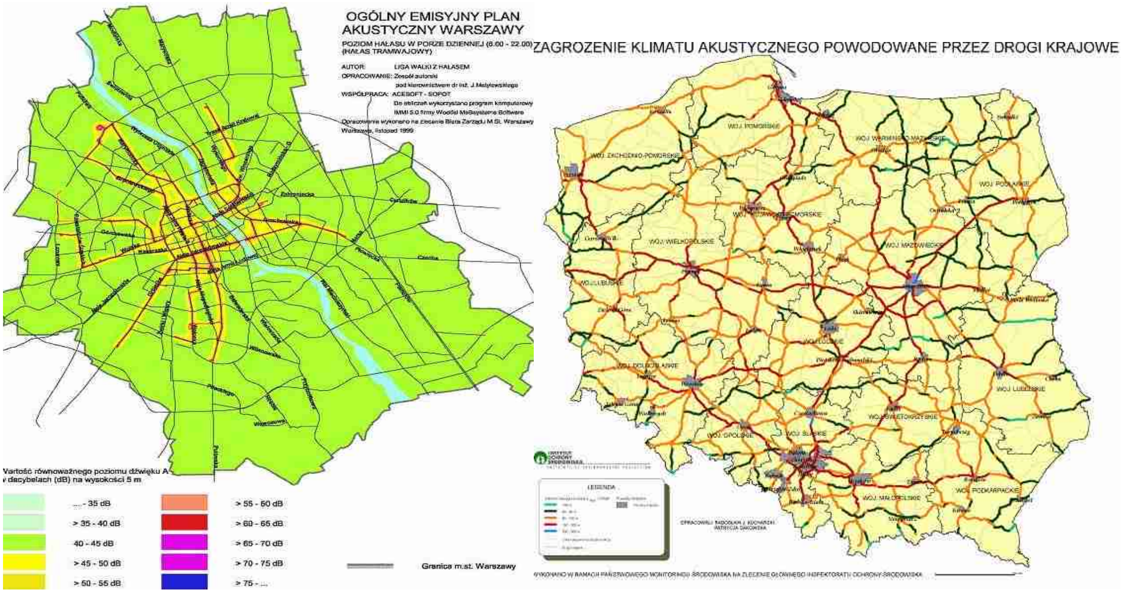


Figure 4: Different scales of noise map. Left: Tram noise map for Warsaw, 1999, daytime. Noise propagation included. Scale 1:100.000. [Liga Walki z Halasem, Poland]; Right: Road traffic noise on major roads in Poland, scale 1:5.000.000.

For impact studies noise maps are produced at a much more detailed level. Typically 1:1000 to 1:5000 scale, showing only a few kilometer of a new infrastructure. Such detailed maps allow the assessment of future noise levels at each and every exposed façade. In some cases, noise levels are represented as individual “numerical” values in labels rather than by contour lines and or color scale only showing the range.

1.5 Different noise indicators

After the European Noise Directive has come into force, there is a common understanding of the obligatory harmonized noise indicators, namely the long term average A-weighted day-evening-night level L_{den} and the long term average A-weighted night time level L_{night}. It is important to note, that the application of this quantity implies, that the behavior of the source should be distinguished in three different periods of time, i.e. a day period of 12 hours, an evening period of 4 hours and a night period of 8 hours. The source behavior per period of time should be averaged over a long period, typically one whole year. The weather conditions representative for the noise propagation between the source and the receiver should be assumed to be typical for the local climate, i.e. the weather conditions should represent the weather that is typical for that specific location or region for an even longer period of time, e.g. 20 years.
The harmonized indicators have been selected with great care, and have been proposed to the European Commission by the European working group on Health and Socio-economic Effects of noise. The reason to prefer these quantities, among others, is that they correlate fairly well with the noise annoyance experienced by the residents in the area under concern. Hardly any other quantity shows a similar good correlation with general annoyance. L_{night} represents a reliable indicator for sleep disturbance, although this quantity is still subject to further research.

Obviously, most noise maps that have been produced in the past did not comply with the requirement to express the noise situation in terms of the harmonized indicator, and a large variety of very different indicators can be found (see Table 2). From the above consideration it is obvious that none of the alternative indicators shows the same capabilities as L_{den} when it comes to mapping and predicting annoyance. But when we look back to chapter 1.3, we realize that there are many other purposes for noise description where different indicators may be equally or even better suited than L_{den}.

The following table presents an overview of the different quantities used. Note that all quantities refer to a noise level outside buildings, unless specified otherwise. The question whether or not to include the façade reflection is discussed elsewhere (Chapter 4).

Quantity	Description	Comment
$L_{Aeq,\ x\ hours,\ 1\ m}$	averaged A-weighted noise level, integrated over a given time interval, from 30 minutes to 24 hours, measured at 1 m from the road/rail side	Suitable to detect real time emission hot spots, not suitable for annoyance prediction. Gives link with real time air quality presentation. Attractive for presentation as levels are recognizable by residents
$L_{Aeq,\ 1\ day}$	24 hour average A-weighted noise level	No direct relation with annoyance, no information on distribution of high levels over the day
E	"Emission number".	No physical relevance. Suitable to detect hot spots.
SEL or L_{AE}	Time-integrated A-weighted level, condensed into 1 second integration time	No relation wit annoyance, possible indicator for sleep disturbance. As the numbers are high no clear indication of hot spots.
$L_{A,\ max}$	Highest reading of a collection of A-weighted noise level samples in a given time period	No relation with annoyance, possible indicator for sleep disturbance. As the numbers are high, no clear indication of hot spots, unless for occupational health
L_{Adn}	Long term average A-weighted sound level over 24 hours, where the night period is penalized (usually with 10 dB)	Comes fairly close to the preferred indicator L_{DEN}. Dose response relationship studies tend to ignore the – small – difference between L_{DN} and L_{DEN}
$L_{A,day}$, $L_{A,night}$	Long term averaged A-weighted sound levels for day and night periods	Used in the French legislation, day is 06:00 to 20:00, night is 20:00 to 06:00. Conceptually the levels are yearly averaged values. Separate limits apply to different noise sources (e.g. road and railway), and to different periods (day and night).
L_{ETM}	Highest reading of three long term average A-weighted noise levels, i.e. over day, evening and night, where evening and night are penalized with 5 and 10 dB respectively	Has been in use in The Netherlands only. Requires too much explanation to be practicable. By definition $\geq L_{DEN}$
$L_{ADEN,\ inside}$	Long term average 24 hour level inside a dwelling, where evening and night period are penalized with 5 and 10 dB respectively	No direct relationship with annoyance. In use in Norway
L_{DEN}	The harmonized indicator for END, long term average 24 hour level, where evening and night period are penalized with 5 and 10 dB respectively	The preferred quantity for future mapping under END. Hardly ever applied in mapping practice up till now. Some countries will use it in parallel to their own national quantities
L_{Night}	Average A-weighted level over the average night time period of 8 hours	According to END, the preferred indicator for sleep disturbance and an obligatory quantity for noise mapping

Quantity	Description	Comment
MKM or L^*_{DEN}	“Environmental Quality Quantity”. Equal-annoyance corrected cumulative A-weighted noise level, combining the contributions of different noise sources, including evening and night penalties, attempting to assess the cumulative effect	Suitable for equal annoyance representation of different sources, either separate in separate maps, or cumulative in one combined map. Introduction of this quantity for END mapping purposes was rejected by WG HSE.
L_{10}	Level in dB(A) exceeded more than 10% of the total exposure time.	British legislation used to be based on this indicator.
EPNL, PNLTmax	Effective Perceived Noise Level, Tone Corrected Maximum Perceived Noise Level	This indicator is typically used in aircraft regulations (e.g. aircraft certification), sometimes also for expression of noise exposure due to air traffic. Because of the specific frequency weighting and pure tone corrections it has been believed that this indicator correlates better with annoyance due to aircraft. Recent studies show that this might be questionable at least when annoyance is due to a sufficiently large number of noise events.
TAL, NAL	Time-Above-Level, Number-of-Events Above Level.	Assessment of annoyance due to aircraft.

Table 2: noise indicators

1.6 Assessment methods for noise maps

As indicated above, noise levels to be presented on a noise map can be assessed either by direct measurement (called monitoring if the measurement takes place in a structured and repeated way) or by computation, using a set of measured or calculated input data and a propagation model.

Obviously the direct measurement method can only be applied in an existing situation. Direct measurement is an efficient method if the source is fairly constant in time, e.g. in the case of occupational noise maps in process industry. In the latter case, a distinction has to be made between open air noise maps, where outdoor noise propagation models could be used in the case of a computational approach, but the scattering effects in dense machinery is difficult to assess, machinery in closed buildings, where a computational approach is to be preferred if one wants to predict the efficiency of measures like screening, encapsulation and absorptive ceilings etc.

In the past noise maps were even produced based on scale model measurements.

Figure 5: scale model studies for noise mapping (Centre des maquettes, Grenoble).

Measurement

Noise levels are assessed during relatively short observation times (from a few minutes to several days). One has to make sure the emission levels and propagation conditions are representative of the longer periods over which the relevant noise indicator has to be assessed (e.g. yearly averaged L_{day} and L_{night}). The French NF S31-085 standard requires that measurements be combined with simultaneous monitoring of traffic flow and speed and meteorological observations. Under restrictive conditions, the standards allows for corrections in order to extrapolate the measured results to yearly averaged values.

Monitoring

In some countries, particularly in urban areas, it has been common practice to use real time information for mapping purposes. This practice shows parallels to the way air quality monitoring networks are used to present air quality data, e.g. on NO_x or ozone concentrations, to be used in an environmental warning system. The approach has certain pros and cons: most important disadvantage is that the indicator, an instantaneous or a short time average noise level has no direct relation with annoyance. However, the system could be used to assess the long term average situation in a very empirical and reliable way.

Computation

The most common method for noise mapping is computation, both of the source’s noise production and of the noise propagation. Computation methods for roads and railway lines have been developed in Harmonoise [90]. Computation methods are treated in more detail in chapter 3.

2 Input data for noise mapping

According to the Good Practice Guide on Noise Mapping produced by the EU working group on the Assessment of the Exposure to Noise [1], “the acquisition of input data required for the purpose of strategic noise mapping and the production of exposure data will be a major task for Member States”. The current practice of collecting data is described below.

2.1 Standardization of data collection

Noise mapping has become common practice in many countries. However, due to technical limitations (available input data), to the use of specific computation methods and to end-user specifications, every noise mapping exercise has been a virtually unique experience. In most cases, a lot of information has been collected during the production of the noise maps but most of it remains unexploited after finishing the task of producing the noise map. As such, noise mapping is often considered an expensive task with “low” output compared to the “high” inputs in terms of data collection and computation efforts.

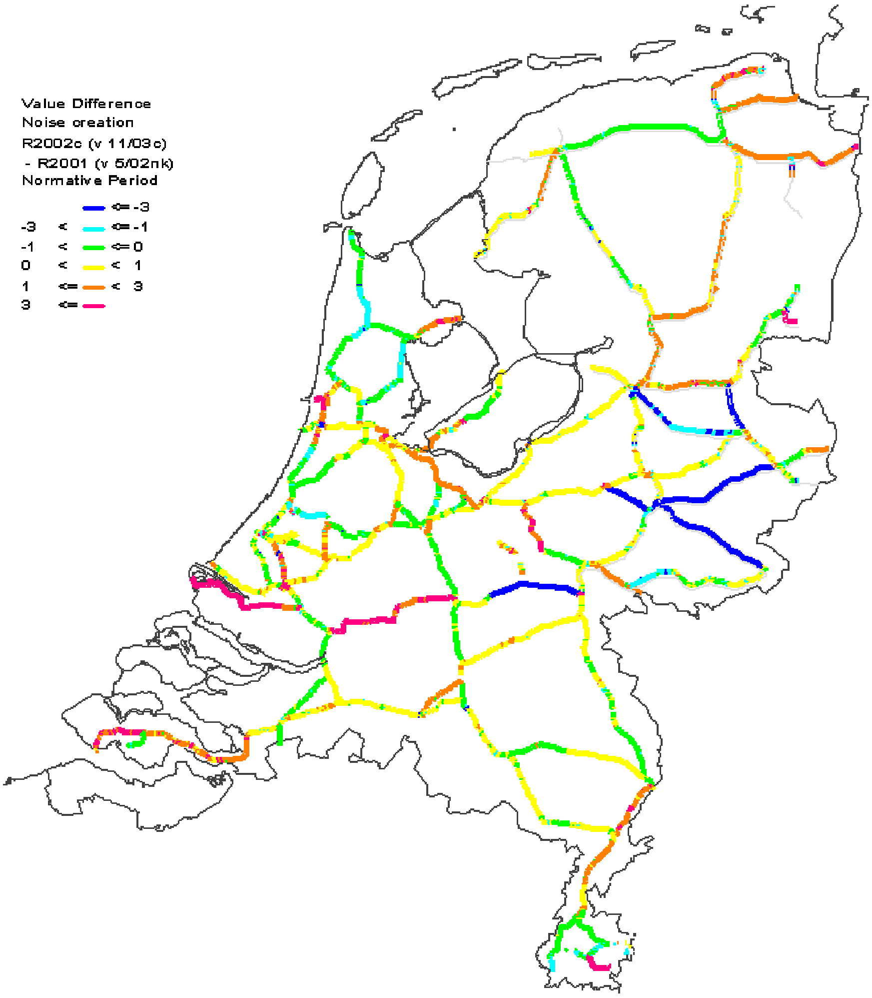


Figure 6: Increase of the noise emission of rail traffic in The Netherlands. Expected values for 2010-15 compared with 2002 (in dB(A)).

Results from different noise mapping projects are too often expressed in terms of very specific end-user specifications (target groups, target applications,…), leading to a large spread in presentation and reporting techniques. This makes comparison or assembly of results at a larger scale very difficult. Re-use of input data for different applications (e.g. from identification of conflict situation to evaluation of action plans) is not guaranteed if it is not considered part of the initial specifications of the project.

Recently, dynamic noise mapping systems have been developed. Beyond collection of input data and computation of static noise maps, such systems store, maintain and update all input data in a common GIS database thus allowing regular updates of the noise maps and fast evaluation of proposed action plans. Coupled with traffic monitoring, such systems may even provide real time information about noise exposure. In some cases, dynamic noise mapping has become part of an integrated environmental monitoring and management tool, supplying support for efficient environmental policies and closer involvement of the citizen.

From this, it is clear that noise mapping must be viewed more as a process than as a final product. As such, noise mapping is no longer an isolated task of collecting data and producing graphical maps, but deals with efficient collection and update of input data, sharing data (and costs) with other applications and tools used in traffic / land-use planning and environmental management, exploitation of results and presenting data in appropriate forms to specific target groups.

2.2 Availability of data

The availability of detailed and accurate data needed to set up noise maps has increased. Databases with for e.g. topography, land-use, buildings and traffic flow are available on both local and national scale from the authorities and several commercial data suppliers. Some parties have developed tools to support the transformation of data and to speed up the process of noise mapping. Examples of widely available input data for noise maps:

Sweden

In Sweden normally the local authorities have most of the input geo data needed for noise mapping. However, this information does in almost all cases origin from Lantmäteriet, a company whose database covers all Sweden with geometric information regarding roads, railways, terrain, houses etc.

Information about railway traffic is supplied by Banverket (the national rail administration of Sweden).

Most information about road traffic within the cities is handled by the local city authorities while Vägverket (Swedish National Road Administration) has the information for roads between cities (and also some additional info about road traffic in cities).

Spain

In Spain the following databases are used:

Cartographical data:

- National Boundary: Instituto Geográfico Nacional (IGN), Centro de Información Geográfica Nacional (CIGN) escalas 1:25.000 y 1:50.000 (MTN25 y MTN50),
- Autonomical Boundary: (in general 1:10000) Instituto Cartográfico de Andalucia Instituto Cartográfico de Cataluña (ICC) Instituto Cartográfico de la Comunidad Valenciana (ICV) Atlas de Geografía de Aragón Sistema de Información Territorial de Navarra (SITNA)

- Regional Boundary: (in general 1:5000) Cartografía de Bizkaia Cartografía del Territorio Histórico de Álava Sistema de Información Geográfica de Gipuzkoa
- Local Boundary (Town Halls) in general 1:2000 or 1:500

Source data:

- Minsiterio de Fomento has data about the main roads and railways, their axes and their traffic in 1:200000.

Land uses and population:

- Dirección General del Catastro has catastral cartography of urban and rural areas of 7.584 municipalities.

UK

In the UK, the Ordnance Survey provides the MasterMap system. OS MasterMap is an intelligent digital map designed for use with geographical information systems (GIS) and databases.
Based on the National Grid, it includes topographic information on every landscape feature – buildings, roads, phone boxes, postboxes, landmarks.
OS MasterMap depicts the real–world digitally and presents this comprehensive, advanced information as themes in a series of layers.
Each feature has its own unique identifier or TOID® – a 16–digit reference number that can be shared with other users across different applications and systems. This allows easy data association and greater accuracy, focusing on real–world objects on the map.

For railway noise mapping in the UK there are a number of disparate databases available, which the UK Government and the infrastructure owner Network Rail, are currently bringing together for efficient data sourcing. Railway traffic flows are available from Network Rail data which is able to be filtered into vehicle type and day, evening and night flows with AEA Technology Rail's ACTRAFF software. Track types and the location of infrastructure is available via the GEOGIS database, with more detail on, for example, elevated structure type, kept in separate, often local, databases. Terrain and structures very close to the railway are not currently comprehensively logged, but aerial surveys and camera-based surveys based on train-mounted systems provide some of this information. If rail head roughness is to be included in the mapping, network-wide roughness information is available via the AEA Technology Rail NoiseMon system.

Netherlands

Some of the most relevant sources of information for input data for noise mapping:

- NWB (National Road Network), all streets, country roads and highways;
- AHN (Actual Height Information Netherlands), detailed height information of ground level and buildings;

Figurer 7 Example of AHN data combined with aerial photography for Amsterdam city center (source Ministry of Traffic)

- Central Bureau of Statistics with GIS data for neighborhoods, land use etc;
- Topographic Service data like buildings, houses in great detail (TOP10).
- Aswin, rail database in the Netherlands [58], track location and geometry, track types, train categories, train speeds, driving conditions, geometry, etc.

France

IGN, the National Geographical Institute produces and markets highly detailed digital maps (e.g. BdTopo, BdPays) including topography, building heights and center lines of all road and railway platforms. Data can be purchased by local authorities and made available to noise engineers carrying out the noise mapping projects.

The Ministry of Transport produces and updates digital maps of traffic data on the entire national road and highway network.

Population data at a large scale aggregate level is freely available from INSEE, more detailed information can be purchased, however French legislation does not allow data at the individual level (e.g. per building) to be published or distributed.

Other example of database:

- NPD (Noise-Power-Distance tables), aircraft database where the L_{AE} level is integrated for level flights at constant speed and scaled for different power settings and distances;

Most authorities exchange this kind of data based on data-for-data contracts, so they can use data at low cost or no cost at all. Increasing collaboration between different levels of authorities and commercial data suppliers has lead to more usable data, suited for noise, air pollution, traffic flow management on any required scale.

In some other countries such databases are not available and noise mapping mostly relies on the re-use of existing data provided by some external data source: digital terrain maps, cadastral data, traffic monitoring systems, GIS systems set up by other agencies for different applications, etc. In some cases the data have to be bought from a data provider. It is then not unusual that data collection and transformation of existing data into a suitable form for noise map calculation schemes represent the main cost in the process of noise mapping.

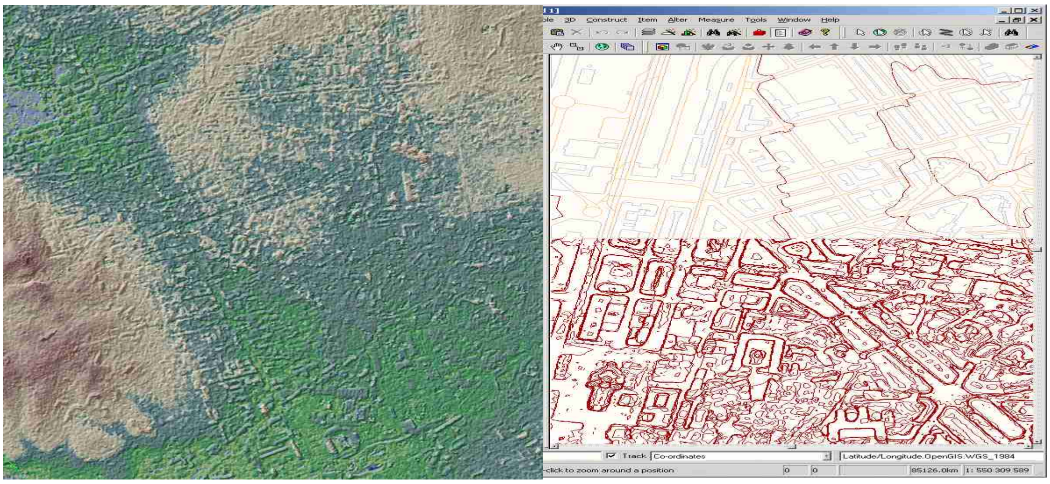


Figure 8: digital terrain map

Other ways of data acquisition

Ways of acquiring geographical data are: in situ observation, aerial photographs, detailed topological maps established by geographers for the sole purpose of the project, measurement or monitoring of unknown noise sources. For the purpose of large scale noise mapping however this level of input data collection is not acceptable because it is much too expensive.

Acquisition of traffic data may be critical because it is not always under control of the stakeholder responsible for the noise mapping project. Major highways, railways and airports, if not obliged by legal disposals, may prefer not to collect or not communicate the required input data about fleet composition and traffic conditions to local authorities (e.g. freight transport is commercially sensitive for this kind of information). In practice one has to infer missing data from existing noise maps and/or validate emission values based on control measurements.

Conclusions

In general, there is a discrepancy between the ambitions of those who produce noise maps and action plans on the one hand and the available input data on the other. Geographical information can be acquired in sufficient accuracy and detail but obviously there is a cost element involved. The discrepancy is noticeable for instance in traffic modeling, where the alignment of the roads is often available only in rough terms (up to 10 meters in horizontal sense) whereas the acousticians need less than 1 meter precision for their calculations. Traffic data is often only available in general and crude terms (e.g. composition of the fleet is not detected by the traditional traffic counting systems). Again, it is feasible to collect more detailed data but at a substantial cost. The more precise acoustic models require more precise input data, such as for instance the track quality in railway noise or the road surface quality in road traffic noise. Again, generally this information is only available in very broad terms.

2.3 Data format

Quality of data

Accurate acoustical modeling of environmental noise, no matter how powerful a prediction tool may be, requires high quality input data, both for the geometrical model and for the acoustical properties. The resulting quality of the noise calculation depends considerably on the quality of data pre-processing and on the efforts involved for accurate representation of the situation to be characterized by the noise calculation. As everywhere, it also holds true for any noise calculation program, that the output can only be as good as the input. The increase in computing power allows today considering a more detailed set of situations than, say, 20 years ago.

Harmonized input data model

Because of the wide variety of digital data available throughout Europe (from digitized images to full 3D topographic databases), it is not possible, at the time being, to propose a harmonized input data model for noise mapping purposes. Noise mapping is mostly a local activity, based on locally available data and largely depends on local topographic characteristics.

However, what is needed is a harmonized way to asses the quality of input data and the expected influence this may have on the accuracy and usability of the resulting noise maps. Collection and dissemination of such data will provide local authorities and infrastructure managers with useful information for setting up new noise mapping projects.

Required data format

In all cases, minimal information about underlying input data and additional assumptions made by the noise engineers should be reported together with the calculated noise levels in order to allow correct re-use and interpretation of the results.

Storage of the emission and exposure levels in GIS format is needed, so that they can be shared, exchanged, assembled and exploited not only within the scope of the legal obligations defined by the EU-Directive but also as a solid basis for future research on dose/effect relations and health issues.

A list of needed data, dependent on the computation model used, and the data availability:

Geometrical data:

- Numerical terrain model (grid points or altimetric lines)
- Intersection of platforms with numerical terrains (embankments, viaducts, bridges,..)
- Buildings (base height, height above ground, gutter or roof top, number of floors,…)
- Ground characteristics (uniformly averaged, area specific, interfered from aerial photographs)
- Climate data
- Barriers (height, length, angle, type)

Road traffic data :

- Fleet composition and vehicle categorization (monitored, deduced from national data, arbitrary or legal values)
- Flow and speed distribution (with hourly, weekly, seasonal variations per vehicle category)
- Road platforms (center line/number of lanes)
- Location of driving lines on the platform
- Road surface characteristics
- GSM / GPS measurement of driving speed on real traffic flows (disputable), or location dependent design speeds

Rail traffic data :

- Flow and speed distribution:
- Number of coaches
- Number of axles per coach
- Number of coaches per train
- Length of trains
- Train categories (based on braking systems)
- Railway platforms (center line/number of lanes)
- Location of tracks on the platform
- Track roughness and maintainance conditions
- Track type

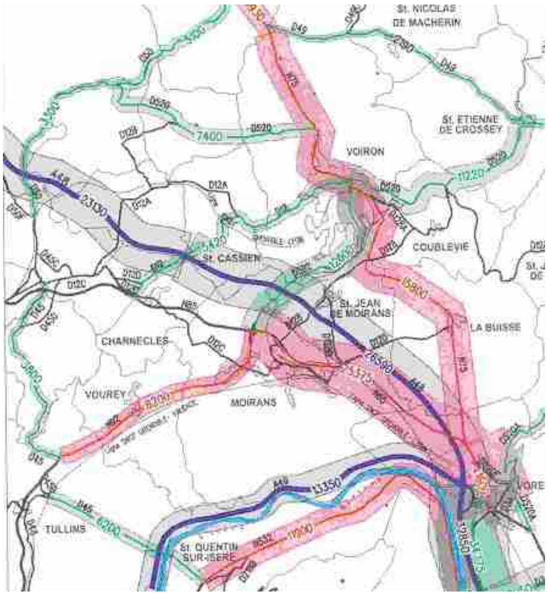


Figure 9: this map shows the expected « averaged daily traffic » on all major roads, based on actual traffic flow measurements and forecast models (France).

Aircraft noise:

- Number of movements per aircraft type or category
- Operating conditions
- Type of runways and maintenance conditions
- Preferred tracks and track dispersion as a function of meteorological conditions

Industrial noise:

- Location (3D) of sources/equivalent sources
- Sound power level of sources
- Directivity of sources
- Duration of operation (for intermittent sources)

Population and land-use:

- Population data: per building, per housing block, per town, per district
- Categorization of building use : industrial, commercial, offices, housing, schools, rest homes, hospitals, house boats, recreational
- Data available per cadastral unit, per floor, per building, per zone
- Quiet areas or areas of natural beauty

- Remark: population and land-use are not essential to modeling an computation but they are required for establishing strategic noise maps and conflict maps if noise limits are related to land/building use.

2.4 Gis: storing databases

Experience has demonstrated that noise maps can be (should be) stored and manipulated by means of existing GIS technology. Within the scope of the Imagine project, we use the more common term noise map as a shortcut for what we consider <u>spatial noise databases</u>. Spatial noise databases should be able to contain any kind of noise related data linked to their relevant geographical information.

The formal framework of GIS is well suited for the production, storage and manipulation of noise data. The paradigm of coupling <u>graphical items</u> (geographical location) and <u>associated attributes</u> (named / typed values) makes GIS more powerfull than standard database systems. Moreover, GIS provides standardized ways to locate geographical data (independent of scale and coordinate systems) and general tools (union/intersection of graphical items, proximity checking, assembly and combination of attributes, frequency / histogram analysis,…) for manipulation of such data.

