Journal of Sound and Vibration (2000) **231**(3), 961–973
doi:10.1006/jsvi.1999.2532, available online at http://www.idealibrary.com on IDEAL®

METHODS AND TOOLS FOR MONITORING AND PREDICTION OF THE LARGE-SCALE ENVIRONMENTAL IMPACT OF RAILWAY NOISE

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(*Received in final form* 23 *September* 1999)

Due to environmental impact regulations there is a demand for methods and tools to determine noise reception levels near railway lines. Currently, a wide variety of methods and tools is available. Fast computers now enable us to develop powerful tools that combine simplified prediction methods with GIS systems. These new systems allow the study of noise reception levels and environmental impact on a large-scale (complete network, national or international), while more detailed and labour-intensive methods and tools are used when demanded by law. This paper presents a brief overview of the noise prediction methods and tools used in the Netherlands. The focus is on the advantages and restrictions of the different methods. Finally, the paper gives an overview of the actual advantages and restrictions of the recently extended Gerano method Gerano98 (Geographic Railway Noise). Gerano was originally based on the "basic Dutch calculation rules for railway noise". Gerano98 was extended using simplified prediction schemes for the most relevant parts of the "detailed Dutch calculation rules for railway noise". This most recent calculation method, combined with geographic input features, provides the possibility of determining noise impact and the noise measures to be taken on both the medium and large scale. Examples of the application of the methods and tools to specific (medium- and large-scale) projects are provided. The medium-scale project presents the results of a selection of the prefered line between Amsterdam and Zwolle. The large-scale project (the complete Dutch railway network) shows the results of the comparison of noise measures at source with noise barriers or housing insulation. For both projects the applicability and the usefulness of the methods in these situations is discussed. In conclusion four developments of the Gerano concept are described which have recently been finished or will be so in the near future.

1. INTRODUCTION

This paper presents a brief overview of the standard noise prediction methods and tools which are used in the Netherlands. Also a description is given of a special purpose GIS (Gerano) developed by NS Technisch Onderzoek for large-scale noise studies. The advantages and restrictions of the different methods are highlighted.

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In the conclusion the application of Gerano to medium- and large-scale projects is provided: use of Gerano for the development of the Dutch railway line between Amsterdam and Zwolle and use of Gerano for the development of noise emission quota as a supplement to current noise legislation.

2. DUTCH PREDICTION MODEL

The Dutch prediction model [1] is used mainly to obtain the noise reception level in a particular area. The area of interest varies from about 1 km^2 when noise reception levels are required for a small urban development to 250 km^2 for global studies where ranking of different variants of new railway lines is required. Building a calculation model with software which includes the Dutch calculation model is labour intensive.

The Dutch prediction model for railway noise [1] can be used at two different global levels:

1. The basic method (SRM I) is used for situations with little variation along the railway line and without noise reduction by noise barriers and other obstructions.
2. The detailed method (SRM II) is used for situations with many differences along the railway line or with noise reduction by noise barriers and other obstructions.

2.1. NOISE EMISSION

Figure 1 shows schematically the main components of and differences between the sound emission models of the two calculation methods. Method SRM I only calculates an overall dB(A) level and represents the energy of the sound source as one line source at 0.25 m above the track. The more sophisticated method SRM II calculates each octave band and represents the energy for normal trains as 2 line sources (0.0 and 0.5 m above the track) and for high-speed trains such as the French TGV at 4 line sources (0.5–5.0 m above the track).

2.2. NOISE PROPAGATION

Figure 2 shows schematically the main components of and differences between the sound propagation of the two calculation methods. Method SRM I calculates only "infinite straight railway lines" without noise reduction by screens and other objects. The average emission of that line is a weighted sum of the sound emission of the section within a length of 4 times the distance between the line and the reception point. Because the basic assumption of the "infinite straight line" only the minimum distance d is taken into account.

Method SRM II calculates the sum of the individual reception level for (1) each section, (2) each sound source and (3) each octave band. Within each segment there is an equal noise emission and sound reduction. The maximum angle of a segment

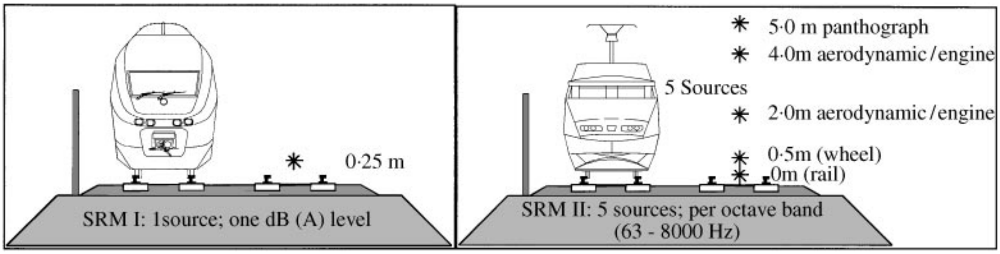

Figure 1. Main components of the sound emission of the methods SRM I and SRM II of the basic Dutch calculation rules for railway noise.