However, GIS only supplies support for spatial databases, not the required semantics related to some specific application. As a general framework, GIS provides the necessary <u>syntax</u> for storage of spatially located data, independent of any specific domain of application and almost independent of specific software and data formats. However, <u>semantics</u> are not integral part of GIS data / software and must be specified by particular groups of interest based on their specific domain of application.

As a general rule, GIS provides a clear separation between <u>storage</u> of information (the spatial noise database) and <u>presentation</u> of such data (traditional or emerging noise map techniques). The storage should be harmonized as much as possible in order to maximize potential exploitation. Standardization of the presentation is needed to some extent, for comparison of different maps (different sources, or different areas), see paragraph 1.3. However different presentations are needed depending on the target group, the foreseen use, the scale of the project, etc… The extension of standardization is subject to deliberation in the Imagine project.

2.5 Requied level of detail

Detailed input is required for high accuracy of noise map calculations but may be stored and maintained only at the local level (by the authority responsible for producing the noise maps). There is a clear need for a harmonized representation of aggregated data so that data can be assembled at any required level (from local authorities to a complete EU noise database). Global noise maps do not always require graphical representation; e.g. reporting on populations exposed to excessive noise levels can be done in tables and graphs, not needing maps.

Global emission databases can be used as default values in local noise mapping, for evaluation of action plans or land planning (because of the legal aspects, land planning is better based on reference data than on actual data, e.g. maximum capacities of roads rather than actual traffic data).

Detailed noise databases may separate noise contributions from lots of different noise sources (e.g. for every main road, for every type of train, for different aircraft types,…). This allows faster update of noise maps when only one of the sources is changed.

2.6 Up-dating data

The implementation of the EU-directive END I [3] requires efficient reporting of noise exposure at the different geographical / administrative levels. The levels vary from local authorities and managers of infrastructures responsible for the actual noise mapping projects, through national agencies responsible for the collecting and assembly of data at the national level, up to reporting and exploitation of results at the European level. The efficiency of this process clearly relies on common reporting specifications and GIS is without doubt the appropriate tool for supporting such a common database approach.

GIS allows storage of noise data (of any kind, from emission levels up to exposed populations or noise emission / immission limits) together with the geographical datum to which it relates (from a single measurement / computation point up to some area delimited by administrative limits). Complementary information from citizen’s complaints or collection of noise related health problems can also be coupled to GIS thus allowing cross-analysis of noise exposure levels and annoyance / health effects based on spatial location.

2.7 Source data for industrial noise

Unlike road and railway noise, for industrial noise most source data has to be measured on the spot to calculate the source power. Next to this source power the working hours of each relevant individual source has to be known and the position of the source (on top of a building, a door in a hall, on the ground, etc). So we deal with a large variety of sources with respect to sound power, operation time and location.
For most of the existing guidelines the sound power data has to be in octave bands, at least for the octave bands form 63 till 4000 Hz. Only the Nord 2000 method calculates in 1/3 octave bands.
For the determination of sound power levels of noise sources various standards are available. Which standard is best suited for noise mapping purposes will depend on the type of noise source and the surroundings which affect the acoustical measurements in the vicinity of the sound source considered. Standards from the following organizations have been searched:

- ISO
- DIN
- VDI
- IEC
- BSI
- ANSI
- ASTM
- HMRI (Dutch)

Standards matching one of the following properties can be regarded as not or less suitable for noise mapping purposes:
precision methods in reverberating/anechoic/semi-anechoic test rooms;
survey methods (insufficient accuracy);

methods demanding specific operation condition for rating purposes and comparison (measurements during actual operating conditions in practice are required)

From a total of some 200 noise related standards, a limited number of standards appear to be useful for noise mapping purposes. An overview of the measurement methods thought to be most suitable is given in Table 3. With the measurement methods shown in Table 3 it is thought that all regular industrial situations can be assessed. (EN standards are standards that are to be adopted in national legislation if they are referred to in European directives.)

organization	reference	year	title
ISO, BS, EN	3740	2000	Acoustics - Determination of sound power levels of noise sources - Guidelines for the use of basic standards
ISO, BS, EN	3744	1994	Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane
ISO, BS	8297	1994	Acoustics - Determination of sound power levels of multisource industrial plants for evaluation of sound pressure levels in the environment - Engineering method
ISO, BS, EN	9614-1	1993	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points
ISO, BS, EN	9614-2	1996	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 2: Measurement by scanning
ISO, BS, EN	9614-3	2002	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 2: Precision method for measurement by scanning
DIN	45635 Blatt **	various	Geräuschmessung an Maschinen: Luftschallmessung (large number of specific standards for various machine types)
VDI	2571	1976	Schallabstrahlung von Industriebauten (Sound radiation from industrial buildings)
HMRI	II.2	1999	Geconcentreerde bronmethode (Concentrated source method)
HMRI	II.7	1999	Uitstraling gebouwen (Sound radiation from buildings)

Table 3: Standards suitable for determining sound power levels for industrial noise mapping purposes

3 Computation methods

3.1 Computation methods – roads

In this paragraph, six national calculation models for road noise are mutually compared. The models are currently applied in Europe, except Nord2000, which is still a proposal in most nordic countries. All six models are reviewed for a number of important parameters. Information for the comparison is gathered from some HARMONOISE state-of-the-art reports (see Harmonoise website www.harmonoise.org), and from a report on the selection of interim calculation methods [16]. Table 4 lists some models, their date of issue and the date of the last update, if available.

Country	Model	issued	updated
Austria	RVS 3.02 Lärmschutz (RVS 3.02)	dec 1997	--
France	NMPB (draft standard Pr S 31-133)	1996	--
Germany	Richtlinien für Lärmschutz an Straßen (RLS-90)	oct 1990	
Netherlands	Reken- en Meetvoorschrift Verkeerslawaai II (RMV-II)	may 1981	mar 2002
Joint Nordic	New Nordic Prediction Method (Nord 2000)		--
U. Kingdom	Calculation of Road Traffic Noise (CRTN)	1975	1988

Table 4: List of reviewed national calculation models

Harmonoise
The Harmonoise method is not finished yet. A provisional description can be found on the Harmonoise website Harmonoise, WP 1.1, Source description for road traffic noise www.harmonoise.org .

3.1.1 Model characteristics

In this paragraph, all models are compared based on a number of parameters that are important for road noise source modeling.
In Table 5, it is noted for each model which noise indicator is used, i.e. the number that the source and propagation model together are meant to produce, what approach is used to calculate the noise from a certain road, and if the calculation is done in spectral bands.
In Table 6 the time periods are given for which the model may produce its results. For the calculation of L_{den} and L_{night} values, separate values for day, evening and night are needed. In [16], it has been reviewed if each model is capable of providing the values needed to calculated L_{den}.

Model	noise indicator	calculation approach	spectral resolution
RVS 3.02	$L_{A,eq}$		only overall levels
NMPB	$L_{A,eq}$	decomposition of line sources into equivalent point sources	1/1-octave 125 – 4000 Hz
RLS-90	$L_{A,eq}$	road is divided into segments; separate $L_{A,eq}$ values are combined	only overall levels
RMV-II	$L_{A,eq}$	road is divided into segments (max. 5° horizontal angle)	1/1-octave 63 – 8000 Hz
Nord 2000	$L_{A,eq}$ and $L_{A,max}$	road is divided into uniform line sources	1/3-octave 25 – 10000 Hz
CRTN	$L_{A10,1h}$ and $L_{A10,18h}$	road is divided into segments; contributions from each segment are combined at receiver position	only overall levels

Table 5: General characteristics of each model

model	time period	adaptable for L_{den} and L_{night}[1]
RVS 3.02	day: 06.00 – 22.00 night: 22.00 – 06.00	yes
NMPB	day: 06.00 – 22.00 night: 22.00 – 06.00	yes
RLS-90	day: 06.00 – 22.00 night: 22.00 – 06.00	yes
RMV-II	day: 07.00 – 19.00 evening: 19.00 – 23.00 night: 23.00 – 07.00	yes
Nord 2000	any	yes
CRTN	06.00 – 24.00	no

Table 6: Calculated time periods for each model; does this allow for Lden and Lnight calculation?

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[1] *as defined in [16]*

model	source description	source position	source height[2]
RVS 3.02	single point	centre of road lane	0.5 m
NMPB	single point	centre of road lane	0.5 m
RLS-90	single point	centre of road lane	0.5 m
RMV-II	single point	centre of each lane	0.75 m
Nord 2000	three line sources	At the position of the closest wheel	0.01 m / 0.15 m / 0.30 m
CRTN	single point	3.5 m from nearside carriageway edge	0.5 m

Table 7: Description of model source

In Table 7, the layout of the calculated source for each model is given. Most models use a single point source at 0.5 m, whereas the RMV-II uses a height of 0.75 m. The Nord 2000 model uses three sources to account for the finite dimensions of the vehicle and the distribution of the various vehicle noise sources (rolling and propulsion noise) over different heights; here, the emitted sound power is equally distributed over the three sources.

In Table 8, the capability of each model to account for various vehicle types, variations in vehicle speed, and for vehicle acceleration, is judged. Table 9 then lists the occurrence of corrections for road gradients (i.e. road inclination or declination), variations in road surface types, especially porous types, and for horizontal and vertical directivity, is given.

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[2] *relative to road surface top*

model	different vehicle classes	vehicle speed correction	range [km/h]	acceleration
RVS 3.02	passenger cars, light trucks and heavy trucks	correction factor available	?	?
NMPB	light vehicles and heavy trucks	graphical representation of speed influence	light: 20-140 heavy: 20-100	yes
RLS-90	light and heavy vehicles (% of HDV)	parametric, $L_w = f(v)$; here *v* is road speed limit	?	?
RMV-II	light, medium heavy and heavy vehicles	parametric: $L_w = a + b \cdot \lg(v)$	light: 30-160 heavy: 30-110	yes
Nord 2000	light vehicles, 2-axle and multiaxle heavy vehicles	database with 5 km/h classes	light: 30-155 trucks: 30-115 and 30-100	no
CRTN	light and heavy vehicles (correction for % HDV)	correction is function of speed	50-108	no

Table 8: Incorporation of vehicle speed and vehicle class in source level

model	gradient	road surface		directivity	
		general	porous	Horizontal	vertical
RVS 3.02	yes	yes	yes	No	no
NMPB	yes	yes	yes	No	no
RLS-90	yes	yes	yes	No	no
RMV-II	yes	yes	yes	No	no
Nord 2000	yes	yes	yes	Yes	yes
CRTN	yes	yes	yes	No	no

Table 9: Other corrections to source model

In Table 10, the characteristics of the propagation part of each model are given. For each model, it is indicated if the propagation model incorporates, besides geometrical spreading effects, sound absorption by air and ground, ground inclination, sound barriers and other obstacles, and reflections by nearby facades.

model	atmospheric attenuation	ground absorption	slope	barriers	obstacles	facade reflections	meteo effects
RVS 3.02	yes	yes	no	yes	yes	multiple	no[3]
NMPB	yes	yes	yes	yes[4]	yes	multiple	yes
RLS-90	yes	yes	yes	yes	yes	multiple	no[3]
RMV-II	yes	yes[5]	yes	yes[4]	no	multiple	yes
Nord 2000	yes	yes	yes	yes[4]	yes	multiple	no
CRTN	no	yes	no	yes[4]	yes	yes	no

Table 10: Characteristics of propagation model

3.2 Computation methods – railways

3.2.1 Overview of different computation methods

An overview of different methods in different countries is given. Input data for the models mostly come from databases which are described in paragraph 2.2.

CRN (Calculation of Railway Noise)

The Calculation of Railway Noise is the standard UK method, which defines the measurement and prediction procedures.

The railway is split into one or more segments. For each segment the reference SELref is determined at a given speed and at a distance of 25 m, taking into account the type and length of the train and the type of track and track support system. “On-power” diesel locomotive noise is also taken into account. Corrections to the SELref are made for distance of the reception point from the track, ground and air absorption, the effect of screening by barriers, and the angle of view at the reception point, and for reflection effects at the reception point. The resulting SEL values are converted to values of L_{Aeq} taking into account the time period required and the number of trains.

The L_{Aeq}s are combined for each segment to obtain the total day and night L_{Aeq} for the railway.

NMPB (Nouvelle Méthode de Prévision de Bruit)

A French prediction method for railway noise called NMPB-FER [33] has been developed on the basis of an already existing one for road traffic noise. This method is an octave band approach and is today included in the engineering model MITHRA-FER [46] developed by CSTB. The method specifies two calculation procedures: with meteorological conditions favorable to sound propagation and with atmospheric homogeneous conditions. The result is a long term equivalent A-weighted noise level obtained by the combination of the two calculations and taking into account the percentage of time when favorable conditions occur.

RMV (Reken- en meetvoorschrift) [18]

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[3] *model does contain ‘down wind’ correction*

[4] *model includes ordinary (straight) barriers, as well as separate corrections for wide and inclined barriers*

[5] *absorption not adjustable; ground is either reflective or absorbing*

The source is given as an equivalent sound power level per kilometer track, calculated for eight octave bands from 63 to 8000 Hz, taking into account train categories and track superstructure. Corrections can be made for braking and bridges. The Dutch model source heights at 0 and at 0.5 meter above the rail head, situated in the middle of the track. Category 9 (high speed train) is modeled with four line source heights (0.5, 2, 4 and 5 meters). For calculation of the propagation effects the line sources is split into angles of 5º seen from the receiver. The speed dependency is incorporated as $b \cdot lg(v)$, where b is a constant given per octave band, source height and category. The emission of each octave band is calculated according to $E = a + b \cdot \log v + 10 \log Q$,
Where v = train speed and Q = number of coaches per hour.

Schall 03

The German Schall 03 scheme was published in 1990 [34]. A new Schall 03 method is being developed at the moment, but the changes will be limited. The actually used method will be presented here. The source characteristics in sound levels are given as an equivalent, total sound pressure level at 25 meters from the middle of the track at a height of 3.5 meters above the head of the track. The actual source for further calculations is placed in the middle and at the height of the railhead.
The line source is divided into segments l, such that $d/100 < l < d/2$, where d is the distance from the track to the receiver. This results in separate L_{Aeq}'s, which are then combined. The sound pressure level is calculated as a standard value (51 dB) with corrections for category, intensity, speed, angle, track (sub-structure), bridge, directivity, brake, crossing and radius.

ÖNORM S 5011

[19]

SEMIBEL

[21]

Nordic method

This is the former official Nordic prediction method for train noise. It was published in 1996 [20] and then replaced the much simpler Nordic84 [32]. The method is used to calculate the octave and A-weighted equivalent and maximum levels for any given time
period. The sound propagation part is closely related to the Dutch method. It gives results for the atmospheric condition of positive temperature gradients and/or downwind, in accordance with existing national noise criteria. The method describes two type of sources:
The total traffic consisting of any combination of trains and operating conditions
Any single train as a source, with a choice of train types and operating conditions
The former is used for calculating L_{eq}, the latter for L_{max}.

A large number of measurements were carried out in the various Nordic countries to give input data to the method. The measurement results are now providing useful input to Nord2000. The method handles complex terrain, abate in a simple manner, and is implemented as the computer programme NoMeS.

Nord2000

NB: This model is described here, although it is still a proposal, whereas the just described Nordic Model is the currently used model in the nordic countries.

In Nord2000 a prediction method for train noise [53][22][23] is described. The model consists of separate ‘modules’ for road and rail traffic sources and a ‘module’ for sound propagation. The source modules contain data on point source strength and source position while the propagation module contains algorithms for calculating third-octave band attenuation during transmission from source to receiver. The noise contributions of rail traffic are calculated for 6 sub sources at six different source heights.

Weather conditions can be taken into consideration and screens/reflectors are handled in a way that will lead to more reliable and 'natural' looking noise maps than if the old methods were used. The propagation model uses the concept of Fresnel-zones.

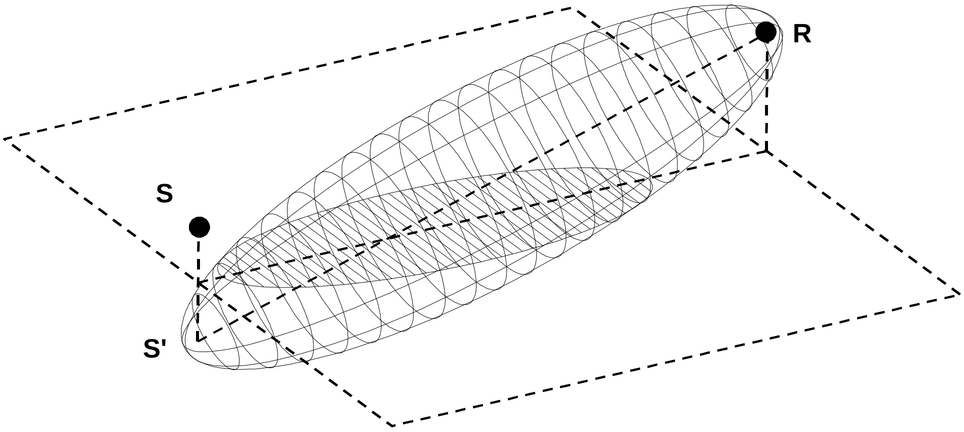


Figure 10: Definition of Fresnel ellipsoid and Fresnel-zone

Harmonoise

The Harmonoise method is not finished yet. A provisional description can be found on the Harmonoise website Harmonoise, WP 1.2, Source description for railway noise www.harmonoise.org .

Comparison of different railway noise models was made in Draft version 1.3 by the EU Framework Directive on Environmental Noise, WG3 [4]. The summarizing table from this report is borrowed here.

Models

Country	Method	Literature
Austria	Önorm S 5011	[19]
Denmark	Beregning af støj fra jernbaner, Fælles nordisk beregningsmetode	[17]
France	MITHRA 4.0	[46]
France	NMPB	[33]
Germany	Schall 03	[34]
Netherlands	RMV	[18]
Joint Nordic	The Nordic Prediction Method	[20]
Switzerland	SEMIBEL	[21]
United Kingdom	CRN	[35]

	L_{den} ? 1)	Strategic modeling	Noise mapping	Kicak area oreductuins	Briadband Awt keveks	Octave band levels	Different train types	Track gradient	Train speed correection	Track/sleeper/ballast type corrections	Meteorological effects-long-term averaging	Meeorological effects correcto	Propagation over hard/soft ground	Misc vegetation types	Undulating/sloping ground	Barriers	Rerflection effect	Total score	Is transmission part of model validated?	Is full model validated?	Has model been updated?	Comparable road trffic model	Additional procedures
Austria	Y	4	4	4	4	4	4	2	2	1	1	1	4	4	2	4	4	49	-	-	Y	Y	Y
Denmark	Y	4	4	4	4	1	4	2	2	2	2	1	4	3	4	4	2	47	Y	N	N	Y	Y
France (NMPB)	Y	4	4	4	4	4	4	1	2	2	4	2	4	3	4	4	4	54	Y	N	N/A	Y	Y
France (MITHRA)	Y	4	4	4	4	4	4	1	2	2	4	2	4	3	4	4	4	54	Y	N	N/A	Y	Y
Germany	Y	4	4	4	4	1	4	1	4	3	1	1	1	4	4	4	4	48	Y	N	Y	Y	Y
Netherlands	Y	4	3	4	4	4	4	2	2	2	4	2	4	2	4	4	4	53	Y	Y	Y	Y	-
Joint Nordic	Y	2	3	4	4	4	4	1	3	3	1	1	4	4	4	4	1	47	N	Y	N/A	Y	Y
Switzerland	Y	2	2	4	4	1	4	1	2	2	1	1	1	1	1	4	1	32	Y	Y	N	Y	N
United Kingdom	Y	4	4	4	4	1	4	4	2	2	2	2	4	2	4	4	2	49	N	N	N/A	N	Y

Table 11: comparison of computation methods, from in Draft version 1.3 by the EU Framework Directive on Environmental Noise, WG3 [4].

1) Can the model be adapted to predict L_{den}

Y: Yes

N: No

1, 2, 3, 4: Indicates the ease of adaptability

1: Criteria not included within model/model cannot be adapted

2: Model can be adapted

3: Model can easily be adapted

4: No adaptation required

3.3 Computation methods - airports

The calculation of aircraft noise involves several steps. First, a large data pre-processing must be used to reduce the complexity of a real world situation to a limited set of representative situations. These situations are then used as input for the acoustic calculation. The results are summed up according to the number of movements and according to weighting of the time of day to produce the L_{DEN} (combined level for day, evening, night). Usually calculations are made for many receiver locations arranged in a grid with spacing from 50 to 300m. Finally, noise contours of equal levels are interpolated from the values of the grid points. While the overall procedures are universal, the complexity of the acoustic models may vary considerably.

3.3.1 Aircraft performance

For a single acoustic calculation we need to know the positions of the aircraft and the power settings of the engines. Ideally, this information may be provided by “flight deck recordings” in the aircraft’s cockpit. Alternatively, flight path may be described using the radar information from traffic control and engine power (max. take-off or reduced power) may be estimated using the “Actual Take Off Mass” (ATOM) provided by the airport or using the length of the trip. If it is possible to get from the different carriers the specific flight instructions for the pilots, i.e. the requirements on power, speeds, flaps and transition heights, then it is possible to calculate the climb profile (altitude versus flown distance) using the formulas published in SAE AIR 1751 [37] and using aircraft specific coefficients listed in the INM database [41][42].

3.3.2 Aircraft data

The primary task of an acoustic model is to estimate the L_{AE} (see Chapter 1.5) of a flight operation (departure or landing) for a specified aircraft. The calculation of L_{DEN} then takes into account the number of movements associated with individual L_{AE} and the weighting according to time of the day. The new Volume 1 of DOC.29 (*Applications Guide*) is a user guide addressing data handling and quality issues for defining airport scenarios to be calculated.

3.3.3 Evolution of acoustic models

The main differences in aircraft noise calculation concern the acoustic engine, i.e. the acoustic model used to calculate the level of a single flight (L_{AE}) and the database associated with that specific model.

CPA models
In early days using hand calculations or very limited computing power, the maximum level of an aircraft was deduced directly from the distance at the Closest Point of Approach (CPA). The level L_{AE} was estimated by assuming some typical time duration for an event. Curved flights are accounted for by corrections. The German model AzB, issued in 1975, uses this structure [64].

Integrated models
The integrated models represent the next step in complexity. Here, a data base is established, where the level L_{AE} is integrated (using the 10 dB down rule) for level flights at constant speed of 160 knots and scaled for different power settings and distances: the Noise-Power-Distance tables (NPD). This database is maintained by FAA (USA) in collaboration with aircraft manufacturers. It is publicly available. As in the CPA-models, the level L_{AE} is estimated in the integrated models

using the closest distance from the flight path to the receiver (sometimes called “slant distance”) as entry point to the NPD-tables. Correction terms apply to account for curved flights and for speeds differing from 160 knots. The concept of integrated models are put forward in each of the three documents: SAE AIR 1845 (1986) [37], ECAC DOC.29 (1986) [38] and ICAO Circular 205 (1988) [39].

The lateral attenuation accounts for level corrections for receiver points to the side of the flight track. It includes effects of fuselage shielding, propagation (turbulence, scatter) and ground effects for a microphone at 1.2 m above soft ground. Originally formulated in SAE 1751 (1981) [40] using data from B 727, it deviated considerably from new data for most chapter 3 aircraft. The working group SAE A-21 made new measurements in the past few years and is revising the SAE 1751. The new version, to be published probably in 2005, will differentiate between two aircraft classes: aircraft with engines mounted at the tail will correspond to the old SAE 1751, while aircraft with engines mounted at the wing will have a standardized lateral directivity to account for a level increase of about 2 dB for sound radiation slightly to the side.

Segmentation models

To account for variable power settings (take-off / climb power) and for a better representation of curved flights, the integrated models were extended to the concept of segmentation. Here, the flight path is broken down to a series of straight segments, each of which may have its individual power setting and speed. The segmentation allows for a more realistic representation of the flight procedure. However, as segmentation violates the basic concept of the data base for integrated models, a mathematical model of longitudinal directivity had to be introduced for the segmentation model to properly weight the contributions of the various segments to the resulting sound level L_{AE}. This is known as the noise fraction [42][43]. To account for longitudinal directivity at the start of roll, another correction function is applied there. In a segmented model, a departure including a curve may be broken down into 10 to 30 segments. The lateral attenuation is used in a similar way as in the integrated models.

The segmentation models are in widespread use, due to fast computation time and the availability of the only international accepted database of NPD-data. (The original NPD-database from FAA (USA) is updated in collaboration with EUROCONTROL to become the “Aircraft Noise and Performance (ANP) database, accessible by internet). Examples of segmentation models are INM (USA) [41][42], ANCON (UK) [43], DANSIM (DK), NORTIM (N). The revised DOC.29, to be published in 2004 by ECAC [43], recommends also segmentation. As there is no spectral information available in the data-base, aircraft noise can only be calculated for the artificial atmosphere with the damping coefficients defined in SAE AIR 1845 [37], which roughly correspond to 25°C.

Simulation models

Simulation models break the flight path down into a series of discrete points. For each point, the geometry from the source to the receiver is clearly defined. The task of the calculation is reduced to a standard situation in acoustics. If required, cross sections of the terrain may be calculated and various sound propagation models may be used to account for wind, temperature and ground effects, barriers etc. The level at the receiver can be calculated, provided the information about the sound emission of the source for the appropriate direction is available. This requires a three dimensional, spectral characterization of sound power for the aircraft in flight condition at a specified power setting of the engines.

At the receiver, there results a level from each consecutive position on the flight path. When these levels are lined up, the time history of the sound level is reconstructed (or simulated), comparable to measured level-time histories. Therefore, simulation models may be used not only to calculate L_{AE}, but any acoustic parameter that could be measured, like e.g. statistical level distribution, time above a specific level, NAT (number above threshold) etc.

Time step models

There exist variations on how to select the source positions on the flight path. For time step models, the spacing equals the distance flown in a time increment, e.g. one second. Examples of time step models are FLULA (CH) [45], the standard model used in Switzerland with an independent directivity database, NMSIM (USA), a extension of a segment model to short segments, NORGARD (N) used at airport Gardemoen (Oslo) with directivity data measured locally, and RNM (USA), the Rotorcraft Noise Model, which suffers from a shortage of publicly available source data for helicopters.

Other simulation models

The dominant part of the sound level history occurs for close positions of the aircraft. In contrast, the low levels produced by the aircraft during the long time intervals when it is rather far away from the observer, are of reduced importance. In the time step models, each discrete point may be considered as the representation of a short segment of the flight path from the middle between the previous point to the middle between the next point. With a typical speed of 100m/s and a time step of 1 s, this results in an equivalent “segment” of 100 m. Other segmentation techniques allow for longer segments in the less important portions of the flight path, e.g. by using a constant angle increment at the receiver. This allows cutting down on the number of computations. An example using ray tracing from the receiver point is Mithra (F) [46].

3.4 Computation methods - Industry

In many countries a guideline is given for predicting industrial noise. These guidelines can be used for noise mapping but were originally used for compliance checks of limit values in relation to operational permits of individual factories.

The following guidelines for industrial noise propagation are or were used within the EC:

- Guide for measuring and calculating industrial noise (Netherlands 1981/1999), referred to as HMRI 0
- ISO 9613 Part 1, 2 (1996) [56], [57]
- Environmental noise from industrial plants General Prediction Method (Denmark 1982), referred to as DAL [49]
- Outdoor sound propagation VDI 2714/ VDI 2720 (1988) [54]
- CONCAWE (1981) [55]
- NORD 2000 (2000) [24]
- Schallabstrahlung und Schallausbreitung ÖAL 28 (1987) [49]

3.4.1 Input

The input for all these calculation models are more or less the same. We start from source and end with the receiver.

3.4.2 Calculation methods

The calculation methods are, except for Nord 2000, in a general way equal. Next to the geometrical spreading there are attenuation factors for the influence of atmospheric absorption, ground effects, reflections and barriers. The calculations are mostly valid for downwind conditions (wind blowing from source to receiver). This is corrected by introducing a number for an averaged situation. Only Concawe and the NORD 2000 model are able to calculate different types of meteorology.

	Meteorology	Air absorption	Ground effects	Reflections	Barriers	Forest	In-plant screening	Housing	Meteorological effect	
HMRI	x	X	X	X	X	X	X	X	x	
ISO 9613 Part 2	x	X	X	X	X	X	X	X	x	
DAL	x	X	X	X	X	X	X		x	hilly terrain
VDI 2714/2720	x	X	X	X	X	X		X	x	DI chimneys and buildings
CONCAWE	X	X	X		X		X		X	
NORD 2000	X	X	X	X	X	X		X	X	ground roughness, hilly terrain
ÖAL 28		X	X	X	X	X	X		x	

Table 12 Attenuation terms, X: is dealt with, x: is dealt with to some extend

The Nord 2000 model is by far the most sophisticated model. The calculation is based on Fresnel zones instead of (curved) lines, the meteorological effect is elaborated as well as the influence of non flat terrain. However little international experience is available with this model yet. In the Harmonoise project, the Nord 2000 model is one of the starting points.

3.4.3 Receiver

The receiver is not different for the methods. Care should be taken that the reflection of a nearby façade should be taken into account.

3.4.4 Accuracy

The accuracy for the measurement methods vary from precision method to survey method. For the ISO standards the accuracy is given in ISO 3740-1980 depending on frequency and method, ranging from 5 dB for the lower frequencies for engineering methods to 0.5 dB at mid frequencies for precision methods in anechoic rooms.

In the next table the stated accuracy for each propagation method is given.

Method	Accuracy
HMRI	<2 dB in most cases
ISO 9613 Part 1, 2	1-3 dB distance <100 m, 3 dB distance from 100 till 1000m (in case of no reflection and screening)
DAL	1-3 dB distances < 500 m
VDI 2714/2720	1-3 dB distances < 1000 m (Free field conditions and downwind propagation, without influences of forest and housing)
CONCAWE	1 dB distances < 2000 m
NORD 2000	2 dB distances < 200 m
ÖAL 28	not stated

Table 13 Stated accuracy for each propagation method

These accuracy will hold in most cases with down wind conditions. In some cases with larger distances, there are deviations measured of more then 5 dB at 500 meters.

3.4.5 Lacunae

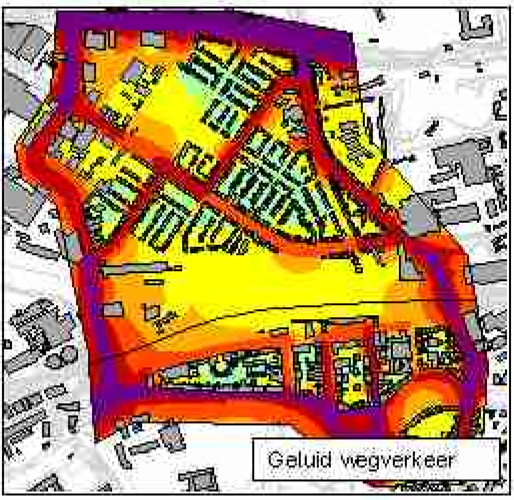
For measuring the sound power level, there are some major differences to be found. The Dutch guide is based on measuring the sound power in the relevant direction of the receiver. The ISO standards calculate the total sound power in all directions. No standards include a direct method to measure the directivity of a source.

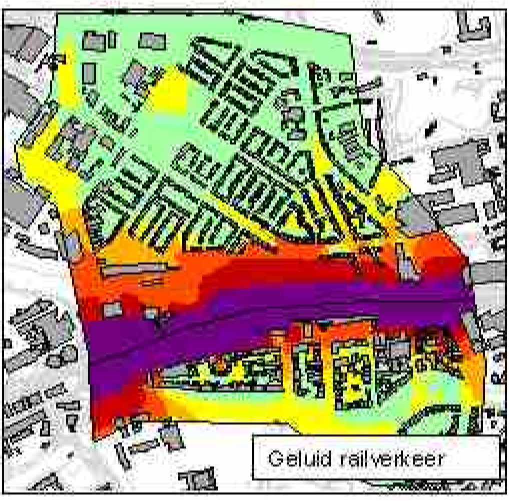
Certainly the prediction methods have their shortcomings [76], most common with interaction by screening of several buildings. Also the possibilities to calculate noise levels in non flat terrain is only dealt with, in a sophisticated way, in Nord 2000.
Except for Nord 2000 and Concawe, only downwind calculations can be made and thereafter the results may be corrected for an averaged meteorological situation. This will not always give the right prediction of the L_{den}. For instance in the situation where predominant winds are blowing from receiver to source (unfavorable conditions), most methods will not be able to simulate this situation and subtract for the downwind situation (favorable conditions) at the highest 5 dB.

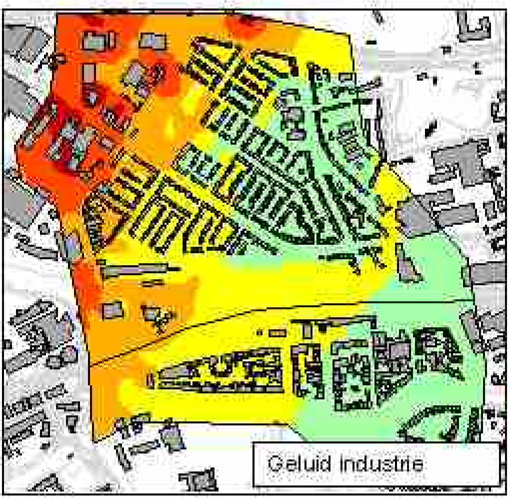
3.5 Multiple source modeling

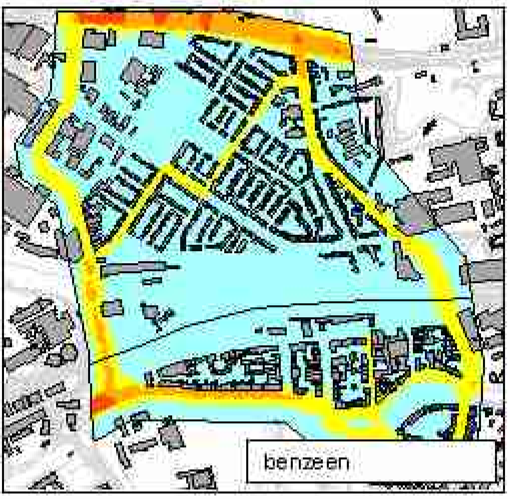
Example of modeling

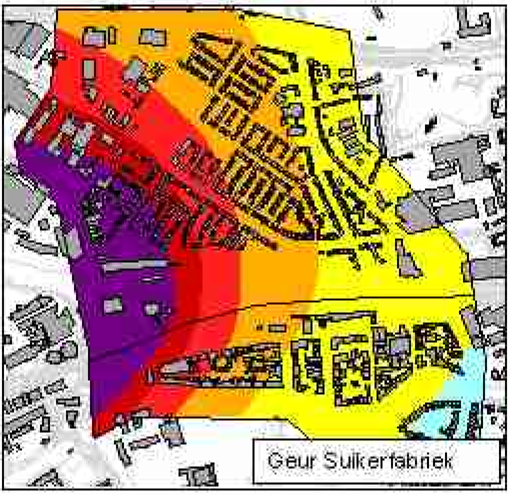
TNO has developed an instrument for Local Environmental Surveys named Urbis. Expertise on emissions, dispersion/transmission, annoyance en health-risks is brought together in Urbis. With this GIS based instrument, TNO can survey relatively fast and inexpensively the local environment of a municipality or district with a high level of detail. Noise, air-pollution by various substances, odor en safety hazards from stationary and mobile sources are considered. The basis of the survey is information available at the municipality or other information providers. The present situation, as well as future scenarios can be examined and compared. Urbis has been developed with support of the LIFE-program of the European Union, the Dutch ministry of Environment and local authorities. An example of maps for road traffic noise, railway noise, industrial noise, benzene concentration, odor and hazard for the city of Breda is given below.

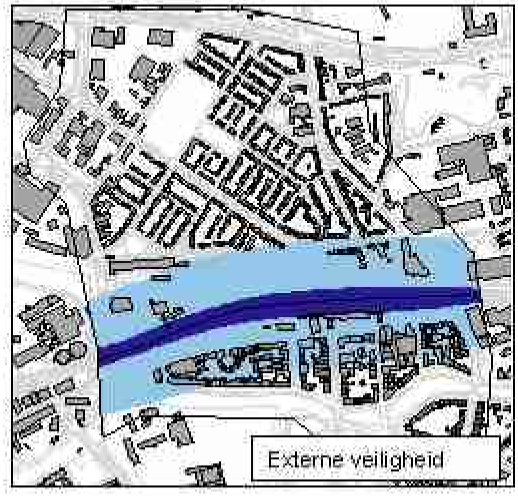

Geluid wegverkeer


Geluid railverkeer


Geluid industrie


benzeen


Geur Suikerfabriek


Externe veiligheid

3.6 Available software packages

This paragraph describes some software packages to perform noise prediction calculations using the calculation models described above.

Soundplan
The Soundplan software package by the German Braunstein + Berndt GmbH company offers calculation modules for road, rail, aircraft and industry noise, as well as for air quality calculations. The road noise module offers calculations according to various national models, including RVS 3.02, NMPB, RLS-90, Nord 2000 and CRTN.

Bruel & Kjaer Predictor 7810
This Bruel & Kjaer software package is developed by DGMR Consulting engineers and allows various calculation methods for road, rail and industry. Predictor supports the management and organisation of multiple studies within a single Predictor project. The software is traded by DGMR in the Netherlands under the name Geonoise. The model can read standard topographic maps and import various standard measurement formats. Calculation methods include various types of buildings, facades and screens. For road noise, the Dutch RMV-SRM2 calculation scheme, the French method NMPB and the UK methods CRTN LA10 and CRTN LAEQ values can be calculated. Projects have ranged from an area of 1km2 covering a few hundred people through to investigating more than 1000 km2 and in excess of one million people. DGMR is a member of the Bruel & Kjaer Prediction Partnership.

Bruel & Kjaer LIMA 7812
The LIMA software is developed by Stapelfeldt Ingenieurgesellschaft mbH and is also traded by Bruel & Kjaer. LIMA reduces pre-processing time through its capability for importing a wide range of data types, and automatic checking and correction features such as 'polygon closing'. Efficient model processing is supported by the optional use of commands and macros in the GUI.
By using multiple processors or networks, it achieves market-leading speed in the production of detailed maps according to UK and international standards such as ISO 9613-2, NMPB, SRM2 and other German, Austrian and English standards.
LIMA can handle several hundreds of thousands of objects - terrain, buildings and emitters - in the calculation of each tile in a model. Each tile may consist of 32 000 x 32 000 grid points. Tiling of even the largest models is automatic. LIMA also copes readily with complex environments such as embankments with barriers, bridges, cantilever roofs, and reflections underneath bridges and roofs. Noise maps for cities such as Birmingham in the UK, Bonn, Stuttgart, Hamburg in Germany and Linz in Austria have been created. On a larger scale regions like Thüringen (18 000km2), Sachsen (20000 km2) and Hong Kong have been noise mapped. Stapelfeldt Ingenieursgesellschaft mbH is a member of the Bruel & Kjaer Prediction Partnership.

Cadna A
Cadna stands for Computer-Aided Noise Abatement. The software was developed by Scantek, a USA based subsidiary of Norwegian Electronic. The Cadna A software is intended for noise mapping of industrial facilities, roads, railways, airports, stationary sources, and HVAC equipment.

IMMI

The IMMI software is traded by Wölfel Measurement Technique in Germany. More than 20 different European and International calculation methods are available for IMMI. The software calculates the propagation of noise outdoors taking into account all physical influences on the propagation pathway. Results can be shown either graphically in form of noise maps or numerically in detailed results lists.

An air-dispersion module makes it possible to produce combined maps for noise and air quality. The combination of noise and air pollution modeling with IMMI is already practiced in Brussels, Belgium. IMMI interfaces with existing GIS data by means of an ArcView-Interface.

MITHRA

MITHRA is a prediction software package dedicated to sound propagation modeling. It considers the most important variables for a given site such as building layout, topography, noise barriers, ground type, meteorological effects, etc. By selecting the appropriate modules, MITHRA is directly configured for road traffic, railway aircraft and industrial noise prediction, as well as aircraft noise. The topography can be easily defined with a digitizing tablet, by importing DXF or GIS files, or even by on-screen digitizing over raster files using an optional dedicated module. MITHRA software is licensed by CSTB.

4 Mapping output data and their treatment

4.1 Equal noise level contour lines assessment methods

The simplest example of a noise map is the representation of a single receiver point on a map with an indication of the assessed noise level at that particular point. As the noise level is highly dependent on the local circumstances with respect to receiver height above ground, screening and reflection effects of adjacent building blocks and other possible effects, the value of such a representation is very limited; it can not be applied to gain a general impression of the noise situation or the number of annoyed residents, it can only be applied for instance to assess whether or not there is compliance with a limit value in that particular receiver point.

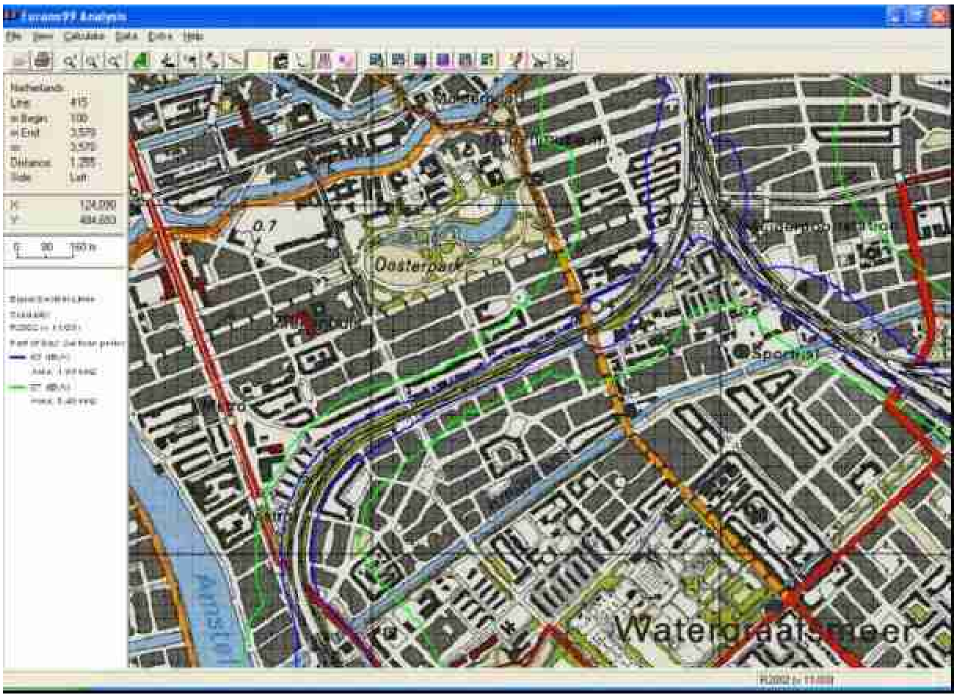


Figure 11: Noise level contour lines

A more common representation includes the assessment of iso noise level contour lines, which allows to attribute building blocks or individual dwellings to classes of noise levels. The contour lines are usually assessed as interpolations between plotted points on a grid. There is a contradiction between the grid density required for an accurate assessment of the interpolated lines on the one hand and the computation effort on the other. Different grid sizes and grid point distributions can be applied to minimize calculation time: for point sources a circular grid is to be preferred, where the step size can be increased with increasing distance to the source. For line sources like roads and railway lines, a square grid can be used, where the grid width can be increased with increasing distance to the road/railway.

In the case of clear distinction between rural and built up areas, the grid size may be adapted to the situation, with low grid point density in rural areas and high grid point density in built up areas.

All this is rather a matter of the software builder than the modeling engineer, although some software packages may allow the modeling engineer to build a custom made grid.

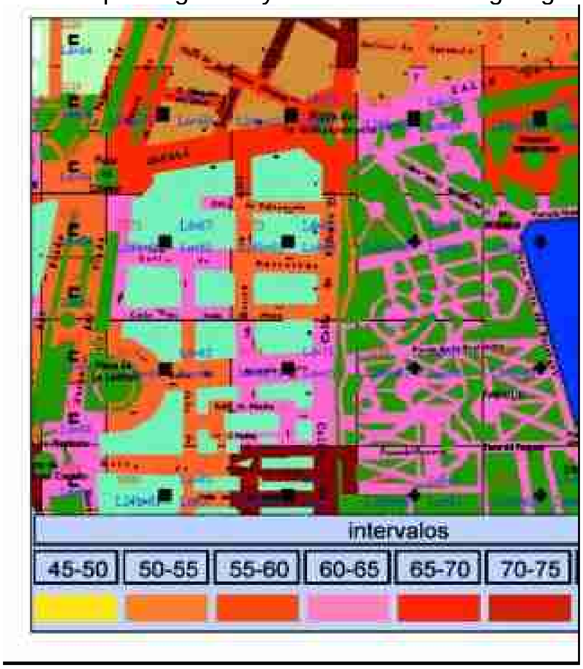


Figure 12: example of Grid Noise Mapping in Spain.

As a general rule of thumb, a grid point distance of approximately 1 dB should be achieved to have optimal accuracy. However, when strong diffraction effects are involved, there may be effects where the noise level with increasing distance does not show a continuously decreasing function, and as a consequence grid point interpolation may be difficult to interpret, particularly when automated in the software.
This is the case particularly in built up areas, where often an accuracy is suggested that really can not be achieved. Results of contour line plots in built up areas should be interpreted with great care.

Noise contour maps show different step size in their presentation as well. Some types of colored maps with shading in the colors suggest, that a 1 dB increment is assessed and presented, whereas other maps rather show 5 dB increment. As the latter presentation is closer to the achievable precision of the maps, the difference is rather artificial, because even the 5 dB increment maps are sometimes used to assess compliance with limit values, using a 1 dB or less compliance criterion.

In practice, it has become a habit in some countries to present contour lines as “polder-contours”, i.e. ignoring the screening effect of buildings. Although this is a more fair presentation with respect to the achievable accuracy and credibility of the maps, the practical use of these maps, e.g. for annoyance assessment, is very limited. A compromise between the polder-contours and the built up contours is represented by the contour lines that take into account a fixed amount of inner-urban screening. In this case only the first façade row is computed as free field incident sound, whereas for every other grid point in a built up area, a fixed inner urban screening factor is subtracted. The inner urban screening factor may even be made dependent upon the building type, e.g. high rise buildings or low buildings.

Noise contour lines show some distinct disadvantages in daily use. First of all, when applied to decide whether or not façade insulation should be provided for, the strict use of a contour line may lead to a situation where half the dwellings in an apartment building are liable to receive

insulation, whereas the other half is not. When the distinction is based on a calculated level difference of only a few tenths of a dB, the difference in treatment may be hard to explain to residents! In such cases one had better made the assessment on the basis of separately calculated levels for separate dwellings.
The same applies to different receiver heights which are difficult to present in contour maps, but may be easier to present in single receiver point maps.

4.2 Façade reflection

In the “best practice guide” produced by the WG-AEN [1], it was already highlighted that in some countries the noise level to be assessed for annoyance purposes is the incident sound level, i.e. ignoring the reflected sound against the façade of the building. The principle is shown in the following picture.

As most of the dose-response relationships from field surveys are based on incident sound (65 dB in the picture) instead of real sound level (68 dB in the picture, including the contribution of the sound reflected against the façade) it is the incident sound that needs to be assessed and that should be presented in the map. The façade should therefore be ignored as a reflecting plane for receiver points that are directly attributed to that façade, but should be taken into account for receiver points that are attributed to another façade or that are located in the free field.
In the software, this can be solved by attributing receiver points to façades (something that the modeling engineer has to be responsible for). But in terms of continuity of contour lines, this may represent a difficulty, as the 3 dB façade correction is quite substantial compared to the increment size between the contour lines.

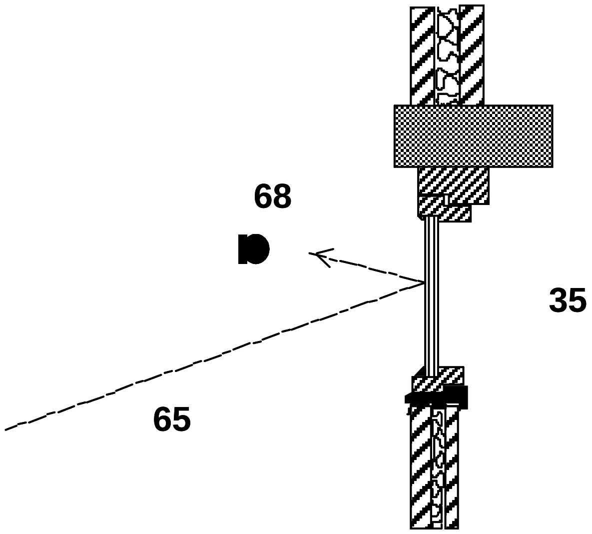


Figure 13: The incident sound level at the façade is 3 dB lower than the real sound level.

4.3 Dose response relationships

One important parameter to present by means of a noise map is the expected number of annoyed people. General annoyance (incl. speech and communication interference) is best assessed on the basis of L_{den}, whereas sleep disturbance can be predicted on the basis of L_{night}. Usually three classes of annoyance are distinguished, viz. moderately annoyed, annoyed and severely annoyed. For each of the three classes dose response relationships exist for different sources of noise, viz. road traffic noise, aircraft noise, railway noise and industrial noise.

The most comprehensive assessment of dose response relationships on the basis of L_{den} was made by Miedema [9], [10], who collected and analyzed the results of many different field surveys.

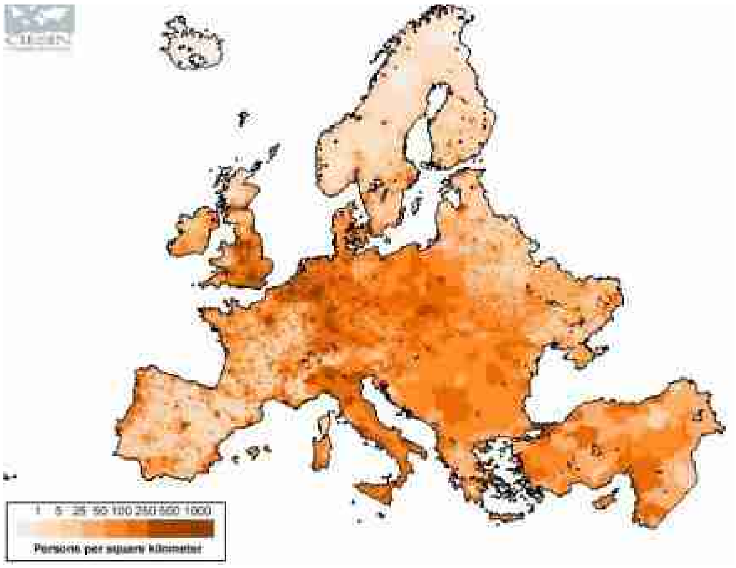
It is important to note, that specific characteristics of the noise one is exposed to, such as an impulsive or tonal character, may lead to higher annoyance scores. These characteristics are not included in the L_{den} indicator, so for sources with such characteristics, like shooting ranges, racing courts, fans with tonal character etc. the number of annoyed people may be underestimated.

Another important element is the fact that the outcome of the assessment in terms of numbers of annoyed persons is a prediction, based on generally accepted dose response relationships. The result is not an assessment of the true number of annoyed people in the area under concern, as it would come out of e.g. a field survey. This true number may differ significantly from the assessed expected number, first of all because of the limited accuracy of the dose response relationships, but also because the real annoyance experienced depends on many other factors than just the noise level.

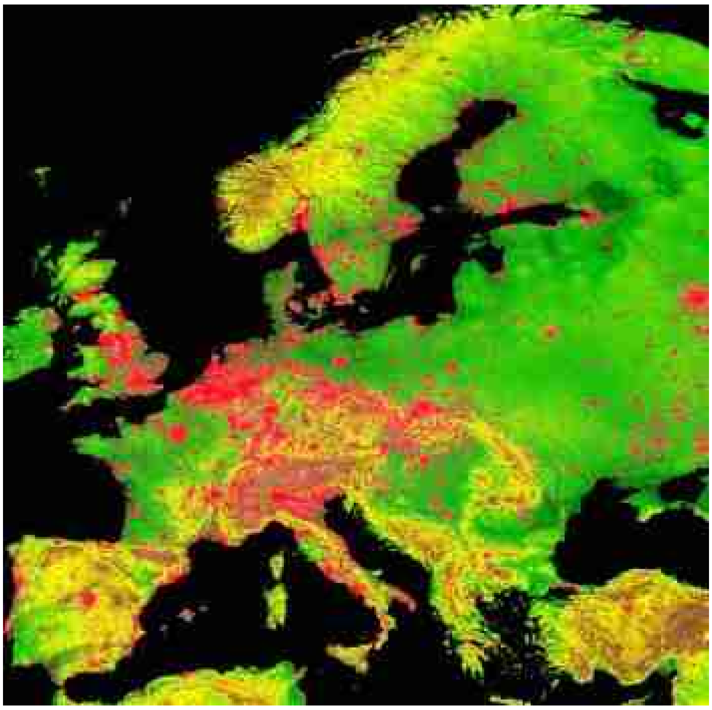
The assessment is carried out by assessing the number of people living in a certain area between two contour lines (this assessment can be made with the tools that are available in a GIS system), using the population density (see next paragraph) as the main parameter. A simple multiplication of the number of residents living in a certain area with the percentage of people expected to be annoyed from the dose response relationship results in the expected number of people moderately annoyed, annoyed or severely annoyed.

Obviously there are different dose response relationships for different noise sources, and it has been stressed by different researchers that the presentation of similar noise maps on the basis of a color code linked to the L_{den} value for different noise sources, may lead to misinterpretation of the results. One way out of this is to present the noise exposure in terms of equal annoyance colors. This has not been practiced so far in the different member states, but this might be a recommendation for the EU mapping operation.

4.4 Population density maps



Population density maps are presently available from almost every country in the world with acceptable accuracy and density. As different maps may lead to different results it is recommendable to agree on a limited number of standards for noise mapping purposes.



The two pictures shown here represent population density maps for Europe, the upper one based on national count figures, the lower map represents stable night lights which are considered representative for the overall density.

Population density may differ from one area to another, even inside cities. It is a matter of what objectives the noise maps serve whether or not such differences are relevant to include.

5 Measurement and monitoring

Introduction

On European level Lden was introduced in the directive 2002/49/EC. Similar indicators have previously been used in some countries, e.g. in Sweden for aircraft noise and in France for road traffic noise. Most countries have worked with Leq during 24h or day and night. Some countries, e.g. UK with L10, have used other metrics. Many countries have had the policy to prefer computational predictions to measurements. Summing this up means that there is comparatively little experience of measurements in full conformance with the directive and the details of the source models of Harmonoise. On the other hand there is much experience of different elements of a possible measurement procedure.

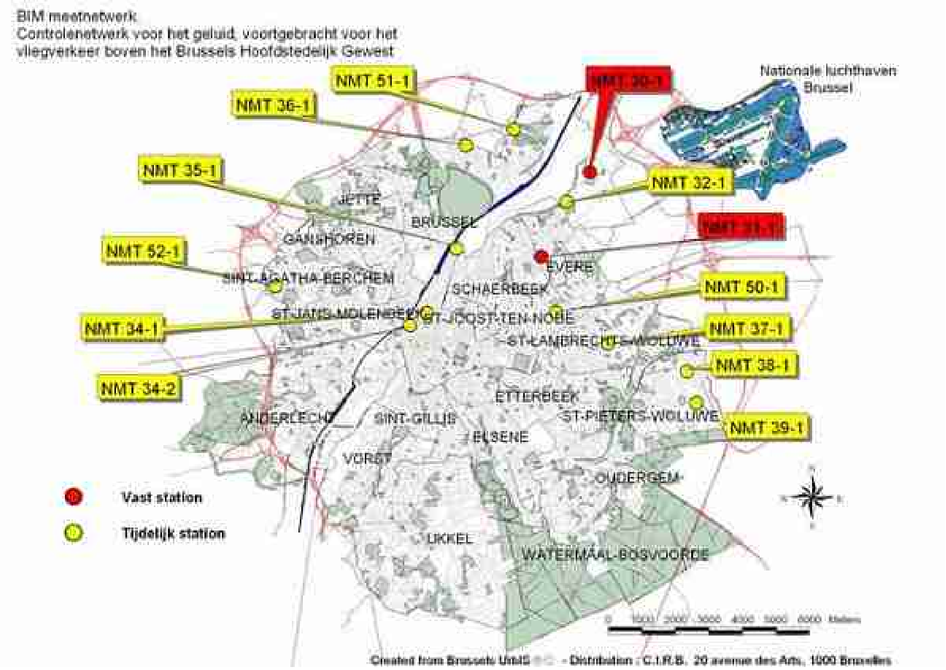


Figure 14: BIM measurement network in Brussels for aircraft noise. From: http://www.ibgebim.be/SousSites/Carto_Stations_bruit/stations_NL_2004.htm

This chapter focuses on the different measurement methods used in the countries of the WP 3 partners. For each country the road traffic methods have been used as reference, which means that only deviations from this method have been described for rail and air traffic and for industrial noise.

5.1 General methods

ISO 1996-2

This standard, [65], is still at the DIS stage and can be considered as a kind of international consensus document. It is a general standard dealing with all kinds of sources and all kinds of metrics. It focuses on short term measurements and does not really deal with L_{den} measurements although they are mentioned. The contents of the standard is summarized in Table 14 below.

Equipment	Class 1 or 2 instruments
Metrics	L_{eq}, L_{max}, L_E, L_N (percentile levels).For rail and aircraft noise L_E is used to calculate L_{eq}.
Frequencies	Weighted and in frequency bands
Type of measurements	Short term measurements are dealt with in detail Long term measurements are only outlined Combinations of measurements and calculations are included. Reference is made to national prediction methods.
Microphone positions above ground	Industrial, road traffic, rail traffic: 1,5 m and 4,0 m Aircraft noise: 6 m
Microphone positions relative vertical surfaces	Flush mounted (+6 dB) 0,5 – 2,0 m in front of façade (+3 dB) Free field (reference) Guidelines are given on how and when to apply the different mounting procedures
Indoor measurements	3 microphone positions in the room
Measurement distance	Any
Meteo conditions	Any, but preference on favourable propagation
Operating conditions	Minimum requirements are given for short term measurements: Road traffic: At least 30/vehicle category Rail traffic: At least 10/vehicle category Aircraft:At least 5/category
Corrections	Includes informative methods to determine presence of tones
Measurement uncertainty	Evaluated based on repeatability (operating conditions), equipment, meteo conditions and background noise

Table 14: Summary of ISO 1996-2 (2003 DIS version)

Other sources

VDI 3723 describes the application of statistical methods for the description of varying ambient noise levels. This standard can be used to determine confidence intervals of measured values.

5.2 Source specific methods

5.2.1 Road traffic noise

UK

In terms of assessing noise levels for the *Noise Insulation Regulations* (SI NIR, 1975 - 1988) [11], arising from a new road development, or from substantial alteration to an existing road scheme, to ensure consistency and repeatability, calculation of levels is preferred over direct measurement. The measurement procedure is contained within *“Calculation of Road Traffic Noise (CRTN)”* (DoT, 1988) [27]. However measurements may be taken under certain, specific circumstances i.e. for cases where traffic ranges fall outside of the validity of the calculation method, for cases where site characteristics are too complex to make the use of standardized data unfeasible, or where direct measurements would prove the most economic form of assessment. See Annex 1, page 89, Table 17 and Table 18.

The Nordic countries

The metric used in the Nordic countries is $L_{Aeq,24h}$, which, in some countries, is supplemented by L_{AFmax}. The measurement methods used are the Nordtest methods [85][86], which are similar to ISO/DIS 1996-2:2003 [65]. The preferred method is to calculate rather than measure, because it is considered to be too expensive to carry out reliable measurements. The reference condition is a free field above ground but since about 30 years the most common measurement position is a flush mounted microphone and the free field level is then obtained by subtracting 6 dB. See Table 19 in Annex 1.

France

The French standard NF S 31-085 [66] is summarized Table 20 in Annex 1. It includes two features, which makes it a bit different from other standards. One is that it includes special objective procedures to evaluate whether the traffic flow during the measurement time interval is representative and the other is that it gives specific guidelines on how to describe the meteo conditions during the measurement.

The objective procedures used to evaluate the representativity include measurements of L_{10} and L_{50} and maximum differences between consecutive samples using time-weighting F or S. The meteo conditions are to be divided into unfavorable, homogeneous and favorable and the propagations conditions are divided between these. However, no corrections are made. It is only checked if the meteo distribution during the measurement time is about the same as distribution during the reference time, e.g. one year.

Italy

The Italian Government has issued, since 1995, a framework law addressed to the environmental noise pollution. It is a very comprehensive regulation, which tries to take into account many of the real-life situations, also considering differences that could arise in treating different kinds of sources. This is the case of transportation infrastructures (roads, railways, airports and harbors). The Italian law allows assessments with respect to noise only by means of measurements, with the exception of airport noise, so that great attention is given to measurement methods and instrumentation specifications. The technical directives of the law are summarized in Table 21 in Annex 1.

Poland

The noise levels are either calculated or measured. See Table 22 in Annex 1

Germany

There is no measurement procedure. The legal limit refers only to the calculated value. The German government has issued a directive dealing with road and rail traffic which is a by law to the German environmental Act (16. BImSchV Verkehrslärmschutzverordnung) (Traffic noise protection regulation). This regulation contains limiting values for the daytime and the night-time (22 h to 6 h). The input data for road traffic are:

- number of vehicles per day
- legal speed limit (not the actual speed)
- road surface
- percentage of heavy lorries (day and night)
- type of road (city, connecting road between cities, federal road, federal highway)
- barriers.

Using these data the level at 25 m distance is calculated. From there the down wind level is calculated.

A heuristic propagation model is used which leads to energy equivalent levels close to those obtained using ISO 9613-1 and -2.

Spain
In Spain both the central and the autonomic governments are involved. Both Leq, L10, L90 and Lmax are used. There are no real measurement standards, only some minor guidance in regulations. The limit on maximum wind speed is about 3 m/s. In general low microphone heights are used. Corrections for tones and impulses are used.

Greece
The environmental implications from all road/highway projects are examined prior to the construction, in conformity to European regulations and procedures (Directives 84/360/EEC and 85/337/EEC) which use a project classification according to the possible effects. Likewise, the important roads that can have major impact are examined accordingly via an environmental impact assessment study (EIA) which examines the road scheme for the implications in the acoustical environment. In order to do that a road traffic noise prediction methodology is used.

According to the Ministerial Decision 17252/1992 (Official Gazette 395/B/19 June 1992) the index that is used is the L10 (18hr) in dB(A) according to the UK Regulations CRTN (Calculation of Road Traffic Noise). The limit-value over which is compulsory to start taking measures is 70 dB(A). This is calculated at a distance of 2,0 m. from the front of the nearest set of buildings. In the case of special uses next to highways like schools, hospitals, etc. that are sensitive to noise, the above limits can be up to 10 dB less.
The expected road traffic noise values are calculated for various highway development scenarios and compared with actual noise measurement values, especially for the urban areas of the project. Real time noise measurements are executed in the areas where the project is going to pass through (one measurement for every 500 m) and for a number of noise indices Lmax, L1, L10, Leq, L95, etc.

If the actual or potential building-receiver is at a distance of over 300 m. from the edge of the road then no anti-noise measures are necessary. In the Greek legislation there is also provision for the use of the French traffic noise prediction methodology (Guide de Bruit) Leq dB(A) for the time period from 08:00 to 20:00.
If the estimated dB(A) value exceeds the one previously mentioned then it is necessary to plan necessary actions to tackle the problem i.e. road realignment etc. If this is not feasible then the EIA must include a preliminary study for noise protection measures (such as noise barriers etc.).
The phase of the road construction noise is examined according to the BS 5228 /1984 of the UK Regulations according to a detailed plan of the necessary work-site relevant machinery needed for the project.

‘For major new highways (such as Attiki Odos in Athens) a 24-hour noise measurement system was developed and put in operation. The 24-hour road traffic noise system measures the following indices in each point : Lmax, L1, L10, L50, L90, L95, Leq dB(A) and calculates Lden and Lnight. The measurements are carried out by all weather precision noise analyzers (sound level analyzers type I) at fixed positions and away from reflecting surfaces. They work together with weather stations and atmospheric pollution monitors. Traffic data are also monitored through toll system. Mobile units also measure (the same indices like previously stated) at a height of 4 m. There is another 24-hour road traffic noise measurement system in Thessaloniki.

5.2.2 Rail traffic noise

UK

For rail traffic, the measurement procedure closely follows that for road traffic, and is contained within *"Calculation of Railway Noise (CRN)"* (1995). Again, as with road traffic, computation is the preferred method of determining noise levels.

Unlike road traffic, the assessment parameters for the Railway Noise Insulation Regulations (SI RNIR, 1995 - 1996) [12] are the $L_{\mathrm{Aeq,\ 18\text{-}hour}}$ covering a period of 06:00 – 24:00) and the $\mathrm{L}_{\mathrm{Aeq,\ 6\text{-}hour}}$ covering a period of 00:00 – 06:00). The basic procedure to calculate $\mathrm{L}_{\mathrm{Aeq}}$ values involves correcting sound exposure levels (SELs) based on the vehicles comprising individual train types, for track and traffic conditions. See Annex 2, Table 23.

The Nordic countries

The metric used in the Nordic countries is $L_{\mathrm{Aeq,24h}}$, which, in some countries, is supplemented by L_{AFmax}.

As for road traffic the preferred method is to calculate rather than measure. The measurement methods used is the Nordtest methods [89], which is very similar to ISO/DIS 1996-2:2003 and the method for road traffic noise. L_{eq} is normally calculated from L_{E} measurements.

At least 3 trains of each category contributing to the overall noise level with a total length of at least 500 m shall be measured.

France

NF S 31-088 is similar to the road traffic method.

Italy

In principle like road traffic noise but with the following corrections:

The evaluation is based on SEL measurements of each train pass-by; events are considered valid only if the maximum level exceeds the background noise by more than 10 dB.

For railway noise, if the above condition is not satisfied at the receiver, the operator should adopt an alternative method. He should measure the noise level at a new point (reference point), where the condition is respected, and simultaneously at the receptor, in order to build a correction factor to apply to the measurement.

The minimum measurement interval is 1 day; the microphone is to be located 4 m above the ground and 1 m in front of the most exposed façade.

Germany

As for road traffic but with the following input:

- number of trains of a certain type
- trains with disc brakes
- trains with block brakes
- speed
- type of track
- barriers.

5.2.3 Aircraft noise

ISO

There is an old standard, ISO 3891, which has been under revision for many years. There has been many problems with conveners and the scope of the future standard is not quite settled. The number has changed and now there exists a lay-out for a 5th ISO/CD 20906, [35].
The 1978 version of the standard uses a microphone height of 1,2 m in an idealized unobstructed hemi-sphere above totally reflecting ground. The wind speed shall not exceed 5 m/s at 10 m. The metric is the effective perceived noise level, L_{EPN}, but there is also procedures to determine L_{eq}. The atmospheric conditions shall be such that the atmospheric attenuation in the 1/3 octave band centred at 8000 Hz shall not exceed 10 dB/100 m. It seems that the UK procedure in 3.3.2 is identical to or at least very similar to ISO 3891.
ISO 20906 is dedicated to automatic monitoring and it includes a simple threshold system of sound event recognitition suitable for air fields with low traffic. There is an annex giving some hints on how to apply GUM to determine the uncertainty of the results. Background noise is determined by the 95% exceedance level. See Annex 3, Table 24: Summary of ISO/CD.5 20906

UK

There are 2 measuring methodologies described in this standard:
Spectral analysis as a function of time (used where a high reproducibility of the normalised results is required)
Frequency weighting (used where basic measurements are required for simplicity or low cost)
These are used to measure the 2 main operating states of aircraft, those in flight and those on the ground. See Annex 3, Table 25 and Table 26.

The Nordic countries

In Sweden the metric used is FBN, which in principle is equivalent with L_{den}. In principle it is also used in the other countries but in Sweden and Norway it is supplemented by maximum levels (normally with time-weighting S).
The preferred microphone position is 10 m above ground. The meteo conditions shall comply with those of ISO 3891. When the angle of elevation is less than 45º it has to be downwind conditions. See Annex 3, Table 27 .

Italy

For airport noise a special indicator is used (L_{va}), that takes into account the night period, penalizing it by 10 dB(A).
The noise indicator is built on SEL measurement of each vehicle transit; events are considered valid only if the maximum level exceeds the background noise by more than 10 dB.
airport - 3 periods of 1 week during the year.
3m above the reflecting floor and far away from vertical reflecting surfaces.

Greece

Presidential Decree 1178 (Official Gazette 291/A/5 October 1981) deals with the measurement and the control of aircraft noise by means of land use planning. The Law classifies 14 different land use areas and examines the approval of planning permissions for future development for 3 noise exposure contours. The classification is according to the US Noise Exposure Forecast (NEF) curves in EPNL. The 3 contours are : areas with aircraft noise greater than 40 NEF, areas with aircraft noise between 30-40 NEF and areas with aircraft noise less than 30 NEF.

NEF curves exist for all major Greek airports and it is the duty of the Environmental Division of the Civil Aviation Authority (CAA) to update the curves and provide information to potential developers etc. As in the case with the other transportation infrastructure projects, for new developments, there is always a EIA study which identifies potential aircraft noise problems using the INM 5.0 US aircraft noise prediction model for a list of possible future air traffic scenarios.

The implications of the future operation are compared with existing situations. For the existing acoustical environment a set of real time measurements is foreseen for a number of noise indices such as L_{max}, L_1, L_{10}, L_{eq}, L_{95}, etc.

For Athens International Airport (Elefterios Venizelos) a 24-hour aircraft noise monitoring system measures the following indices : L_{max}, L_{eq} dB(A) and calculates L_{den} and L_{night}. The measurements are carried out by all weather precision noise analyzers (sound level analyzers class I) at fixed positions plus a mobile unit. They work together with weather stations and atmospheric pollution monitors. Air traffic data are also monitored through radar system.

5.2.4 Industrial noise

UK

In the UK industrial and construction noise falls under the same regulations and consequently has the same measuring methodology. The regulatory controls governing industrial and construction site noise fall under the Control of Pollution Act 1974, sections 60-61, and the Environmental Protection Act 1990. COPA allows a local authority to designate a noise abatement area. Any Industrial sites within this area are required to register their noise level and then not exceed this level. Under the EPA it is suggested that noise from sites should be kept below 10dB above background levels. At all sites other than landfills operators should draw up noise action plans where the noise levels exceed 5 dB above the background. Enforcement action would be considered where noise levels exceed 10 dB above the background.

There are no standard noise limits for construction noise, and these tend to vary between local authorities. See Annex 4.

The Nordic countries

The principles are the same as for road traffic noise. All measurements take place under favorable propagation conditions. Corrections for rating levels are made for tones and impulses. There are objective methods for tones (see ISO 1996-2) and impulse sound (coming Nordtest method, [75]). Measurements are often combined with calculations. A method to determine emission of industrial sources is given in [88].

Italy

For non-transportation sources a “differential criteria” is also adopted; each source individually should not increase background noise by more than 3 dB during night-time or 5 dB during day-time.

The microphone is located at least 1 m from any reflecting surface at an height depending on receiver position. For generic noise sources, you are free to choose the measurement duration and sampling;

Germany

The first regulation on noise measurement is based on a VDI standard of 1960. Basically, this standard became a By Law in 1968 named “Technical instruction for noise protection”. This regulation, which had many flaws was revised in 1998 (see ref. [20]). It incorporates the same limiting values as defined in 1960 as well as the old measurement procedure to evaluate impulsive noise, the so called “5 s Taktmaximalpegelverfahren” which means translated the “5 s interval measurement procedure”.

For residential areas it defines a 35 dB limit for the noisiest hour of the night and a 50 dB limit for daytime. The limiting values go up by 5 dB from residential areas to general residential areas mixed areas and commercial (50/65 dB) and industrial zones (70 dB day and night).
The limiting values are to be compared with the “maßgeblichen Wert des Beurteilungspegels”, which may be translated by “reference value of the rating level”.

The following chapter will describe how these values are obtained. Basically, one has to distinguish between the case of a prognosis, when a new plant is under licensing and the case after the plant has been built and operates within the production limit specified in the license.

Basic definition

The limiting values mentioned in the introduction are related to the total noise load resulting from industrial and commercial enterprises. In the case of an application for a new plant, the additional load (Zusatzbelastung) resulting from this is needed.

If the present load (Vorbelastung) plus the additional load are less than the limiting value, a license has to be granted. However, if the present load is above the limit a license can be given if the additional load is less than -6 dB from the limit. In cases, where extraneous noise is more than 95% of the time above the limit, a license can be granted as long as the total load is not higher than this value.

For commercial and mixed areas the limit refers during daytime to a 16 h long term L_{eq}, whereas at night-time the most noisiest hour has to be considered. For residential areas the time between 6 and 7 a.m. and 8 to 10 p.m. additional 6 dB are given and for holidays and Sundays for the time between 6 and 9 a.m., 1 and 3 p.m. and 8 to 10 p.m.

Prognosis

The prognosis has to establish the additional load of a plant under the most unfavorable emission conditions. This is done based on sound power levels obtained from experience, published data or as in most cases guaranteed by the manufacturer of the plant. These data are used as a basis to model the plant and calculate the hourly long term Leq using ISO 9613 parts 1 and 2. For daytime Cmet is accepted from 1,8 dB up to 5 dB for night-time, usually nothing beyond 1,8 dB.

The reference point for the calculation is a point 0,5 m in front of an open window in the neighborhood which is expected to obtain the highest load with respect to the limiting value under consideration. The room should be used for permanent habitation.
A special clause in the appendix makes it mandatory that the prognosis is given together with an estimation of the uncertainties.
However, up till now, the size of the uncertainties is not taken into account, basically it is sufficient

to fulfill the limit with the value of the best estimation. However, increasingly the uncertainties are added to this value. Due to the fact that Germany has a federal constitution, this is handled differently in different parts of the country.

Measurement
There are two types of measurements. The first type deals with the question whether or not the total noise load is above the limit and the other whether or not the additional noise load is in agreement with the value mentioned in the license.

Total noise load
The total noise load is evaluated on the basis of the long term L_{eq} with additions for tonal information content and impulsiveness. This type of measurement is performed at the site under interest.
If the difference between the lowest and highest value measured during different day is around 1 dB one measurement is sufficient, if differences of 3 dB are observed, three repetitive measurements are necessary (DIN 45645 and VDI 3723-1). If the differences to the expected value are more than 3 dB a maximum of 5 measurements is required. Using the measurements the reference value to be compared with the noise limit is L_{eq} over all measurements. This value is compared with the limiting value after 3 dB have been subtracted. If the resulting value is above the limit, it is assumed that the total noise load is above the limiting value. If no transgression is observed, it is assumed that the situation does not significantly derive from a situation described by the limiting value.

Additional noise load
In this case mostly the sound power level is measured using ref. [23,24] and similar standards. Again the reception noise level of this additional noise load is calculated using ISO 9613.
It is also accepted if the noise load is not established from sound power level measurements but from measurements performed at a range where the additional noise load dominates the total noise load. Using this, the reception noise level may be calculated from those measurements using ISO 9613. As for the case of prognosis and the total noise load, an estimation of the quality of the results must be given. How to do this is described in VDI 3723. However, other documents may be used such as classical statistics or ISO Guideline on the expression of uncertainties in measurements.

Greece
Presidential Decree 1180 (Official Gazette 293/A/6 October 1981) defines the maximum permissible noise limits from permanent mechanical installations and all kind of machinery and industrial noise.
This Law applies for the whole 24hr period of time and covers all urban areas as well. The max permissible noise emission is measured on the border-line between the source of noise and the potential receiver’s property.
Four different land-use type of areas are designated with the following respective L_{max} noise limits:

1. legislated industrial areas : 70 dB(A)
2. areas where industrial use dominates : 65 dB(A)
3. areas where industrial uses co-exists equally with urban uses : 55 dB(A)
4. urban areas : 50 dB(A)

If there is structural connection between the noise source area and a house then a limit of L_{max} 45 dB(A) is taken regardless of the land use category.
If there are complaints for noise, special units from relevant bodies (such as prefecture or ministry etc) take measurements to check the above limits.
However, this legislation is in a process of modification with introduction of more severe noise limits during night period.

5.3 Summary

The different methods studied are summarized in Table 15: summary of the findings.

	ISO	UK	Nordic	F	I	PL	DE	ES	GR
Measurements preferred for road and					X				X
rail		X	X	X			X		X
Calculations preferred for road and rail	X		X	X		X			
Measurements and calculations mixed									
Equipment Class 1	X	X	X	X	X		X		
Class 2	X						X		
Calibration every year		X							
every 2 years	X		X	X	X		X		
L_{eq} (L_{day}, L_{night}, L_{eve})	X	X	X	X	X	X	X	X	X
L_{max}	X		X					X	
L_E	X		X						
L_N	X								
$L_{A10,\ xx\text{-}hour}$		X						X	X
EPNL	X	X							X
Frequency weighting	X		X	X	X	X			
Frequency bands	X		X		X				
Max wind speed (m/s)		10	5	3-7				3	
Short term measurements	X		X		X				
Long term measurements	(X)		X	X	X				
Microphone positions above ground									
1,2 m		X				X		X	
1,5 m	X		X						
2 m			X	X			X		
4 m	X				X		X		
6 m (aircraft)	X								
10 m (aircraft			X						
Microphone positions rel. vertical surfaces									
Free field	X	X	X						
Flush mounted	X		X						
0,5 – 2 m	X	X	X	X	X	X	X		X
Microphone positions relative carriageway edge		x							
Indoor measurements	X		X	X	X				

	ISO	UK	Nordic	F	I	PL	DE	ES	GR
Measurement distance									
Any	X		X	X	X	X	X		
Others		4-15 m							
Meteo conditions (any)	X			X		X	X		
favourable	X			X	X		X		
Operating conditions									
Minimum time		X			X				
Road vehicles per measurement interval	30/cat		30/cat	200-500		450			
Rail	10		10						
Aircraft	5		5						
Corrections Tones			X		X		X	X	
Impulses			X		X		X	X	
Low frequency					X				
Measurement uncertainty evaluated	X		X		X		X		
not evaluated				X					

Table 15: summary of the findings

5.4 Conclusions and discussion

There is no measurement method available anywhere to determine L_{den}. The method covering most aspects is ISO/DIS 1996-2, which gives the best guidance to evaluate the measurement uncertainty for short term measurements. However, it does not specifically deal with long term measurements like L_{den}. All methods also share the deficiency that they do not have the same source model as Harmonoise. This means that they do not take into account all relevant parameters needed to monitor the operating conditions of road and rail vehicles when carrying out short term measurements.

A French standard describes how to translate the actual meteo conditions into propagation classes. This is a good starting point. However, no guidance is given how to correct the results if the distribution of propagation classes deviates from the statistical distribution of the reference time interval, which, for L_{den}, is a typical year. This standard also contains some interesting details for qualifying road traffic noise measurements to be representative. May be the technique used could be applied to automatic monitoring systems.

Many different measurement positions relative reflecting surfaces are used. However, in this respect, ISO 1996-2 should give a satisfactory coverage, may be with some clarifications to take into account special situations like those in Italy where the road often extends to the façade of the nearest house.

All methods investigated share the weakness that the measurement uncertainty has not been properly taken into account. The most ambitious attempts have been made by Nordtest and ISO but more efforts are needed to fully comply with the GUM ([34]).

ISO/CD.5 20906, which deals with the monitoring of aircraft noise, is the only method we have come into contact with dealing with long term monitoring yielding methods to discriminate unwanted noise using statistical methods or pattern recognition. That method will be a good starting point for aircraft noise. VDI 3723 could, however, possibly also be of some use in this context. For road traffic noise, as mentioned above, the French standard NF S 31-085 could also be of interest for automatic monitoring systems.

6 Action plans

The previous chapters describe ways of collecting noise data, intended for mapping, including measuring and monitoring. The final purpose of the collection of all these data is to estimate the exposed populations, the degree of annoyance, and to serve as an input for noise policy for local and national authorities. If reduction of the annoyance is desired, the authorities may decide to carry out noise action plans. The total noise emission can be reduced by reducing the noise emission per source, i.e. source reduction (paragraph 6.1), or by reducing the number of sources, here called volume reduction (paragraph 6.2). Action plans in different countries are discussed in this chapter.

For traffic, both infrastructure and vehicle conditions are revised. Some general points are:

- Combining noise sources as to reduce the total area of annoyance (all sources)
- Intelligent planning of noisy events over time periods and over sites for both industry and freight traffic
- Intelligent infrastructure as to optimize the circulation efficiency
- Quality of the infrastructure
- Promotion of least noise producing actions/vehicles/engines/roads

Apart from the source emission, the immission at the receiver position can be reduced by measures at the receiver (paragraph 6.3).
In the final paragraph the measures are judged on their quality and applicability. A general insight in the possibilities is given.

6.1 Source reduction

Several source reduction techniques can be distinguished. First the noise production of existing (noisy) sources can be lessened by damping or shielding the source. Putting the source underground, tunneling and tunnel isolation, wheel and rail dampers, insulation of the source by boxes and small barriers close to the source are examples of damping or shielding.
In some cases maintenance is the way to avoid noisiness. Examples of maintainable sources are moving parts in motors (industry, aircraft, traffic), bogies, road surfaces, rail and wheel surfaces (grinding regimes).
Further, replacement of existing noisy sources by less noisy ones helps to reduce noise production. New silent techniques, like silent vehicles/aircraft, silent motors, road types, track types are developed. For trains and aircraft this is a slow process because of the long lifespan of the vehicles.

6.1.1 Source reduction - Road traffic

This paragraph lists some examples of action plans implemented in various European countries, or currently under development, regarding the reduction of the source emission of road vehicles. Generally, source reduction for road vehicles may be divided into three categories:

- reduction of tyre/road noise by low noise road surface types;
- reduction of tyre/road noise by low noise vehicle tyres;
- reduction of vehicle drive line (propulsion) noise.

In this paragraph, some examples of action plans will be given for each of these categories, as well as examples of general action plans for road noise source reduction.

Road surface types

In several countries, research and development is performed and stimulated to acquire new road surfaces with better (quieter) acoustical properties. Porous asphalt has been a standard solution for several decades now, with particularly good performance for high speed traffic. Double layer porous asphalt, the two layers being tuned to different frequencies, may be efficient in reducing the generation of air pumping noise (an important element of tyre road noise) and also in optimizing the acoustic absorption of the road surface. Research is presently focusing at optimizing the absorptive properties and at broadening the range of application of porous asphalt under different conditions, particularly winter conditions.

Type approval

With regards to the classification of road surfaces in terms of their noise behavior, there is presently no type approval procedure that applies across the whole of the European Community. Several recognized national procedures exist, e.g. the Netherlands has Croad (which uses SPB measurements for type approval and CPX for checking conformity of production), the UK has the HAPAS system (which includes an optional noise test), and there is a French system AVIS (although it is unclear whether there is a noise option included in this). In the longer term (beyond the end of 2005) there may be the potential for a Europe-wide system following on from a classification system being developed under the SilVia project [97].

Examples

A project started in Finland in 2001 to find suitable products to be used in quiet asphalt surfaces and to develop better methods for the measurement of noise. Seven test roads were paved between 2001/02, four on national highways and three on municipal roads in Helsinki and Espoo. A large number of test stretches were laid on these roads, including porous asphalt and SMA. The results of this project were expected at the end of 2003. Similar projects have been issued by a Dutch ministry within the IPG program mentioned above.

The SIRUUS (Silent Roads for Urban and Extra-Urban Use) project investigated innovative low noise road surfaces and included both laboratory and full-scale trials. The objective was to develop effective noise-controlling pavements concentrating on sound absorbing properties, micro- and macro-texture characteristics and hydraulic properties. The expected reductions were of the order of 3 dB(A) in urban/extra-urban areas relative to traditional porous asphalt and 5 dB(A) relative to traditional dense bitument surfaces. It has recently been reported by Autostrade of Italy that their ‘Euphonic’ surface, incorporating Helmholtz resonators below the wearing course, has produced noise reductions significantly greater than conventional porous asphalts.

The Dutch Ministry of Spatial Planning, Housing and the Environment has called a directive for the stimulation of low noise roads. According to this directive, the city council may be subsidized for the application of a low noise road surface type to its roads. A minimal sound level reduction, relative to the reference surface, is defined for single-layered (3 dB(A)) and double-layered (4 dB(A)) road surface types. Among the minimum reduction demand, there are other criteria including a sound level monitoring program after construction, and arrangements for maintenance. This procedure was enforced in 2001 and has induced the construction of low noise road surfaces in many cities since.

Vehicle tyres

Although the relevance of tyres in the production of rolling noise is evident, the possibilities of applying low noise tyres are very restricted due to European legislation. The recently implemented tyre noise directive EU/2001/43 regulates the acceptance of tyres in the EU market and therefore restricts national and/or local regulations on the noise of tyres. The effect of the regulation on improving the noise characteristics of tyres, however is very low due to the non-technology forcing limit values. National stimulation programs may help to improve the situation slightly, but for instance the German Blaue Engel program and the Nordic Swan program has not received great interest from tyre companies so this type of stimulation by noise labeling suffers from a similar lack of effect.

The tyre manufacturers' role is very complex since they are operating in a field where OEM's and End Users state extensive requirements on the tyre, without the possibility to use low noise properties as a special marketing tool.

Propulsion noise

In general, the most effective instrument in reducing the noise produced by the vehicle itself is the type approval for the vehicle manufacturers. Among the list of criteria for each new vehicle produced are criteria for the maximum noise production. Over the last 25 years, for instance, the noise limit for heavy trucks has been decreased with more than 10 dB, which has caused the average drive line noise of heavy vehicles to decrease with over 6 dB. For cars, this approach has been less successful and one must fear that due to the regulations that are currently being formulated in ISO and GRB workgroups the emphasis will shift towards rolling noise in which the tyre plays a dominant part. Only after market replacement is regulated, this will lead to lower noise tyres in future

6.1.2 Source reduction - Railways

Wheel roughness

Rolling noise is the dominant generating mechanism in railway noise. Rolling noise is caused by roughness. The most direct and straightforward way to reduce railway noise is therefore to eliminate roughness. In the case of tread braked rolling stock and normally maintained track, the roughness of the wheel is dominant over the roughness of the track. Although the resulting noise is radiated both by the track and the wheel, the best way to reduce rolling noise in that case is to reduce the wheel roughness.

K-blocks

Therefore, in 1998 an action plan was devised by the Union Internationale des Chemins de fer (UIC) [93], Union Internationale des Wagons Privés (UIP) [94] and Communauté de Fer Europeens (CER) to produce freight wagons with low noise composite brake blocks (K blocks) or disc brakes. For existing vehicles the intention was to apply this low noise technology retrospectively, ideally with composite blocks that would be a direct replacement for cast iron blocks (the LL block). The EC Noise Technical Specification for Interoperability for Conventional Stock, due to come into force in 2004, will require new wagons to be fitted with exactly this low noise equipment if the specified levels are to be met. Although there have been some early programmes in member states, the EC-wide action plan has proved very difficult to implement at the current time, particularly as it has not proved easy to devise an LL block that can be homologated. A comprehensive study on the "Status and options for the reduction of noise emission from the existing European rail freight wagon fleet" has recently been carried out by AEA Technology Rail for UIC, including a third-party assessment of the proposed action plan.[8]

Rail roughness

Only in the case of disc braked rolling stock and normally maintained track, the roughness of wheel and rail are in the same order of magnitude, and noise reduction should best be attacked by reducing the rail roughness. This can be achieved by intensified maintenance of the track, often indicated as "acoustic grinding".

Other options

Other options for railway noise reduction at source have been investigated in the STAIRRS project in terms of their costs and benefits. A summary of the different measures, the expected noise reduction and some remarks with respect to their efficiency are presented in the following table. The expected reductions are order of magnitude, not exact values.

Noise mitigation measure	Expected reduction of noise creation	Comments
Acoustic track grinding	3 dB	No effect as long as wheels are rough, so no effect for conventional freight traffic, but a necessity to have the full effect of K-blocks. However, on normal well maintained track the effect of K-blocks could be almost complete.
Tuned rail absorbers	3 dB	Still in experimental phase, costs need to be reduced. Adverse effects need to be avoided
Wheel shape optimization	1 dB	Heavier wheels are not an option for freight stock
Wheel dampers	1 dB	Elastomer material does not withstand high temperatures that are caused by tread braking. Can only be applied if tread braking is avoided Ring dampers without elastomer have small effect
Bogie shrouds	1 dB	Not effective as long as the track is not treated
Bogie shrouds and low trackside barriers	12 dB	Combination was demonstrated to be very effective, but only if sufficient overlap between shroud and barrier is guaranteed even with varying load. This is not a practicable condition in international traffic
Speed synchronization (100 to 80)	2 dB	Could be an option near urban areas, but possible bottleneck effects on line capacity
Night time ban	5 to 10 dB	Depending on whether the shift is towards the evening or towards the day. Highly criticised because of the drastic effects for international long distance transport

Table 16 Summary of the different measures and the expected noise reduction

The conclusion from the above table is that a change of brake blocks represents the most efficient way to reduce rolling noise at source. It is therefore the preferred option.

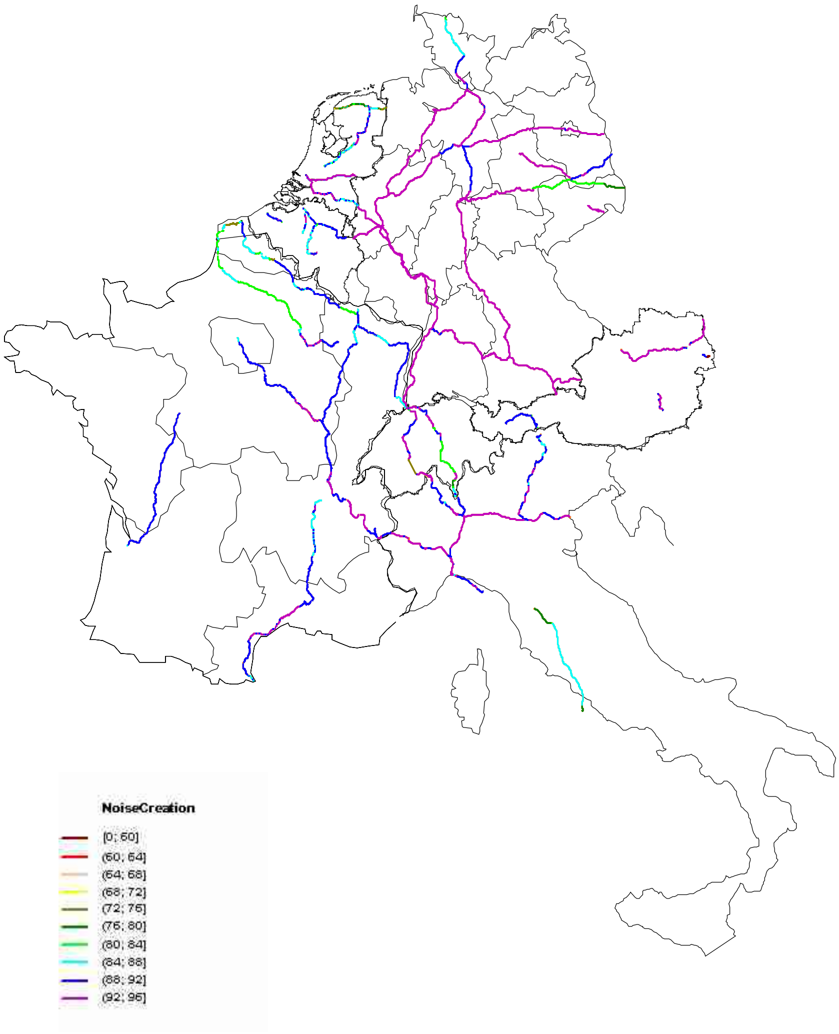


Figure 15: Noise creation on the 11'000 km chosen. From: Eurano, decision support tool

The EC working group Railway Noise, in it's position paper [6], indicates – among others - the following priority instruments for railway noise reduction:

- Noise emission limits for new interoperable vehicles,
- The retrofitting of the existing cast iron block braked freight wagons,
- Incentives for the use of low noise vehicles,

Normal maintenance grinding programs should take noise emissions into consideration.

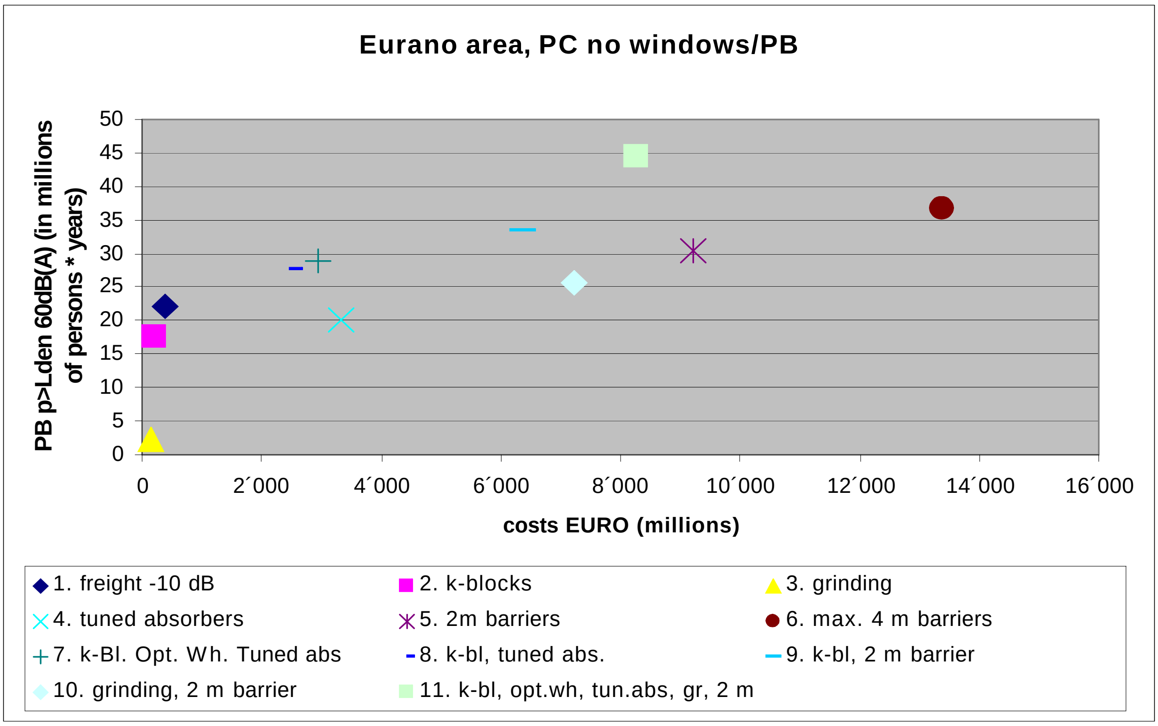


Figure 16 Example of solution versus costs; results from decision support tool (Eurano)

6.1.3 Source reduction - Airports

Action plans

The International Civil Aviation Organisation (ICAO) has defined a multi-step "balanced approach" for controlling noise on an airport-specific basis. This approach takes into account the four principal ways of reducing the impact of aircraft noise:

- reduction at source;
- noise-abatement operational procedures;
- land-use management;
- operating restrictions.

Once an airport's specific noise problem has been identified, based on objective, measurable criteria, a cost-benefit analysis of the four types of noise reduction measure must be performed. Measures are then selected to achieve maximum environmental benefit most cost effectively. Additionally, the balanced approach provides for transparency, by requiring consultation with stakeholders, dissemination of information and dispute resolution.

Presently aircraft noise is a major constraining factor on the growth of the aviation industry with up to 60% of European Union (EU) airports currently implementing some sort of operational restriction (see 6.2.3) on aircraft movements. Apart from these operating restrictions, measures for reducing aircraft noise impact have mostly been based on the "phase-out" of older aircraft. Both of these approaches place the major part of the financial burden on airlines. This balanced approach is, therefore, a major change in thinking about the methods of reducing aircraft noise impact. The requirement to more thoroughly investigate the use of operating procedures and land-use management places at least some of the responsibility on airports and air-navigation service providers.

The Advisory Council for Aeronautics Research in Europe (ACARE)'s Strategic Research Agenda (SRA) is designed to work towards a goal of a 10 "EPNDB" reduction in noise around airports by 2020, i.e. a reduction of perceived noise by half current amounts. This document promotes four threads towards achieving this result:

- Quiet Aircraft
- Rotorcraft of the Future
- Noise abatement procedures
- Community impact management

It is noticeable that the use of operating restrictions does not appear in this list.

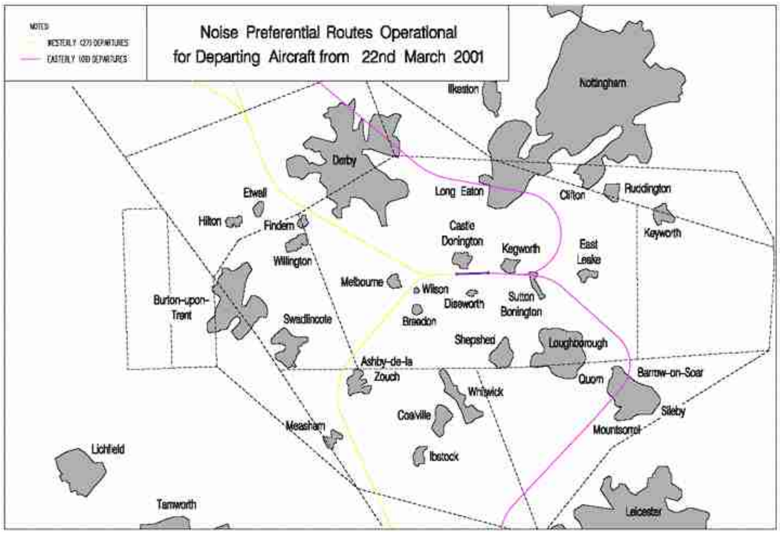


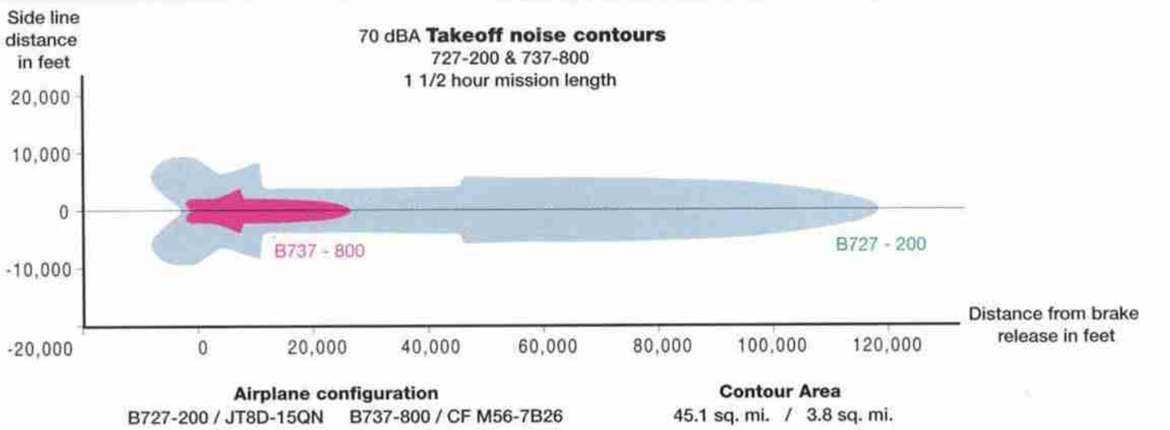
Figure 17 Examples of preferential routes (airport Nottingham)

Aircraft noise has two main sources: engines and airframe. In turn these two are composed of other more definite sources

Engines

For the generation of engine produced in the 1960s, turbojets, there were three distinct sources producing very different noise spectrums. Rear-directed jet noise dominated, although a large amount compressor noise was directed forwards. Turbine and combustor noise and more compressor noise compounded to the noise directed towards the rear.

In the last decades of the twentieth century, turbojets were replaced by high bypass-ratio turbofan engines. This new technology has had the effect of greatly reducing jet noise, although this is still significant, and turbine and combustor noise. Compressor noise is no longer a problem. These engines are now, however, dominated by fan noise - both forwards and rear facing. On the whole,



though, today's engines are much quieter than those of thirty years ago - noise footprints for an equivalent power of modern engine being of the order of only 5 to 10% of the size of the older type (see diagram).

Increasing bypass ratios has resulted in even quieter aircraft but the limits of this technology are being reached and it is not considered that much more can be done without a major technological breakthrough. Future improvements will be in large due to developments in the nacelles used to house the engine - to see whether these can incorporate a shielding effect - and in the jet nozzles - a recent technology demonstrator has shown certain advantages in using a serrated nozzle. However, the trade-off between lower noise and increased emissions has to be carefully monitored. Other possibilities for source-noise reduction may come from more futurist aircraft design such as having engines mounted above the wings, thereby allowing the wing to provide shielding. This could be especially the case of a blended wing-body design.

Air-frames

At take-off, engine noise is dominant to the practical exclusion of everything else. On approach and landing, however, this is not the case, with airframe and landing gear noise accounting for anything up to 60% of total aircraft noise. As an aircraft changes through different airframe configurations during the approach procedure, slats and flaps are progressively extended, at each step creating more drag and thereby more noise. Additionally, landing gear, once deployed, is a major source of noise. On top of these obvious major sources of noise, every deviation of the airframe from the "perfect streamlined shape" is a potential noise source.
Again, the limits of technology are being reached and major airframe noise reduction will only occur with a departure from the standard “cylinder with wings” aircraft design.

Ongoing reduction work

All engine and airframe manufacturers are constantly looking for cost-effective ways of reducing source noise. A large part of this work is being performed in the context of major national and international initiatives, notably the European Union’s SILENCE(R) project and X2-Noise thematic network, and the USA’s Quiet Aircraft Technology (QAT) programme.

6.1.4 Source reduction - Industry

Because of the wide range of sources for industrial noise, no standard source reductions can be given. Only some general information about most common sources [60], [61] are stated below.

Machinery powered by fuel driven machinery

In the last decade, certainly the diesel driven motors have been reduced in noise output as in NOX reductions. The most emphasis is on the latter. With some delay the improvement gathered in the automobile industry will find its way in the industrial machines. The reductions in the next 10 years may be up to 10 dB.

The introduction of fuel cell may be a very useful feature in the future for further noise reduction.

Electric motors

The electric motors can be found in pumps. In general the cooling of these motors are the main cause of noise. A difference of about 6 dB can be found between older types (more then 10 years) and modern types. Noise reduction can be obtained by lowering the rotation speed with a frequency tuning. Furthermore water cooling is a good solution to reduce the sound power.

Centrifugal pumps

The most common noise source is the electric motor of the pump and the attached piping. See for these sources the relevant topics.

Fans

The most common fan type used are centrifugal fans in the industry. They are mostly used for combustion air fans or exhaust fans. Other applications are: transport air fans, suction fans, and cooling fans. The latest developments show that fans used in cooling towers are quietest and may produce 10 dB less noise than its conventional counterpart.

Normal fans can be reduced by using a silencer in the ducts and putting a acoustic isolation of the ventilation housing, and silent electric motors.

Valves

Noise from valves can be reduced by using low noise trims, combined with insulation of the connected piping. The working principle of a low noise trim is based on achieving a gradual pressure drop and minimizing turbulence. Depending on the valve type, flow rate etc, in general reductions of about 10 to 15 dB can be realized.

Enclosures

Putting a machine inside a building is of course not really a source reduction, but widely used in noise abatement. For compressors, steam and gas turbines this is standard treatment. However it has to be taken care of that the build up of thermal energy inside is prevented (often extra ventilation is required). Enclosures are not a feasible solution for every process, often problems arise due to safety.

For the insulation of pipe lines, use can be made of the recently published standard ISO 15665:2003 “Acoustic insulation for pipes, valves and flanges”, which gives guidelines on the effect of various insulation classes.

General

In the European “Position Paper December 2001” [6], a list is given of equipment used outdoor and their maximum sound power level. The equipment range from hand-held breakers and picks to excavators and tower cranes. These sound power levels are given for the year 2002 and a 2 to 3 dB reduction of these levels as of January 2006. Furthermore the German VDI and others give a lot of standards for sound power of all kinds of equipment.

As well as the real source reduction just described, also shielding of the sources is widely applied. Shielding is counted among source reduction if it is carried out inside the industrial area. Roofs, barriers, absorbing materials are examples of noise reducing measures for industry.

6.2 Volume reduction

Paragraph 6.1 dealt with source reduction (measures at the vehicle level); this paragraph deals with the collective production of all noise sources (industry and road, rail and air traffic) in a certain area.

6.2.1 Volume reduction - Road

How can volume reduction in road traffic be achieved? Or rather: what measures/technologies are going to be in place when the first action plans have to be made, and should we be able to model to evaluate their expected effects? For road traffic, a number of parameters can be changed to achieve a reduction in (total or collective) noise production:

- the traffic volume: the number of vehicles in a given time period, on a given stretch of road;
- the composition of traffic (the vehicle fleet – of which types of vehicles does the traffic consist);
- the traffic conditions (traffic dynamics – speeds, acceleration, deceleration, stops and starts);

These three ways to achieve volume reduction will be described in more detail in the following sections and examples of current action planning are given. Also, the possibilities and shortcomings of road traffic models commonly used to assess mitigating measures are discussed briefly.

Number of vehicles

With regard to reducing the number of vehicles, there are many plans to reduce volumes in vulnerable areas and/or periods of the day (night time, mostly). These can be push and pull measures. Measures can influence:

- the number of trips made;
- the time when the trip is made;
- mode choice (measures to achieve modal shift, e.g. from road to rail or from private to public transport).

General examples of measures

Plans to reduce car use:

- Travel or mobility plans for companies;
- Car sharing;
- Car pooling;
- Promoting and improving public transport (including park&ride), bicycle and walking facilities.
- Parking management and charging policy;
- Logistic organization for freight transport;

Restrictions on traffic:

- Roads closed (to all traffic or specific traffic categories) at night;
- One-way roads to manage traffic (e.g. in city centers);
- Reducing the capacity of roads, thus limiting traffic volumes;

Pricing strategies:

- General user charges (e.g. congestion charging, corridor tolling, ...);
- User charges for trucks;
- Policies on taxing;
- Parking fees.

Route/parking guidance systems (static/dynamic), to promote the use of certain routes and parking facilities.

Figure 18: Action plan, simulation of noise levels on a normal working day and during the “No-cars today” operation (Journée sans voiture).

In some cases these measures are applied specifically to reduce noise emissions. However, in most cases more general objectives of sustainability are targeted (emissions of pollutants, safety etc.). Often, measures are taken to relieve (the effects of) congestion; sometimes measures are only for periods during the day (e.g. peak hours) and do not apply during the night. Measures specifically aimed at the night period are rare and include restrictions on heavy goods vehicle movement.

Current practice

Most towns and cities have policy plans regarding traffic and accessibility. These plans usually contain a mix of the measures described above. Many cities have already banned road traffic from certain roads or areas (e.g. pedestrian areas in city centres). Some authorities consider banning all traffic on certain roads during the night in sensitive areas (e.g. national parks).

More efficient logistical processes can help to reduce the actual number of vehicles and thus reduce the vehicle kilometers and tonne kilometers traveled by increasing load factors (reducing empty or partially loaded running of lorries), improving routing, utilizing new information technology to maximize return trip loading, consolidate deliveries, sharing loads and pick-up deliveries with other companies.

Reducing the capacity on a road can be a very effective measure, but care should be taken that the traffic that is diverted does not cause problems elsewhere in the road network. The same applies to the banning of vehicles from certain roads.

Paid parking is the most common pricing strategy, but road pricing systems are studied all over Europe and several systems are already in use, such as toll roads (péage), Eurovignette, congestion charging (in London), etc. Road pricing systems typically charge motorists for entry into a specific area after passing a cordon line, or for using a particular road. The exact nature of the charging system may vary considerably, from a simple entry toll, to systems that vary the price depending on vehicle type, time of entry or exit, distance traveled in the charging area etc. The actual infrastructure required may also vary considerably, including the use of roadside or gantry vehicle recognition systems, transponder systems, smart-card based, in-vehicle charging units. In addition to road pricing systems, several cities (primarily in the UK) are also looking at increased charging for business parking spaces within central city areas to promote the use of public transport systems, such as park-and-ride.

Automatic route guidance systems have the potential to make a significant impact on the reduction or redistribution of noise emissions. Instead of restricting traffic on certain routes, traffic can be guided to suitable routes. Many cities have parking guidance systems, and variable message signs along roads and route navigation systems in vehicles are becoming more common. In the future, vehicles may routinely be provided with real-time, optimal-path information to aid drivers to reach their destinations, whilst large-scale collection of data allows effective traffic management to alleviate congestion, evenly distribute flows and provide rapid response to incidents. Easily available, accurate traffic information is of fundamental importance to any noise mapping exercise.

Examples of current practice

Company travel or mobility plans. In many countries, companies are encouraged or obliged by law to prepare travel or mobility plans, aiming to reduce the car use of their employees and visitors. For instance, in the Netherlands such plans are made for all companies with more than a 100 employees, 500 visitors and/or 2 million transport kilometres.

Congestion Charging London. This is an example of a pricing strategy targeted at reducing traffic volumes in a (large) area. The central London congestion charging scheme was introduced in February 2003. The congestion charge is a £5 (€ 7.50) daily charge for driving or parking a vehicle on public roads within the congestion charging zone between 7.00am and 6.30pm, Monday to Friday, excluding public holidays. The central London congestion charging zone covers 22 square kilometres in the heart of London, including the centres of government, law, business, finance and entertainment. Provisional estimates of year-on-year changes in traffic levels during charging hours show a reduction of 15 percent in traffic circulating within the zone, and a reduction of 18 percent in traffic entering the zone during charging hours.

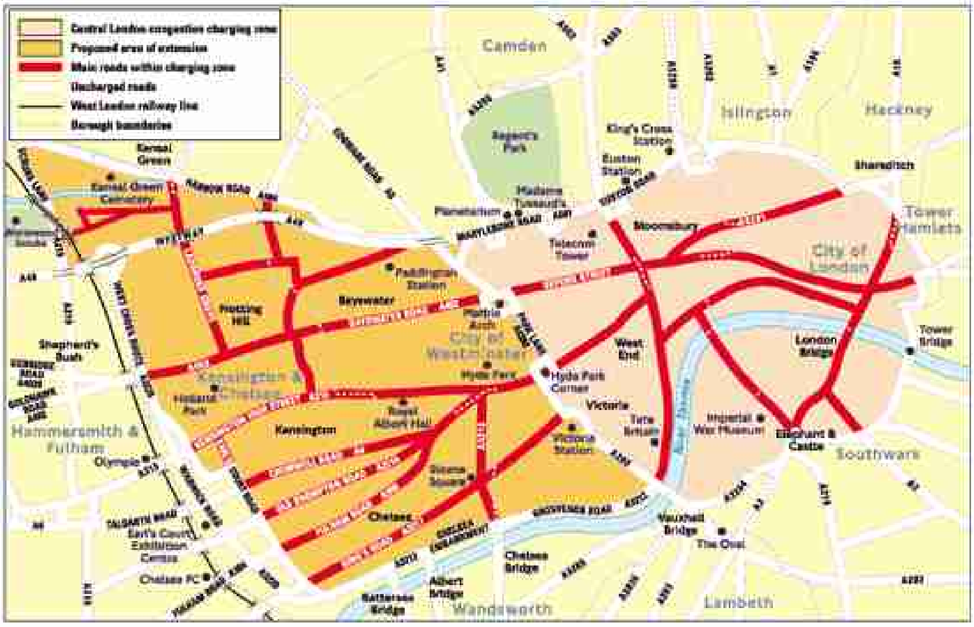


Figure 19: Congestion Charging in London

Parking policy of the city of Bern and The Netherlands. In Hasselt, Belgium and in the Dutch Province of South-Holland, free public transport is offered as an alternative to the car. Bern has a comprehensive parking policy as it comprises quantity, time, price and user oriented policy measures. Most successful were the Blue Zones in residential areas. In Bern, Blue Zones have lead to a considerable decrease of traffic in residential areas, particularly during morning (-14%) and evening peaks (-21%).

Traffic models used to assess measures

Mitigating measures aiming to reduce the number of vehicles are usually assessed with a macroscopic traffic model, which is capable of assessing changes, brought about by the measure, in the number of trips made and the share of each mode of transport (car, public transport (bus/rail), bicycle, walking). If the model distinguishes different periods of the day it could assess also the effects on departure times (when trips are made, e.g. shifts from peak hours to non-peak hours). Pricing strategies can usually be evaluated, but if they are variable for the period modelled a dynamic traffic assignment is needed.

The fact that macroscopic traffic models are able to produce the desired output (changes in traffic volumes in the network) does not mean that all measures can be modelled easily. Macroscopic models are best suited to assess changes in infrastructure (e.g. a new road or added lanes), land use (e.g. traffic generated by new housing estates) and public transport services (e.g. increased bus frequencies or free public transport). Changes in trip generation, mode choice and route choice are based on the traveler's characteristics: car ownership, activity patterns, sensitivity to the duration and cost of a trip (including parking costs) with a certain mode of transport, via a certain route and at a certain time.

Any measures aiming to influence the traveler's preference for making a trip, using a certain mode of transport, route or departure time (e.g. telecommuting, car sharing, route/parking guidance systems, innovations in logistics) are more difficult to model. This would mean that model parameters that are normally kept constant have to be varied (the statistical relationships on which the model is based, between (large) groups of travelers and the characteristics of the trips they make).

Other problems specific to noise assessment include:

Periods of day traditionally modeled for traffic control management and transportation planning do not always match periods needed for noise assessment;
Model output is average values only and often over specific periods of typically two or three hours for peaks and between peaks 5-6 hours;
There is no information on the distributions of speeds.

Composition of traffic – Road
The composition of traffic on a route can be influenced in such a way that noise levels are lower in sensitive areas and higher in areas where this is not a problem. Again, there are push and pull measures: noisier traffic can be prohibited from or encouraged to avoid certain areas for periods of the day.

General examples of measures
Restrictions on specific roads for certain vehicle types (e.g. heavy duty vehicles) on certain roads or in certain areas, always or during certain periods of the day (night, peak periods, e.g. time restrictions for deliveries to shops);
Restricted access zones;
Encouragement of the use of quieter vehicle;
Pricing strategies / user charges distinguishing between vehicle types.

Current practice
Freight traffic is restricted to certain periods of the day in many cities. In addition, city distribution schemes – freight transport with small, environmentally-friendly vehicles – are widely investigated.

Drivers can be informed of restrictions in various ways, some stricter (and therefore usually more effective) than others. Static signs are the simplest form. They can target specific vehicles types, e.g. lorries. Dynamic signs can do this in a more sophisticated way: they can be used to target varying categories of vehicles. In some cases, barriers ensure that only registered vehicles are allowed (e.g. based on license plates, access codes or smart cards).

Road pricing systems may be enhanced to influence traffic composition. For instance, charge exemptions for small “urban” vehicles or public transport vehicles can be introduced, or charges are varied according to vehicle type.

Examples of current practice
HGV Ban in the Beusselstraβe in Berlin. The HEAVEN (Healthier Environment through the Abatement of Vehicle Emissions and Noise) project in Berlin looked at the effects of a HGV ban in the Beusselstraβe, which prior to the ban carried approximately 1100 trucks/workday out of a total flow of 25,000 vehicles/day. Over the period of approximately 1-month, whilst only partially effective (typically 50% of drivers ignored the ban), mean L_{Aeq} levels at a mid-link monitoring site were reduced by during the day and 1.3 dB(A) during the night [31].
Restricted access zone in the city of Prague (Czech Republic). Over a number of years different implementations of zones with restricted access for heavy vehicles were developed. After the implementation of these regulatory measures, the volume of heavy vehicle traffic decreased up to 85% on the busiest routes under monitoring. This traffic was transferred to the more appropriate roads, namely to some parts of the city ring road.
Restricted Traffic Zone Rome. The Municipal Administration of Rome implemented a Restricted Traffic Zone for the city centers (the historic centers and the political area). Between 6.30am and 18.00pm on working days and between 14.00pm and 18.00pm on Saturdays, only vehicles with a

permit are allowed (mainly residents, public vehicles and disabled people). Vehicle access to the zone is checked by the IRIDE electronic gate system. The drop in the flow of vehicles during the hours of restricted access was between 13 and 15% on weekdays and between 7 and 10% on Saturdays.

Figure 20: Restricted Traffic Zone Rome

Distance-related Heavy Vehicle Fee (HVF) in Switzerland. The performance related HVF is the central pillar of the Swiss policy aiming to transfer freight from road to rail. The fee was introduced on the 1st of January 2001 and replaced a former flat charge which was very similar to the Eurovignette. The fee is applied on heavy vehicles with a total weight of more than 3.5 tons and on the entire road net of Switzerland. The rate of the fee depends on three factors: the distance driven, the admissible weight of the vehicle and the pollution from emissions from the vehicle. Parallel to the stepwise introduction of the HVF, Switzerland is harmonizing the weight limit for Heavy Vehicle to the European level of 40 tons. The new regime with the HVF and the higher weight limits for lorries has led to a significant break of former growth trends. Annual increases of about 7% prior to the new regime were replaced by declines of around 4% in 2001 and 3% percent in 2002 afterwards. In 2003 the traffic volume of lorries remained stable.

Traffic models used to assess measures

Mitigating measures aiming to change the composition of traffic can be modeled with various types of traffic models –from macroscopic to microscopic. In order to enable modeling of pricing strategies or restrictions on certain types of vehicles in space and in time the models must distinguish different user classes (noisier and quieter vehicles) and time periods (day/evening/night). This is not always the case and collecting the necessary input data (including data for future years) can be a problem. Another difficulty is that many microscopic simulation models do not include mode and route choice.

Traffic conditions – Road

The characteristics of traffic conditions (the dynamics in speed, acceleration, deceleration, stops and starts) are important determinants of noise production. Improving traffic conditions by influencing these characteristics can contribute considerably to the reduction of noise.

General examples of measures

Reduction of speeds, to be achieved by:

- lowering the speed limit, through road signs (with or without enforcement) or in-vehicle systems (speed assistance/advisory systems);
- changes in road geometry.

Reduction of dynamics in traffic:

- changing traffic lights to smooth out the flow of traffic and to eliminate the need for frequent stops and starts;
- smoothing (motorway) traffic flows in congested areas through Intelligent Transportation Systems (ITS);
- One-way roads to manage traffic (with the objective to reduce congestion or remove conflicts at junctions);
- Route guidance with the objective to reduce congestion;
- changes in road geometry.

Current practice

The lowering of speed limits is mostly done for traffic safety reasons, and as such is a measure widely accepted by road users. The measure is applied in many residential areas, but sometimes also on rural roads. Lowering speed limits can also be applied as a measure to reduce noise levels.

Strict enforcement can help to reduce speeding. However, if the lay-out of a road ‘invites’ speeding, it is better to redesign the road geometry so that the driver understands the local speed limit. It may also help to reduce traffic dynamics (accelerations and decelerations), for instance by redesigning bottlenecks or removing sharp curves.

Traditional traffic calming measures, such as speed humps or chicanes, attempt to reduce vehicle speeds. Studies have shown that use of such measures can lead to substantial reductions in roadside noise levels [28]. However, care must be taken in implementing such measures to ensure that:

- The distance between individual measures is not so great that excessive acceleration and deceleration between measures causes additional noise;
- That traffic flows do not excessively reroute around the calmed area, leading to “rat-running” and increased noise levels around the area;

For areas with high flows of goods vehicles, service vehicles or public transport vehicles measures are appropriately designed to reduce the noise caused when traversing the hump and from the vehicle load.

There is concern therefore that road humps specifically may increase L_{Amax} levels, and low-frequency noise <250Hz, that may be contributing factors in sleep disturbance and night-time annoyance.

Traffic management (TM) and Intelligent Transport systems (ITS) can be used to influence or smooth traffic flow, for instance at intersections (co-ordination of traffic lights, ‘green waves’) or complicated road sections (exit/entrance lanes, weaving sections). Motorists can be informed of the desired behavior by road signs and in-vehicle systems. Variable Message Signs (VMS) are used in a number of countries to advise drivers of mandatory speed limits, road conditions and provide real-time route guidance information. Such technologies may have a limited impact on altering driver behavior, and hence noise levels.

Examples of current practice

30 km/h zones in residential areas. All over Europe, speed limits in residential areas are lowered from 50 km/h to 30 km/h.

80 km/h limit on a stretch of motorway in Rotterdam. On a stretch of motorway running through Overschie (Rotterdam) in the Netherlands, the speed limit was lowered from 100 km/h to 80 km/h. Noise reduction was one of the objectives. Strict enforcement ensured a large reduction of averages speeds and excessive speeding.

LARGAS – 'Driving Slowly Goes Faster'. This Dutch initiative aims at improving urban accessibility and mobility through changing the lay-out of arterial roads. It is based on the premise that bringing down the speed of traffic can actually improve overall travel times, as traffic is homogenized and congestion is avoided. The resulting smoother traffic flows and lower speeds help reduce noise levels.

Dynamic Urban Traffic Control Systems (UTC). UTC systems attempt to control and coordinate traffic signals controlling junctions or crossings by seeking an optimal value for some form of Performance Indicator (PI). Dynamic UTC systems, such as SCOOT (UK), SCATS (Australia), PRODYN (France) or UTOPIA-SPOT (Italy) work in quasi real-time using traffic or pedestrian data collected directly from detector systems on street. Historically, the performance indicator chosen has been to minimize overall delay to traffic flows within the controlled area. However, other optimization strategies are possible, for example to create gates or throttle (flow control) points or to reduce delay to public transport, public service vehicles, pedestrians or cyclists at the expense of the general traffic flow.

Intelligent Speed Adaptation / External Speed Advisory systems. Such systems have already been tested in several European countries – Sweden, UK, Netherlands, Belgium, Spain, and Hungary). Several systems are available:
open/advisory only,
half-open (haptic throttle, making it more difficult to speed),
closed (dead throttle, making it impossible to speed).

The HEAVEN project looked at the effects on noise of a 20% reduction in vehicle speeds at selected arterial roads in both Berlin (Germany) and Leicester (UK) [30]. For Leicester, modeled results suggested a mean reduction in L_{Aeq} levels of 0.4 dB(A) throughout the day and night along a single corridor route (Narborough Road), whilst in Berlin, modeling suggested reductions in L_{Aeq} of up to 3.5 dB(A) were possible. In Berlin the actual application of speed restrictions in Beusselstraβe over a 2-month period, reduced vehicle speeds by an average of 10%, from approximately 40km/h to 35km/h. This lead to a reduction in mean L_{Aeq} levels of 2.0 dB(A) during the day, and 1.4 dB(A) during the night. Unfortunately, this result is somewhat occluded, given that traffic flows during the period in which the speed restrictions were in place were some 20% down than during the reference measurement period see http://heaven.rec.org/.

Providing air-pollution information through variable message signs. Leicester City Council, as part of the EU-funded EMMA (Integrated Environmental Monitoring, Forecasting and Warning Systems in Metropolitan Areas) [29] project has used VMS signs to present drivers with air-pollution information during high-pollution episodes, to promote the use of alternate transport modes. VMS signs could also be used to reduce noise levels. For instance, there are systems that combine speed detection, VMS and ANPR (Automatic Number Plate Recognition) technologies, to flash warning messages ahead of individual drivers who are exceeding speed limits.

6.2.2 Volume reduction – Rail

Number of vehicles

The total number of trains is determined by the railway companies, and restricted by the total capacity of the railways. The total capacity of railway lines is fixed by the number of lines in a certain direction, and by the minimum distance between the trains. The minimum distance is dependent on the safety system used in the country. At this moment new procedures are developed in the European project ERTMS (European Rail Traffic Management System), to optimize the railway capacity by reducing the safety distance [95].
Legislation or noise strategies may impose further restrictions to the total number of vehicles.

Capacity - rail

The capacity of a railway line is determined by the number of tracks and the minimum distance between trains. Other circumstances which influence the total capacity can be:

- the number of stops;
- stopping time at stations;
- converging of two lines.

Apart from the technical restriction, also noise legislation or noise strategies may impose a maximum to the total number of vehicles in a certain time period. With capacity management all influences on the railway capacity are combined. In practice there are different ways of reducing the noise by capacity management:

- restriction of traffic in a certain time period;
- reduction of the speed (traffic conditions);
- use of silent train categories in stead of noisy ones (traffic composition).

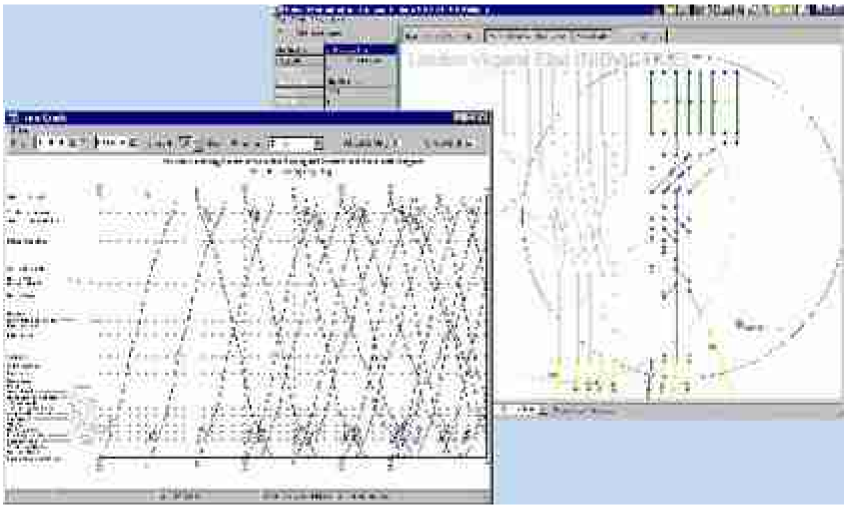


Figure 21: Capacity management

Driving conditions - rail

The quality and organization of the infrastructure influences the train traffic driving conditions. Well designed infrastructure reduces the number of stops and thus the number of accelerations or braking movements.

An intelligent (and mostly expensive) design of the infrastructure reduces the number of stops. Fly-overs, switches at appropriate sites and sufficient number of lanes favor the traffic flow. Other parameters which reduce the number of stops, are:

- Reduction of technical problems;

- Good functioning traffic organization (bugs in computer programs, fast and efficient programming);
- Reduction of number of extra stops by problems with infrastructure (bugs in electricity/switches/ signs/ slippery rails);
- Reduction of number of extra stops by problems with trains (train defects/organization problems);

Reduction of the duration of a technical problem:

- Fast repair or replacement programs;
- Optimal co-operation between railway companies;
- Communication between the companies;
- Traffic organization programs;
- Efficient priority rules (international trains, intercity trains, stopping trains, freight, etc.).

Crowded areas

To reduce noise annoyance in crowded areas, the driving conditions in these areas can be adapted. Good organization of traffic flow could reduce the number of stops in crowdy areas. A more drastic measure is the placement of stations outside city centers, although this is rarely desirable from the public transport traveler's point of view. A lot of noise is produced near stations by braking, accelerating, and the large number of switches at the shunting yards. Besides, often curve squeal is highest in the city centers because of the many track curves near stations. A solution to reduce the curve squeal is speed reduction.

For new situations narrow curves should be avoided in crowded areas, and the quality of the infrastructure can be adapted (distance between tracks, track tilting).

Organization

Intelligent planning and organization of transport reduces the total number of movements from one place to another. Shunting yards are used to combine and recombine the trains. Co-ordination between different companies could optimize the number of trains.

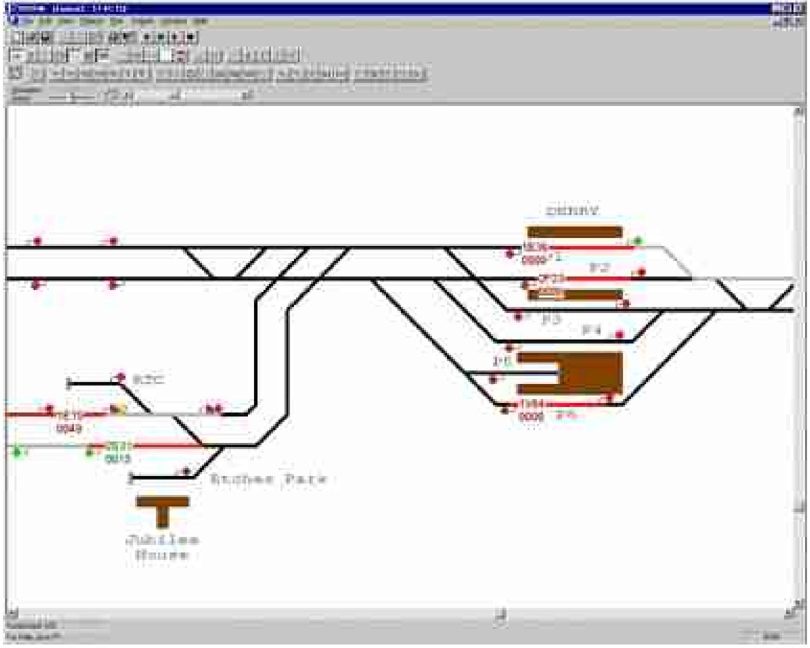


Figure 22: Vision@ System Simulation Software

Pricing strategies

For freight trains, pricing strategies may positively influence the co-ordination between transport companies, and the planning and organization within one company, thus reducing the number of freight trains.

Composition of traffic - rail

Division of the traffic fleet into different noise categories is common use in several European countries. Noise production of trains is mainly caused by roughness of track and wheels. Reduction of the roughness (both wheels and rails) is described in paragraph 6.1.2.

For the trains, braking systems and maintenance conditions determine the roughness of the wheels. So train categories should be based on these parameters. This is more extensively described in the Harmonoise project, by working group 1.2 [90]**.**

Reduction of the noise volume by the composition of the traffic can be achieved by avoiding rough wheels and tracks. This means:

- silent train categories (braking systems which keep the wheel smooth) in critical periods;
- maintenance of the wheels;
- grinding regimes for the tracks;
- the use of not maintained tracks should be avoided.

6.2.3 Volume reduction – Airports

Operational procedures - airports

Operational procedures, the routes aircraft take and the way they fly over these routes, can be used to reduce the volume of noise experienced by local communities. In particular, routes can be deviated, within the limits defined by safety requirements, to avoid communities and overfly industrial or forested land instead. Quite often, though, this is not possible.

Noise abatement procedures (NAPs) can be applied for both departing and arriving flights. On departure, such procedures provide for a thrust reduction to alleviate the exposure of populations living near the airport to take-off noise. ICAO has defined two such noise abatement departure procedures, NADP1 and NADP2, which place the thrust reduction either close to or further away from the airport, depending on where noise abatement is most required.

NADPs involve a trade-off between reduced noise and reduced height. With less thrust, the aircraft climbs less quickly and the noise is, therefore, produced closer to the receiver. Whilst this increased proximity is more than compensated by the reduced engine noise during the period of reduced thrust, the delay in climb means that when, further from the airport, the aircraft resumes a higher level of thrust, it will be lower than it would have been without the thrust reduction. The time at which this thrust reduction occurs can, therefore, be managed depending on whether it is required to benefit communities close to or further from the airport.

On approach, NAPs generally involve a continuous descent approach (CDA). For operational and safety reasons it is generally necessary for an aircraft to fly a level segment immediately prior to the final approach. This level segment enables the aircraft to reduce speed to that required for landing, to turn onto the final approach leg and to intercept the Instrument Landing System (ILS) beam – a signal sent at (typically) a 3 degree vertical angle from the runway threshold - from underneath. From the controller’s point of view, aircraft can be easily separated and sequenced for arrival.

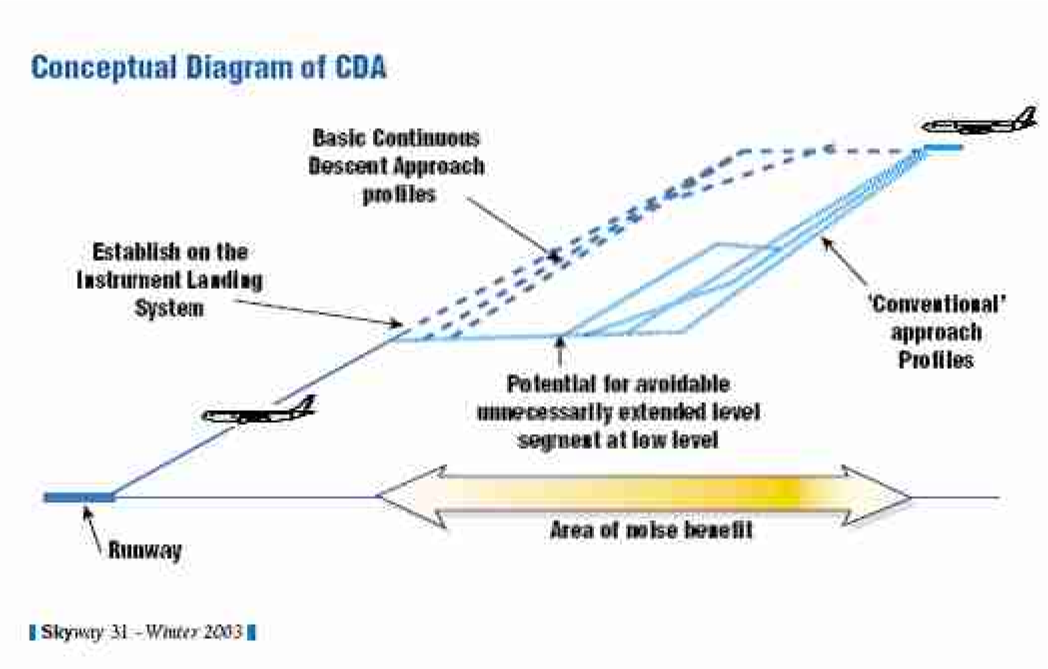


Figure 23: Continuous decent approach

A CDA involves replacing this level segment by a descending segment. This provides noise benefits due to the aircraft's being further from the ground and its having less requirement to apply thrust at the end of the segment in order to maintain speed. However, the approach becomes much more difficult to fly safely, and providing for safe aircraft separation is greatly hindered. This has a major effect on the capacity of the airport.

Work is currently underway in the European Sourdine II project to design and evaluate advanced NAPs that will have minimal effects on capacity, efficiency and emissions while reducing noise impact and maintaining safety.

Operating Restrictions - airports

Operating restrictions are measures that in some way or other, limit the use of an airport by airlines. There are several such measures possible, among them being:

- Setting a limit on the total number of passengers that may pass through the airport in a given period (normally per year). This is the case at Paris CDG;
- Setting a limit to the total number of movements for a certain period. This method is used at Orly;
- Setting a limit to the total amount of noise energy for a certain period or to the number of people within a given noise contour (noise quota). This method is used at Amsterdam Schiphol;
- Curfews where no, or limited, operations may take place during a certain period (usually at night). This option is notably the case at Paris Orly.

A recent study performed by Anotec on noise abatement practices at all major EU airports (those affected by the European Noise Directive) has revealed that the above measures were already taken at many of these airports:

- there is a cap on the number of movements or a noise quota at 30% of the airports;
- curfews are in place at almost 50% of the airports.

It must be noted, however, that according to European Union Directive 2002/30/EC, operating restrictions may only be taken once all other measures under the ICAO “Balanced Approach” have been proven to be technically or economically infeasible.

Land-Use Planning, Aircraft

The easiest way of reducing the impact of noise on people is to remove the people from the areas where the noise is. Unfortunately they don’t always want to move! In fact, given the employment opportunities at an airport, other economic benefits, ease of access for travel etc. people often want to live near to them. It is vital, therefore, that the land around an airport be properly managed so that local populations can get, as far as possible, the best of both worlds.

Land around airports is usually categorized in terms of the use to which it can be put. These categories are generally subject to national law. Close to the airport, for example, land might be restricted to use for warehousing only. Further away, office developments might be allowed with housing being kept further away still. Schools and hospitals are generally kept as far as possible from noise sources.

The categories of land around an airport are generally defined as a function of the noise impact from airport operations, as calculated either by measurement or through modeling, and defined in a noise management plan.

Action to reduce noise impact through land-use planning often involves the airport’s buying housing – though this is more difficult in Europe than, for example, in the USA, as the age and possible historic value of the housing stock can often preclude this.

6.2.4 Volume reduction – industry

For industry reduction of the volume can be achieved by clustering the locations of industrial activity and goods and logistics at the same time.

- Combining noise sources as to reduce the total area of annoyance:

The total area of noise exposure can be reduced by reducing the total area affected by the areas with heavy industrial activity. This means clustering the areas into one big site.

The noisiest industrial activities should be located at the center of an industrial area, not at the edges.

- Location of industrial activities at the edge of the city

Intelligent planning of noisy events over time periods and over sites for both industry and freight traffic:

Changing re-arranging or re-organizing the production process in such a way that the number of noisy processes is reduced. This demands effective organization, planning and co-operation between different industries or departments, and is only effective if the costs are lowered, or if authorities encourage or oblige by law.

In this way not only the total number of events can be reduced, but also the number of noisy events in the critical time period.

Figure 24: Industrial parks in the Netherlands

6.3 Measures at receiver

Traffic noise is traditionally controlled by wayside mitigation measures, i.e. noise barriers. Noise barriers are quite efficient in the sense that they represent a substantial reduction (up to 15 dB) of the reception levels close to the source (see [2]). On the other hand noise barriers have obvious disadvantages:

- they are quite expensive (1000 Euro and more per m length for a barrier of only 1 m height above rail head);
- they have only local effect;
- they represent a visual intrusion, which is less and less accepted by the residents.

In the STAIRRS project different options for noise reduction, both wayside, at the receiver and at source were compared in terms of their life cycle cost. It was clearly demonstrated, as it was in many previous studies, that to control noise reception by means of noise barriers only is by far the least efficient and most costly option.

Alternatively to noise barriers, façade insulation is a usual option. Double-glazing, soundproof ventilation and insulation of light weight façade panels can result in a lower noise reception level inside the house. It is not completely obvious that this will result in a lower annoyance (some studies claim that it will not) and it is also a very expensive solution with very restricted effect. Therefore noise reduction at source would have to be considered as the preferred option.

6.4 Subjective quality of measures

When considering the options for noise mitigation, for instance for a Noise Action Plan, the cost efficiency is likely to be an important parameter. An optimization process could be applied to rank the solutions according to their costs and efficiency, but this is not as obvious as it seems. As far as the costs are concerned, it is important to define an appropriate cost base. The Net Present Value of the Life Cycle Cost, which was used e.g. in the STAIRRS project, appears to be a suitable indicator. Problems of comparability arise when only the investment costs are considered, as one solution may last much longer than another or one solution may require more maintenance than another.

With respect to the efficiency, this can be expressed in “reduction of numbers of annoyed people”. This factor is complicated by the distinction that is generally made between seriously annoyed, annoyed and moderately annoyed people. An efficiency assessment would necessitate a harmonized weighting of these different classes of annoyance, e.g. one seriously annoyed human being counts for 3 annoyed people and for 5 moderately annoyed people (the numbers are completely fictitious !).

Recent publications of the EU working group on Health and Socio-economic Effects of Noise on the “Valuation” of noise annoyance may form a basis for the evaluation of noise effects in economic terms and may thus be applied to assess, in an objective manner, the efficiency of different mitigation options.

When direct health effects are at stake, such an assessment is even more complex. Sleep disturbance may lead to such health effects, and therefore the body responsible for action plans may decide to mitigate the noise sources that lead to sleep disturbance with priority.

In the spirit of the European Noise Directive, this kind of ranking of options is thought to be subject of a consultation of the citizens. However, in carrying out such consultations, it is important to keep in mind that some general social principles seem to apply:

First of all, the noise from the sources addressed in the Action Plan, such as road and rail traffic noise in a city, may not be the sources that people feel most annoyed by. For example a nearby entertainment area which attracts traffic in the evening may be experienced as far more annoying, than the road traffic reflected on the noise map.
People tend to value a visible mitigation measure, demonstrating the authority’s willingness to improve their noise situation, better than a measure that is not generally noticeable. Sometimes the fact that the measure is tangible seems of equal or more importance than the actual reduction achieved. This might apply to e.g. porous asphalt that has a noticeable noise reduction effect but is not clearly visible as a noise mitigation measure.
Noise barriers of modest height are judged positively, particularly when they are designed in such a way that they are “hidden” in the surrounding landscape. This conflicts with the architects ambition to turn a noise barrier into an artistic “statement” rather than a mitigation device.
High noise barriers are valued by people who enjoy the noise reduction without direct interference with the view out of their house. This applies e.g. to residents in a street perpendicular to the road that receives noise barriers. People living along the road generally prefer noise protecting windows over noise barriers.
People tend to value of mitigation measures differently depending on the fact whether they are a victim or a polluter or both. Road traffic speed reduction is highly critized by car users, but valued by residents living along the road. In a public consultation both categories may contribute.

7 Conclusions and recommendations

For comparison of noise maps throughout Europe a harmonized computation model and a harmonized mapping method are needed. This will allow local authorities and infrastructure managers with useful information for setting up new noise mapping projects.

Noise mapping has become common practice in many countries. However, due to technical limitations, to the use of specific computation methods and to end-user specifications, every noise mapping exercise has been a virtually unique experience. Apart from being expensive, incomparable noise maps are produced for different sources and in different areas. For the harmonization of different mapping purposes a standard for data storage is needed.
GIS technology is well suited to produce, store and manipulate noise data. It supplies support for spatial databases, and provides a clear distinction between storage and presentation of data.

The data presentation must be appropriate for the specific target groups and mapping scale. The scale may vary from 1:30.000 for city maps up to 1:5.000.000 for the complete network in a country. For the accuracy of the presentation methods the grid size is determinative. Dynamic grid sizes, which provide high grid density for built up areas, are available and can be standardized. The same holds true for population density maps.

From an overview of computation and measurement methods, differences in methods and in assessed indicators are observed. It turns out that there is little experience of predictions in full conformance with the directive and the details of the source models of Harmonoise.

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ANNEX 1 MEASUREMENT METHODS ROAD TRAFFIC NOISE

UK

The exact procedures for measurement and analysis of data are outlined in Section III of *CRTN* and stipulate measurement requirements under the following headings:
Road surface conditions;
Wind conditions;
Measuring equipment to be used;
Measuring procedure (microphone position and sampling);
Use of concurrent traffic counts;
Analysis of data and derivation of noise parameters.

Table 17 summarizes the requirements of each heading.
It is important to note that the traditional noise metric for road traffic in the United Kingdom is defined as the $L_{\mathrm{A10,\ 18\text{-}hour}}$ level covering a period from 06:00 – 24:00.

For compliance with the END, and to ensure the adaptability of existing UK L_{A10} based noise datasets, recent studies have looked at two main issues:
Conversion of $L_{\mathrm{A10,\ xx\text{-}hour}}$ levels to $L_{\mathrm{Aeq,\ xx\text{-}hour}}$, L_{day}, L_{evening}, L_{night} and L_{DEN} levels (TRL, 2002). An appropriate correction, based on analysis of hourly data for motorway and non-motorway traffic, was found to be:
$L_{\mathrm{Aeq,\ 1\text{-}hour}} = 0.94 \times L_{\mathrm{A10,\ 1\text{-}hour}} + 0.77$ dB(A) for ‘q’ = 200 veh/h.
$L_{\mathrm{Aeq,\ 1\text{-}hour}} = 0.57 \times \mathrm{L}_{\mathrm{A10,\ 1\text{-}hour}} + 24.46$ dB(A) for ‘q’ < 200 veh/h.
TRL (2002) also provides other correction factors for $L_{\mathrm{A10,\ 18\text{-}hour}}$ to EU parameters based on period (day, evening, night) traffic data and straight conversion of $L_{\mathrm{A10,\ 18\text{-}hour}}$ to EU parameters where traffic data is not known, noting that prediction accuracy is degraded. TRL (2002) also notes that long-term annual average parameters would be expected to be lower than predicted values using $L_{\mathrm{A10,\ 18\text{-}hour}}$ levels, given the downwind criteria in CRTN.
The correction factor(s) required to convert UK standard measurements at 1,2m AGL, 1m to other microphone positions (BRE, 2002). Initial findings reported in BRE (2002) compared 24-hour measurement data, taken at microphone positions 1,2 and 4m AGL, 1m from the facades of dwellings, taken at 173 sites across the UK. Generally, levels taken at 4m AGL were found to be higher by 1.4dB(A) - 2.1dB(A) than the comparable 1.2m metrics. Table 18 summarizes the overall findings.

BRE (2002) also reported the development of a conversion factor using a prediction model, to convert measurements at 1.2m height, 1m from the façade to the free-field 4m height, 2m from façade, levels for the END. The predicted correction factor was found to be: mean +0.3 dB(A), with standard deviation 3.5dB(A). However, given the spread of the data and the assumptions made in the modeling procedure (i.e. dominance of road traffic noise at the façade) the conversion factor could actually be 0 dB(A).

Heading	Requirements:
Road Surface conditions:	Road surface must be dry
Wind:	Downwind conditions Avg. downwind speed at height of 1.2m AGL, at a point midway between source and receiver is = 2 m/s. Max. wind speed in any direction = 10 m/s. Microphone windshield to be used. Measure only when L_{Amax} from wind noise is 10dB(A) or greater below road traffic L_{A10}.
Measuring equipment:	Type 1 instrument to be used Standard characteristics originally defined in BS 5969: 1981 NB: BS 5969 has since been superseded by BS EN 61672-1:2003 and BS EN 61672-2:2003. Calibration by accredited laboratory on annual basis.
Microphone position:	Distance: 4m – 15m from nearest carriageway edge Unobstructed view of road (angle of view > 160°) Height 1.2m AGL (above ground level). Mic. Horizontal (grazing incidence). Free-field conditions should apply. If free-field conditions are uncertain – use temporary screen 1m behind instrument, then correct for free-field. Correction for free-field to 1m from façade = +2.5dB(A)
Minimum sample time:	$t_{\min} = \left(\frac{4000}{q} + \frac{120}{r} \right)$ minutes where: q = veh/hour and r = number of samples taken per minute Restrictions: ‘t_{min}’ = 5 minutes in any given hour; ‘q’ =100veh/h and r > 5 samples/min; if ‘q’ < 100veh/h, ‘r’ must be = 60 samples per min, and ‘t_{min}’ = 1 hour.
Traffic counts:	Concurrent volume and composition measurements should be taken
Data analysis:	Calculate $L_{A10,\ 18\text{-hour}}$ using = $\frac{1}{18}\sum_{t=6}^{t=23} L_{A10,t,1-hour}$ Shortened measurement procedures may be used if there is little chance of the LA10 levels for the receiver location being close to the NIR $L_{A10,\ 18\text{-hour}}$ façade level threshold value of 68 dB(A).

Table 17: Summary of UK measurement requirements for Road Traffic Noise

$Lx_{,4m,1m}$ -	$L_{x,1.2m,1m}$	16h	12h	4hr	8hr	24hr	18hr
L_{Aeq}	Mean	1.4	1.4	1.7	1.9	1.4	1.4
	Std. Dev.	2.0	1.8	2.4	1.6	1.9	1.9
L_{A01}	Mean	1.7	1.7	1.9	2.1	1.8	1.8
	Std. Dev.	1.6	1.6	2.0	1.6	1.5	1.6
L_{A05}	Mean	2.0	2.0	2.1	2.0	2.0	2.0
	Std. Dev.	1.6	1.6	1.8	1.4	1.4	1.6
L_{A10}	Mean	2.1	2.1	2.1	1.9	2.0	2.1
	Std. Dev.	1.6	1.7	1.7	1.3	1.3	1.5
L_{A50}	Mean	2.1	2.1	2.0	1.7	2.0	2.1
	Std. Dev.	1.4	1.5	1.2	1.3	1.2	1.3
L_{A90}	Mean	1.9	1.9	1.7	1.6	1.8	1.8
	Std. Dev.	1.1	1.2	1.1	1.2	1.1	1.1
L_{A95}	Mean	1.8	1.8	1.7	1.6	1.7	1.8
	Std. Dev.	1.1	1.1	1.1	1.2	1.1	1.1
L_{A99}	Mean	1.7	1.7	1.6	1.5	1.7	1.7
	Std. Dev.	1.0	1.1	1.1	1.2	1.8	1.0
L_{DEN}	Mean					1.8	
	Std. Dev.					1.8	

Table 18: Difference in dB(A) between 4m and 1.2m assessment positions (source BRE, 2002)

The Nordic countries

Equipment	Class 1 instruments to be verified every 2 years and calibrated before and after each measurement.
Metrics	L_{eq}, L_{Fmax}, L_E.
Frequencies	Weighted and in frequency bands
Type of measurements	Short term measurements are dealt with in detail Long term measurements are only outlined. Combinations of measurements and calculations are included. Reference is made to national prediction methods.
Microphone positions above ground	1,5 m – 2 m
Microphone positions relative vertical surfaces	Flush mounted (+6 dB) 2,0 m in front of façade (+3 dB) Free field (reference) Guidelines are given on how and when to apply the different mounting procedures
Indoor measurements	3 microphone positions in the room
Measurement distance	Any
Meteo conditions	Any, but preference on favourable propagation as these yield better measurement uncertainty.
Operating conditions	The measurement uncertainty depends on the number of vehicles. At least 30 pass-bys for maximum levels.
Corrections	Includes informative methods to determine presence of tones
Measurement uncertainty	Evaluated based on number of vehicles, equipment, meteo conditions and background noise

Table 19: Summary of Nordtest method for road traffic noise

France

Equipment	Class 1 instruments to be verified every 2 years and calibrated before and after each measurement
Metrics	L_{eq} (L_{day}, L_{night}) Reference periods are day (6-22) and night (22-6);
Frequencies	A-weighted.
Type of measurements	The standard distinguishes between 3 different measurements: actual condition, long term traffic and long-term. Long term traffic reflects the long term traffic conditions only and not the long term meteo conditions where as the long term measurement contains all variables. Combinations of measurements and calculations are included. Reference is made to national prediction methods.
Microphone positions above ground	At the receiver (not specified)
Microphone positions relative vertical surfaces	2,0 m in front of façade
Indoor measurements	3 microphone positions in the room. Measured levels are normalized to 0,5s revereberation time.
Measurement distance	Any
Meteo conditions	Stationary meteo conditions are satisfied if the measurement time is in the interval 10 min – 1 hour. Meteo conditions can be ignored at distances below about 100 m. One distinguishes between 3 different meteo conditions: Favourable, homogeneous and unfavourable. Other meteo conditions used for description is radiation and cloud coverage in octas (0/8 is cloudless and 8/8 is fully cloud covered). Maximum wind speed allowed is 3 m/s if L_{Aeq}< 60 dB, 5 m/s for 60-70 and 7 m/s for > 70 dB.
Operating conditions	For short-term measurements 200 (flowing traffic and relatively few heavy vehicles)-500 (pulsating traffic or many heavy vehicles) vehicles are required before one may extrapolate the results. Mean speed is defined as speed superseded by 50% of the vehicles. Two vehicle categories: light and heavy, are used.
Corrections	None
Measurement uncertainty	No details

Table 20: Summary of NF S 31-085

Italy

Equipment	Class 1 and calibration every two years and before and after measurement with calibrator.
Metrics	L_{eq} (L_{day}, L_{night}) Reference periods are day (6-22) and night (22-6);
Frequencies	Weighted and in frequency bands
Type of measurements	Measurement may be executed by sampling or continuous monitoring (long-term);
Microphone positions above ground	4 m above the ground

Microphone positions relative vertical surfaces	1 m from the most exposed façade No corrections are applied for the presence of reflecting surfaces.
Indoor measurements	At the centre of the room, at least 1 m far from any reflecting surface, at an height of 1.5 meters on the floor, executing measurements both with open and closed windows.
Measurement distance	Any
Meteo conditions	Meteorological conditions are taken into account; actually, only wind speed and presence of precipitation are considered, in order to check the validity of the measurement session, introducing no correction to the measured noise level;
Operating conditions	1 week measurements are required.
Corrections	Presence of tonal components (+3 dB), low frequency components during night-time (+6 dB), impulses (+3 dB) and time-limited occurrence of disturbance during night-time (-3 dB, -5 dB).
Measurement uncertainty	Evaluated based on repeatability (operating conditions) , equipment, meteo conditions and background noise

Table 21: Summary of the Italian method for road traffic noise

Poland

Equipment	
Metrics	L_{Aeq} (L_{day}, L_{night}) Reference periods are day (6-22) and night (22-6). L_{Aeq} is often calculated from L_{AE} measurements when the traffic is low.
Frequencies	A-weighted
Type of measurements	Measurements at the source Measurements at the receiver Combinations of measurements and calculations are included. Reference is made to national prediction methods.
Microphone positions above ground	For measurements at the source, microphone is positioned 1.2 m above the ground. If measurements are made at receiver, the microphone is positioned at the place that is of interest (receiver).
Microphone positions relative vertical surfaces	
Indoor measurements	
Measurement distance	Source measurements: If the road is placed in urban area, microphone should be placed 1 m from the road (street) edge. In case of other roads the distance should be 10 m. Receiver measurements: At the receiver

Table 22: Measurement of road traffic noise in Poland

ANNEX 2 MEASUREMENT METHODS RAIL TRAFFIC NOISE

UK

Measurements to determine SELs may only be made in the following circumstances: when railway traffic or site conditions fall outside of the valid ranges of the prediction method, when the guided transport system under consideration does not operate on steel rails (e.g. guided busway systems) and when reference SELs are impractical to obtain.

Section III of CRN stipulates measurement requirements under the following headings:

Track conditions;

Wind conditions;

Measurement equipment;

Measurement procedure (microphone position and sampling);

Analysis of data.

Table 23 summarises the measurement requirements found in CRN Section III.

Heading	Requirements:
Rail surface conditions:	Ballast bed should not be frozen and preferably dry Rail running surface should be dry.
Wind:	Downwind conditions. Avg. downwind speed at height of 1.5m AGL, at a point close to the receiver location, but unaffected by any facades is =2 m/s Max. wind speed in any direction =5 m/s. Microphone windshield to be used Measure only when L_{Amax} from wind noise is 10dB(A) or greater below expected L_{Amax}.
Measuring equipment:	Type 1 instrument to be used. Specification given in BS 6698: 1986 Calibration by accredited laboratory on bi-annual basis.
Determination of SELs	Measure individual SELs for each train pass-by when appropriate – procedure for single vehicles (not complete trains) given in CRN Appendix A1.
Microphone position:	Height 4.5m AGL (1st-floor bedroom level). Mic. Horizontal (grazing incidence). 1m from exposed building façade. Correction for free-field to 1m from façade = +2.5dB(A)
Sampling:	Capture train pass-bys over entire measurement periods, unless mix of trains and speed of trains is fairly constant over the relevant time period. Use of triggers: set triggers to capture pass-bys when levels are greater than 10dB(A) lower than anticipated L_{Amax}. Manual triggering may be done at onset of noise event and continued till train is no longer audible. Need to record train type, speed and direction for each SEL.
Data analysis:	Convert individual train/track-type SELs to train/track L_{Aeqs} (18-hour or 6-hour) based on the CRN calculation procedure. Calculate overall $L_{Aeq,\ 18\text{-hour}}$ and $L_{Aeq,\ 6\text{-hour}}$ based on combining individual train type L_{Aeqs}.

Table 23: Summary of UK measurement requirements for Rail Traffic Noise

ANNEX 3 MEASUREMENT METHODS FOR AIRCRAFT NOISE.

ISO

Equipment	Class 1 between –25ºC to +55ºC.
Calibration	At least once a year.
Metrics	L_{eq}, L_{max}, L_E, L_N (N percent exceedance level).
Frequencies	A-weighted.
Type of measurements	Monitoring $L_{eq,1s}$ or less and sampling L_{pS}.
Microphone positions above ground	At least 4 m. 10 m is recommended.
Microphone positions relative vertical surfaces	At least 6 m from vertical surfaces.
Indoor measurements	None.
Measurement distance	Any.
Meteo conditions	Any, but warning for wind speeds > 10 m/s.
Operating conditions	Each event evaluated has to be verified to be related to aircraft operation.
Corrections	Includes informative methods to determine presence of tones.
Measurement uncertainty	7 pages annex giving guidance to comply with the GUM rules.

Table 24: Summary of ISO/CD.5 20906

UK

Heading	Details
Data acquisition	
Equipment and calibration	1.2m above the ground Microphone at grazing incidence Electro-acoustical measuring chain from microphone to tape-recorder and Calibration as per IEC 561
Test environment	Ideally in open unobstructed hemisphere over a flat and totally reflecting ground surface. Any deviations from this should not cause more than 0.5dB difference to result The cone should be defined by an axis normal to the ground and by a half angle of 80^0 from this axis
Weather	No precipitation RH less than 20%, temperature no less than 5^0c Sound attenuation in the air centred on 8kHz shall not be more than 10dB per 100 metres Wind speed at 10 metres above ground no more than 5 m/s
Data processing	Equipment required to provide spectrum analysis as a function of time is specified in IEC 561

Heading	Details
	Calculation of perceived noise level from measured noise data Calculation of effective perceived noise level
Data normalisation	Differences between test conditions and reference conditions require that ‘adjustments are made’, e.g. differences in speed of aircraft, differences in sound attenuation.
Data reporting	the relevant atmospheric conditions (wind in terms of max, min, average, and direction) comments referring to local topography, ground cover and events that might have interfered with noise readings the aircraft configuration, procedure, and operating conditions and readings of the aircraft position over the relevant time period details of equipment used for flight path measurement and noise measurement and analysis the acoustical readings taken, the ‘adjustments’ to be made and the adjusted figures

Table 25: UK measurements of aircraft noise using spectral analysis as a function of time

The normalised effective perceived noise level obtained at each operating condition shall be averaged arithmetically. Such average results can be expected to have a 90% confidence interval not exceeding ± 1dB established statistically from six tests. The confidence interval for the mean value of a set of measurements can be computed from the standard deviation of the measured values, as a function of the number of measurements.

Heading	Details
Equipment and calibration	Equipment to be used where only the maximum level of the noise events is required (IEC 179) – sound metre with an omni directional microphone Equipment to be used where the variation of level over a period is also required – a recording device to measure the weighted sound level as a function of time Measurements should be accompanied by an acoustical sensitivity check of the measuring system eg pistonphone 124 – dB and 250 Hz
Test environment	Ideally in open unobstructed hemisphere over a flat and totally reflecting ground surface. Any deviations from this should not cause more than 0.5dB difference to result The cone should be defined by an axis normal to the ground and by a half angle of 80^0 from this axis
Weather	No precipitation RH between 30 and 90% Wind speed at 10 metres above ground no more than 5 m/s
Background noise	Background noise to be measured before and after tests. Measurements shall only be considered reliable if the maximum noise level of the aircraft exceeds the background

Heading	Details
	level by 20 dB
Data processing	Single event noise L_{PN} and L_{EPN} Noise exposure in terms of equivalent sound level from a succession of events L_{PNeq}
Data normalisation	Differences between test conditions and reference conditions require that ‘adjustments are made’, e.g. differences in speed of aircraft, differences in sound attenuation.
Data reporting	a) the relevant atmospheric conditions (wind in terms of max, min, average, and direction) b) comments referring to local topography, ground cover and events that might have interfered with noise readings c) the aircraft configuration, procedure, and operating conditions and readings of the aircraft position over the relevant time period d) details of equipment used for flight path measurement and noise measurement and analysis e) the acoustical readings taken, the ‘adjustments’ to be made and the adjusted figures

Table 26: UK aircraft noise measurements with only frequency weighting

Nordic countries

Equipment	Class 1 instruments
Metrics	L_{Smax}, L_E. L_E is used to calculate metrics involving L_{eq}.
Frequencies	Weighted and in frequency bands
Type of measurements	Short term measurements are dealt with in detail Long term measurements are only outlined Combinations of measurements and calculations are included. Reference is made to national prediction methods.
Microphone positions above ground	Normally 10 m. For some surveys 1,5 m can be used.
Microphone positions relative vertical surfaces	Flush mounted microphones are used.
Indoor measurements	3 microphone positions in the room
Measurement distance	Any
Meteo conditions	Any if elevation angle > 45º, else downwind. Atmospheric conditions according to ISO 3891.
Operating conditions	Only general guidelines. No numbers are given.
Corrections	Includes informative methods to determine presence of tones
Measurement uncertainty	Only rough estimates without proper calculations.

Table 27: Aircraft noise measurements in the Nordic countries

ANNEX 4 MEASUREMENT METHODS INDUSTRIAL NOISE

UK

Heading	Requirements
Measurement	Equivalent continuous noise level: $L_{\mathrm{Aeq},T}$ Background noise level: $L_{\mathrm{A90},T}$
Measuring equipment	Equivalent continuous noise level: Type 2 or better instrument or integrating-averaging sound level or better of BS EN 60804. Background noise level: Type 2 or better or better of BS EN 60651 Acoustic calibrator or pistonphone conforming to BS 7189 should be used to check sensitivity before and after readings. Calibration and extensive checks to the performance of the equipment should be carried out every 2 years.
Precautions against interference	Wind, Heavy rain and electrical interference should be avoided. For this measurement windspeeds of over 5 m/s should be avoided even when using a windshield. Measurements would be considered invalid if readings are influenced by the above by more than 10 dB
Reference time interval	1 hr during the day 5 min during the night night is defined as times when the “general adult population are preparing for sleep are actually sleeping.
Measurement positions	Positions, heights and distances from reflecting surfaces should be recorded. Should be outside buildings and a position that will give results that are representative of the specific noise level and the background noise level at the buildings where people are likely to be affected. 3.5m from any reflecting surface other than the ground. Preferred height is 1.2 to 1.5m from the ground.

Table 28: UK measurements of industrial noise

The Specific Noise Level should be determined as a “discrete entity, distinct and free of influence from other noises contributing to the ambient noise, following the appropriate procedures.”

Corrections to noise level readings	
Difference between noise level readings with specific noise present and absent dB	Correction to be subtracted from noise level reading with specific noise present dB
>9	0
6 to 9	1
4 to 5	2
3	3
<3	see below
Note: An estimate of the residual noise during the measurement time	

Table 29: Corrections to noise level readings.

It is possible to determine the equivalent A-weighted sound pressure level of the specific noise $L_{\mathrm{Aeq},T}$ over time interval, T from the equivalent continuous A-weighted sound pressure levels of its components $L_{\mathrm{Aeq},T\mathrm{i}}$ from equation $L_{\mathrm{Aeq},T} = 10\ \lg_{10}\{(1/T)\ \Sigma T_{\mathrm{i}} 10^{0.1\ L\mathrm{Aeq},T\mathrm{i}}\}$
Where
$T = \Sigma T_{\mathrm{i}}$ if components are sequential;
T = maximum value of T_{i} if components are concurrent.

Ensure that the measurement time intervals are long enough to obtain representative values of the equivalent continuous A-weighted sound pressure level.

Rating level

Certain acoustic features can make a noise more liable to be complained about. In these cases 5dB should be added to the specific noise level to ascertain the rating level, otherwise the rating level will equal the specific noise level. These acoustic features include; a distinguishable, discrete, continuous note; the noise contains distinct impulses; the noise is irregular enough to attract attention.

Information to be reported (as appears in BS 4142 :1997):
source under investigation as follows:

- description of source and of specific noise;
- hours of operation;
- mode of operation (e.g. continuous, twice a day, only in hot weather);
- description of premises in which source is situated (if applicable).
- subjective impressions including:
- dominance or audibility of specific noise;
- main source contributing to the residual noise.

location of measurement positions, their distance from the specific noise source and the topography of the intervening ground, distance from specific noise source and any reflecting surface other than the ground including a dimensioned sketch with a north marker;
noise measuring instruments including calibrator or pistonphone used:

- type;
- manufacturer;
- serial number;

- details of the latest verification test including dates.

operational test:
- reference level of calibrator or pistonphone;
- metre reading before and after measurements with calibrator or pistonphone applied.

weather conditions, including:
- wind speed and direction;
- presence of conditions likely to lead to temperature inversion (e.g. calm nights with little cloud cover);
- precipitation;
- fog.
- date and time of measurements.

specific noise level:
- measured noise level(s);
- residual noise level and method of determination;
- specific noise level and method of determination;
- justification of methods;
- details of corrections applied.
- measurement time intervals.
- reference time interval(s).

rating level:
- specific noise level:
- any acoustic features of the specific noise;
- rating level.

background noise level and measurement time interval and in the case of measurements taken at an equivalent location, the reasons for presuming it to be equivalent.

excess of the rating level over the measured background noise level and the assessment.

Written by IMAGINE partner LABEIN

NOISE MAPPING IN SPAIN

There are quite different approaches to develop the urban noise mapping process in Spain.
Here some examples are shown. First of all an example of urban noise mapping applying measurement methodologies. Later on an experience of noise mapping by monitoring noise levels and finally an example of a system to mange the noise mapping and action planning process.

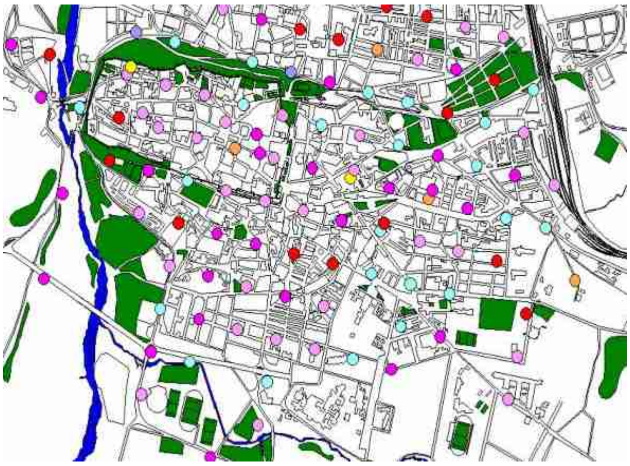
Grid Noise mapping by level measurements:

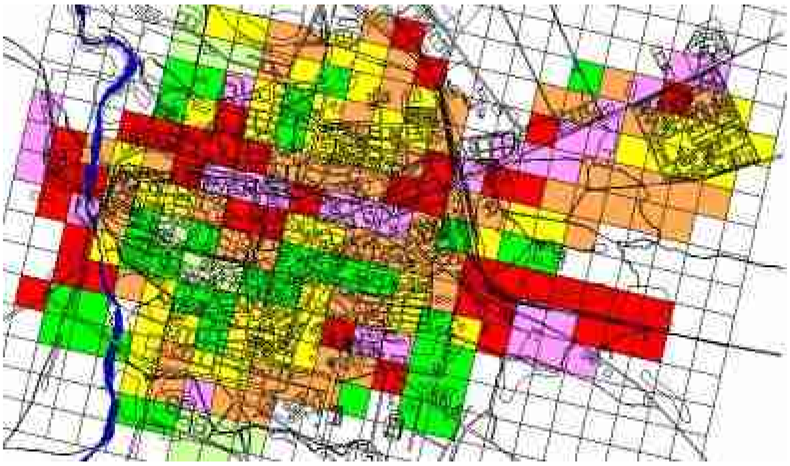
The noise mapping is the result of a noise level measurement campaign on receiver points according to a grid of 200 x 200 m in the city. The environmental noise is caused by traffic, railways, leisure activities and industrial areas.

The methodology is based on 2 short measurements (10 minutes) in eacht daily period (weekend day, weekend night, working day and working night). The results are combined with some monitoring during longer periods (more than one day). The noise levels of different sound descriptors were recorded (mainly L_{Aeq}, complemented with L_{Amax}, L_{Amin}, L_{01}, L_{10}, L_{50}, L_{90} and L_{99}).

The number of results to be represented in these noise maps are quite large: a lot of analyzed points, measured in different periods and using different descriptors.

The following figures show the type of presentation used in such noise maps.

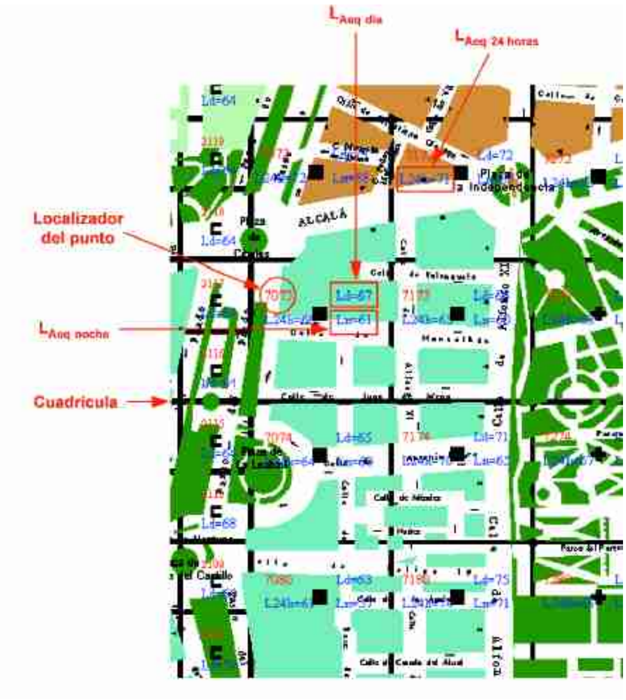


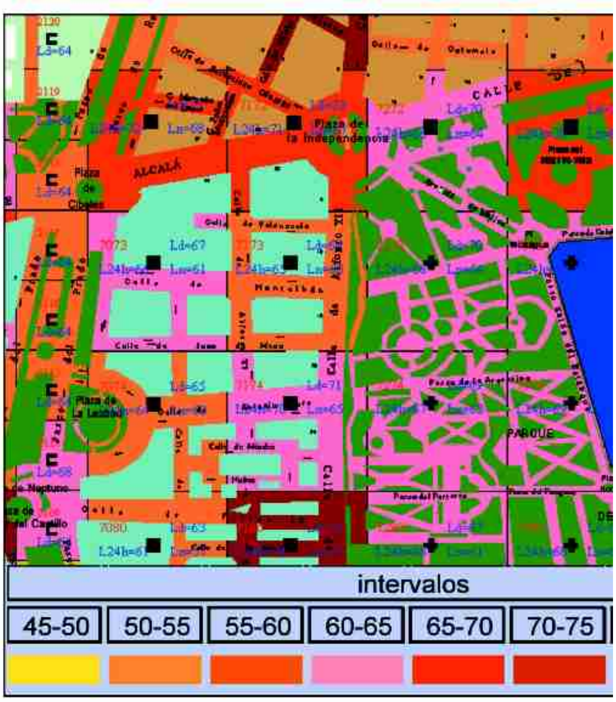


On time noise mapping by monitoring noise levels:

The results of a Grid Noise Mapping by level measurements are being used to build the base for a on time noise mapping. The real time information is gathered by means of a static monitoring network and mobile measuring cars taking levels among the city. This project is nowadays under development and its goal is to create a Permanent Updating System of the Noise Mapping.

Here two examples of the Grid Noise Mapping are included.



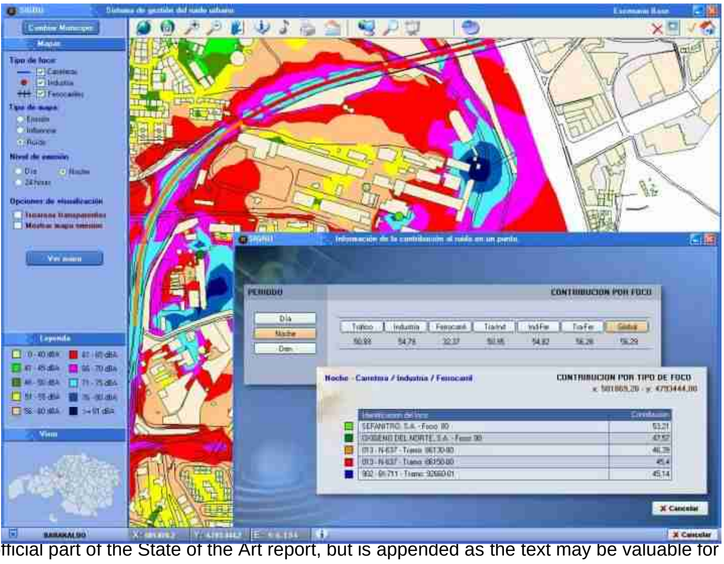


Noise Management System for noise mapping and action planning:

There are also some experiences of Noise Maps created applying calculation methods for road, railways and industrial noise. Different commercial software are being used for that. The methods used are diverse as there is not any Spanish official method.

In some cases the Noise Map results are loaded into a GIS application, becoming a Management System designed to help in the sound environment progress monitoring and in the definition of action plans to reduce noise. Therefore it can give information about the relevant source contributions, it assesses the sound environment in terms of population exposed to noise and it allows to build scenarios in a simple way. These dynamic maps help Administration technicians and Policy makers to define action plans and their benefits and to share the decision process between different Administration boundaries.

The following figures show a source contribution analysis based on the noise map and a assessment of the sound situation by “population exposure to noise” data.



PERIODO

Día

Noche

Den

CONTRIBUCION POR FOCO

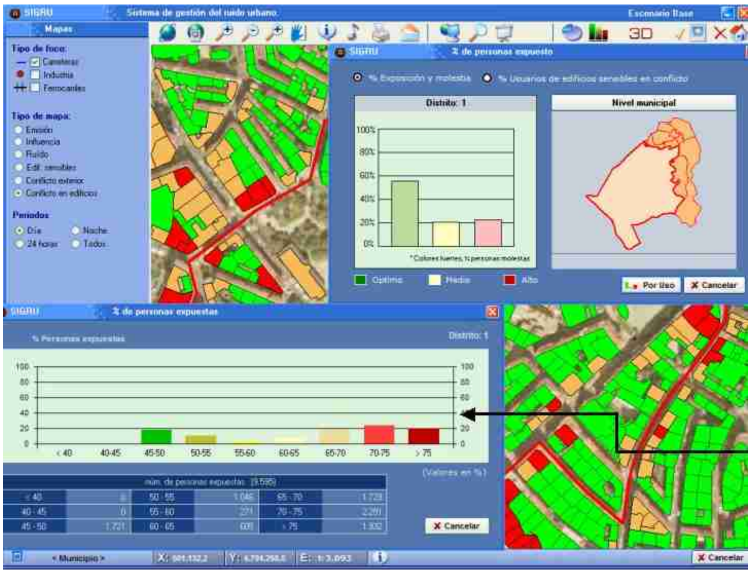
Tráfico	Industria	Ferrocarril	Tra/Ind	Ind/Fer	Tra/Fer	Global
50,93	54,78	32,37	50,95	54,82	56,26	56,29

Noche - Carretera / Industria / Ferrocarril

CONTRIBUCION POR TIPO DE FOCO

x: 501869,20 - y: 4793444,80

Identificación del foco	Contribución
SEFANITRO, S.A. - Foco 00	53,21
OXIGENO DEL NORTE, S.A. - Foco 00	47,57
013 - N-637 - Tramo 06130-00	46,39
013 - N-637 - Tramo 06150-00	45,4
902 - BI-711 - Tramo 92660-01	45,14



Preparation of the EU mapping operation

The transposition of the END into the Spanish legislation has already started. A new Law has been approved last year and its technical and practical regulation is under discussion and hopefully it will be finished by next July.

Regarding to the noise mapping of agglomeration there will be an expertise group which will discuss the practical problem of the END implementation.

Infrastructure Noise Mapping

Up till now, mainly new infrastructure have been studied by means of their EIA. Other analysis were caused by citizen complaints. According to railways noise, during last year the technical requirements to create and fulfill the train emission database were studied.

To answer to the END implementation, some practical pilot project are being carried out to identify the critical points in the noise mapping and to define a common way to solve them or some recommendations to do it.

Written by IMAGINE partner DGMR

NOISE MAPPING IN THE NETHERLANDS

Use of Noise maps

The past few years many small and large scale noise maps have been set up by both national and local authorities in the Netherlands. The primary use for these noise maps are noise policy support and acoustic surveys of cities, major roads and railroads. Recent noise maps have become more and more accurate due to the availability of more accurate input data and increasing performance of noise prediction/calculation software to allow for highly detailed computations. Noise maps are presented as color maps showing both thematic data and contour lines and are in some cases available to the public on/via the internet. Some of the internet noise maps also allow users to select a specific (future) scenario, a specific period or a specific noise type. In some cases the different noise types are cumulated to one integral noise map to help identify noise hot spots. As of this moment there are no practical guidelines available for noise mapping in the Netherlands.

Input data

The availability of detailed and accurate data needed to setup the noise maps has increased, a lot of data for e.g. ground characteristics, land use, buildings and traffic flow are available on both a local and national scale is readily available from the authorities and several commercial data suppliers. Some parties have developed tools to support the transformation of data and to speed up the process of noise mapping. Examples of widely available input data for noise maps in the Netherlands:

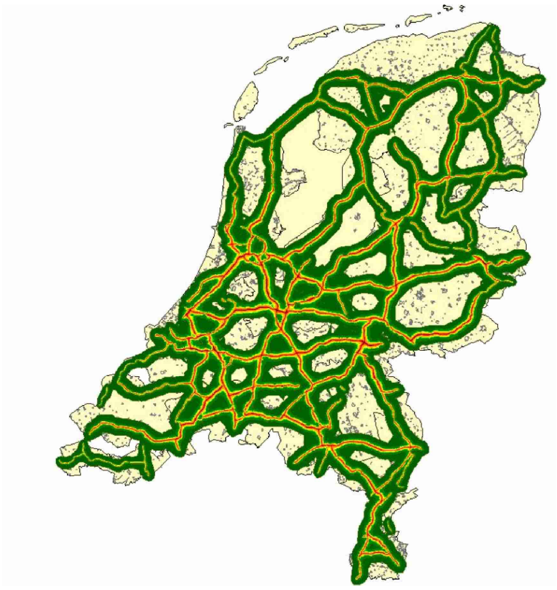
- NWB (National Road Network), all streets, country roads and highways;
- AHN (Actual Height Information Netherlands), detailed height information of ground level and buildings;
- Central Bureau of Statistics with GIS data for neighborhoods, land use etc;
- Topographic Service data like buildings, houses in great detail (TOP10).

Most authorities exchange this kind of data based on data-for-data contracts, so they can use data at low cost or no cost at all. Increasing collaboration between different levels of authorities and commercial data suppliers has lead to more usable data, suited for noise, air pollution, traffic flow management on any required scale.

EU Mapping operation

In 2003 two new methods (SKM1 and SKM2) have been developed which allow the Dutch methods for industrial noise, road traffic noise and railroad traffic noise to be used as interim methods. SKM will be the base method for noise calculations and setting up noise maps in compliance with the END. Existing noise prediction software and noise mapping software will be adapted to this new method.

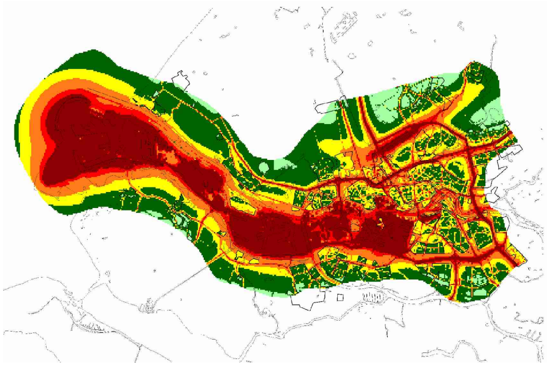
Some examples of multi source noise maps in the Netherlands



The Directorate General of the Ministry of Transport has developed the noise mapping system Silence 2 for national, regional and trajectory scale noise calculations and noise maps. Silence 2 is a new application for the standardization of noise mapping on the Dutch (6000km) highways. It provides a filled database and a Predictor Road traffic SRM2 calculation core in a user-friendly ArcView GIS environment. Silence can be used to formulate environmental policies on improving the quality of life. Silence has tools for automatic conversion of data, performing calculations, presentation of noise maps, determining the number of exposed people and residences, houses and supports dynamic noise maps. Silence 2 allows for adjusting the detail of data and customization of the accuracy of noise mapping. Silence 2 is used by all the departments of the Dutch Ministry of Transport.

The railroad traffic counterpart is also available to monitor the impact of railroad traffic on the environment.

The City of The Hague, department of city development, produced a noise map for the larger part of the Hague. For this 70km2 noise map all road noise and railroad noise in the city of The Hague was calculated for various periods. This high detail noise map is for example based on individual buildings, tracks and ground characteristics. The results are presented in a noise map and will be used for making decisions about building new houses, apartments buildings, large scale building projects and city noise policies in combination with other noise sources. This is also a pilot project where very accurate and high density flight data was used to determine ground level heights and building heights. The railroad network was built by using the Dutch ‘Acoustic Time table’ containing all train traffic flows within the Netherlands. The Dutch National Road Network, containing all roads/streets in the Netherlands was used to generate the road network.

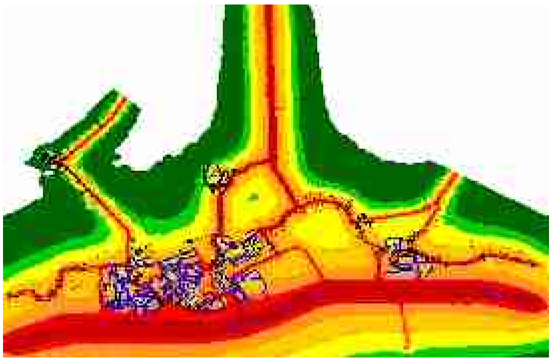


DCMR Environmental service Rijnmond Schiedam developed the noise map “Deltaplan Noise”. The objective of this plan was to calculate the noise annoyance in the Rotterdam area, to locate the most annoyed spots and to look for solutions and measures. This noise map combined several noise sources such as Industrial sources (harbor area), Roads, Railroads, Airplanes, Ships and the cumulations of these different noise types. The calculations were converted to annoyance levels (in accordance with the Miedema weighting) and compared with questionnaires.

The City of Vlaardingen, environmental service has developed a system to monitor the environment in the city. Different noise types can be monitored - industrial sources, road traffic, railroad traffic, shipping traffic noise - as well as air pollution and external safety.) These Noise Maps were based on dense calculation grids (10m x 10m). Calculations were made by using urban area screens according to a Dutch method(developed by DGMR) for simplifying screening and reduction in urban areas. GIS was used to create noise maps, display noise emissions per street, cumulate different types of noise and confrontation with complaint data.

The City of Etten-Leur has made a Noise Map for road traffic and railroad traffic noise for the whole of City of Etten-Leur for 2004 and future scenarios 2010 and 2015. These Noise Maps were based on very dense calculation grids and makes use of urban area screens to simplify noise calculations and preservation of accuracy.

The City of Woerden, department of environmental control performed an inventory of future noise levels from different sources, both separately and cumulatively. Additionally, small-scale studies have been carried out for urban development planning and noise abatement measures.



Schiphol Airport produced a noise map of the total noise annoyance around Schiphol Airport. This includes Industrial Noise, Railroad traffic, Road traffic, Airplanes and cumulations of the different noise types. The noise contours were used to determine the number of exposed houses and the number of exposed residents and inhabitants.

Written by IMAGINE partner KILDE

NOISE MAPPING IN NORWAY

4,5 mill people live in Norway. About 75% live in densely populated areas, i.e. in towns and valleys along the main traffic routes or in concentrated areas between sea and mountain. The noise sources are often fairly close to the dwellings and the topography is complex.

The first serious survey of the noise situation in Norway was carried out in the mid-1970s (1). The investigation found road traffic to be the most important source of noise disturbance. In dwellings, approximately 9% of the population was "*seriously disturbed*" by this source, whilst aircraft noise affected an additional 2% and industry as well as railway traffic caused a similar problem for less than 0,5% of the population. The noise levels were calculated in a simplified manner for a number of representative situations and then extrapolated to national level. This mapping resulted in governmental actions (2), noise research and the development of appropriate noise reduction and planning tools. With updates, some of the methods are still used today.

Noise mapping on a national scale has in recent years been carried out with two different purposes:

1. Regulations under the Pollution control act use limit values for local air pollution and noise. The required noise mapping included all dwellings with indoor noise level, L_{Aeq24h} greater than 35 dBA, and as a next stage, noise reduction in the most severely affected areas within 2005 (3).
2. The Government decided in 1999 to evaluate various national noise reduction aims, as well as possible strategies and costs of reducing the noise impact significantly by 2010 for all major sources (4). The report concluded that the national benefits would exceed the costs for a strategy aimed at reducing the total impact by 15%.

The noise mapping involves three separate steps, the calculation of noise levels for each type of noise source, the identification of buildings (dwellings, number of inhabitants) in each noise zone and estimation of overall noise impact (e.g. total number people seriously affected by the noise situation).

Calculation methods have been developed for all major external noise sources, mostly in cooperation with the other Nordic countries. For road traffic noise the appropriate computer programme for noise and air pollution is described in (5). The noise part is a simplification of the Nordic calculation procedure (6). Airport noise zones are established through the use of the computer program NORTIM, based on the US Integrated Noise Model (INM).

Railway noise is calculated using the Nordic procedures (7), whilst noise from shooting ranges is based on a Nordtest procedure described in (8). These two methods are to a large extent derived from (9) which covers external noise from industrial and sites. Reference (9) is also used for such diverse external sources as motor sports, transport terminals, building and construction activities, etc. The computer programme NOMES, developed by KILDE Akustikk, cover all these sources.

The noise impact is described in terms of the Noise nuisance index, SPI, which is a development of indicators describing the number of people seriously disturbed by the noise situation. The investigations reported in (4) indicate that

- Approximately 30% of the national population is exposed to outdoor levels exceeding L_{Aeq24h} = 55 dBA with road traffic noise alone responsible for approximately 22%.

- Approximately 9% of the population is seriously disturbed by road traffic noise, 1,6% by industrial activities, 0,5% each by aircraft noise and railway traffic, and 0,8 by other sources.

The indicator "seriously disturbed" describes an unacceptable noise situation in a home. For each person "seriously disturbed", it may be estimated that an additional two persons have a reduce life quality due to a lesser degree of disturbance. The types of disturbance can be identified as sleep and rest problems, interference with communication and listening and more diffuse effects relating to stress, concentration, work, etc.

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Written by IMAGINE partner AEA Technology Rail UK

NOISE MAPPING IN THE UK

Road noise mapping

Road noise mapping has not been carried out in the UK to any great extent until recent years. The first major exercise was undertaken by the City of Birmingham in conjunction with the Department of the Environment Transport and the Regions and reported in February 2000. LIMA software was used to map 880 km of road using the UK "Calculation of Road Traffic Noise" (CRTN) procedure which was originally formulated for use with the Noise Insulation Regulations. This procedure predicts L_{10} but these values were converted to $L_{eq.}$ Day time (07.00 – 23.00) and night time (23.00 – 07.00) contours were produced.

The London Boroughs of Brent and Tower Hamlets and Westminster City Council have been active in producing road noise maps in the early 2000s, using Mithra, Atkins and LIMA software respectively.

In 2002 the Scottish Executive commissioned Stanger to carry out a study into the monitoring and mapping of environmental noise. This study identified data requirements, data sources and missing data for road noise mapping, but did not produce any maps.

Also in 2002, the London Borough of Hounslow produced noise contour maps including road noise predicted with IMMI software implementing CRTN, as a tool to explain to residents changes in operating practice at Heathrow Airport.

The UK is currently carrying out a pilot mapping study, of selected areas of England only, to prepare itself for the requirements of the Environmental Noise Directive. A budget of £13m has been allocated for this project. To date (February 2004), the only contract awarded under this project is for the mapping of road noise in London, where 13% of residents consider road traffic noise to be a serious problem. Atkins have been awarded this contract, and are using their NoiseMap 2000 software for the task, applying the UK "Calculation of Road Traffic Noise" procedure which was formulated for use with the Noise Insulation Regulations. L_{10} values are converted to L_{eq} using a process developed by the Transport Research Laboratory. Atkins are working with the Greater London Authority and 33 London Boroughs in this project, and commenced with a trial mapping of 9 km^2 of Southwark. The mapping programme is now nearing completion.

The National Assembly for Wales are also about to award a contract to carry out a pilot mapping study of two 1 km^2 areas in Cardiff (Spring 2004), with roads as the major source to be considered.

Railway noise mapping

In the UK, railway noise maps were produced as part of the Birmingham mapping project (see 2.1). A combination of the UK "Calculation of Railway Noise 1995" (CRN) methodology and the German Schall method applied within LIMA software was used in this instance.

In 2001 a study was carried out for the UK Commission for Integrated Transport by AEA Technology Rail and the Civil Aviation Authority comparing the environmental impact of short haul air travel and rail travel in Britain. The positions of the 90 dB(A) and 100 dB(A) SEL contour was mapped along several inter-city rail routes for typical traffic, allowing the number of people exposed to that level per passenger carried to be calculated from GIS data.

The 2002 Scottish Executive study examined the data requirements and sources for railway noise without producing any maps.

The Hounslow mapping exercise in 2002 included railways (a surface running section of the London Underground system), modelled using an ISO9613-based procedure in IMMI software.

Within the current England pilot study, railway modelling issues are being addressed prior to the commencement of mapping. The main areas of concern are the effects of rail head roughness on rolling noise (CRN and SRM assume a rail head in reasonably smooth condition) and establishing sources of input data for the modelling (eg traffic flows and speeds, vehicle types, track type, elevated structure type, cross sectional dimensions of track and adjacent land and structures). The global and local effects of rail head roughness have been considered in a research study for the Department of Environment, Food and Rural Affairs (Defra), the results of which are about to be published. Data sourcing is still being worked on, although it is expected this will be sufficiently well advanced by the middle of 2004 for rail noise mapping of England to commence.

The imminent Welsh pilot study includes a number of urban railway lines.

Airport noise mapping

Annual contours of noise exposure are produced by the Civil Aviation Authority Environmental Research and Consultancy Department (ERCD) for the airports at Gatwick, Stansted and Heathrow using the ANCON model. Similar approaches have been used by ERCD at the airports at Manchester, Birmingham, Glasgow, Aberdeen, Luton, Leeds-Bradford and Norwich.

ANCON was used to predict aircraft noise contours from Birmingham Airport in the Brimingham study reported in 2000.

In the 2001 AEA Technology/CAA study for the Commission for Integrated Transport comparing rail with air, the 90 dB(A) and 100 dB(A) SEL contours were calculated around a number of airports using ANCON, allowing numbers of people exposed to these values per passenger to calculated from GIS data.

The 2002 Hounslow noise maps used the FAA’s Integrated Noise Model (INM) to predict contours from Heathrow traffic.

Aviation noise contours will be included within the England pilot noise mapping project, probably during 2004.

Industrial noise mapping UK

There has not been a large amount of industrial noise mapping to date in the UK, although the England pilot mapping study will include consideration of industry, probably during 2004.

The Birmingham study included 16 premises, with noise measurements being taken at each site in order to establish the sound power level of the sources. This information was then fed into the LIMA software allowing propagation, and hence noise contours, to be produced.