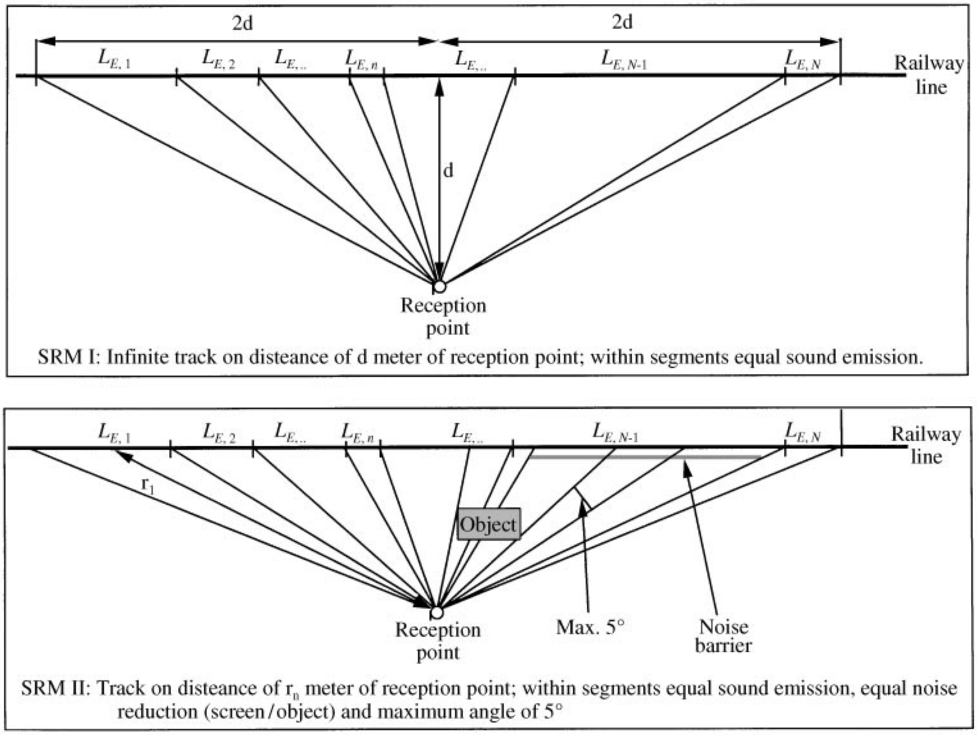

Figure 2. Main components of the sound propagation of the methods SRM I and SRM II of the basic Dutch calculation rules for railway noise.

is 5°. Because the distance between the track–segment and the reception point is determined by each individual calculation, the method is suitable for different parallel and curved tracks.

The two different calculation methods have been implemented in several commercial software tools. Most available tools concentrate on one of the two methods and are primarily used for local studies of railway lines from 1 to 100 km. SRM I is mainly used for simple situations with one railway line and little noise reduction by barriers and buildings. SRM II is mainly used for more sophisticated situations with many noise reduction by barriers and buildings and with more than one railway line. Comparison of the calculated sound levels with environmental parameters such as dwellings and inhabitants is usually performed in separate general Geographical Information Systems (GIS). Gerano is an example of a special purpose GIS with special noise calculation methods based on SRM I as well as on SRM II.

2.3. NOISE RECEPTION

Both SRM I and SRM II calculate the equivalent A-weighted noise reception level in one of three periods within 24 h. These periods are day (07:00–19:00 h), evening (19:00–23:00 h) and night (23:00–07:00 h). The overall 24 h value is the maximum of $L_{Aeq,day}$, $L_{Aeq,evening} + 5$ and $L_{Aeq,night} + 10$. This overall level is compared with the limit level in Dutch noise legislation.

3. GERANO98

Gerano is the platform for medium- and large-scale environmental studies of transportation noise. Gerano has been developed by NS Technisch Onderzoek for the Environmental Section of the NS Infrastructure Departments. The latest software tool of the Gerano platform is Gerano98. Gerano98 is used for:

- decision support systems for development of noise legislation.
- global studies where ranking of various proposals for different new railway lines is needed.
- large-scale studies of the effects (additional noise measures and disturbance) of noise reduction of rolling stock and tracks.
- management of the noise emission from the complete Dutch railway network.

3.1. COMPONENTS OF GERANO98

The components of Gerano98 are:

- Acoustic calculation method for emission levels of railway noise.
- Traffic line typical data (i.e., number of vehicles, speed, track, noise emission).
- Geographical map of the traffic lines.
- Geographic oriented data (i.e., urban areas, number of houses, number of inhabitants).
- Geographic data-collection algorithm.
- Acoustic calculation method for reception levels of railway noise.
- Tool for the noise nuisance act to determine (cost of) noise measures.
- Tool to determine the number of annoyed people.
- Tool to determine the area within a noise contour line.
- Visualization tool for noise emission (difference for two situations), number of trains, track construction, urban areas, noise barriers, noise contour lines, contribution of freight trains to the total noise emission levels.

These components are shown schematically in Figure 3.

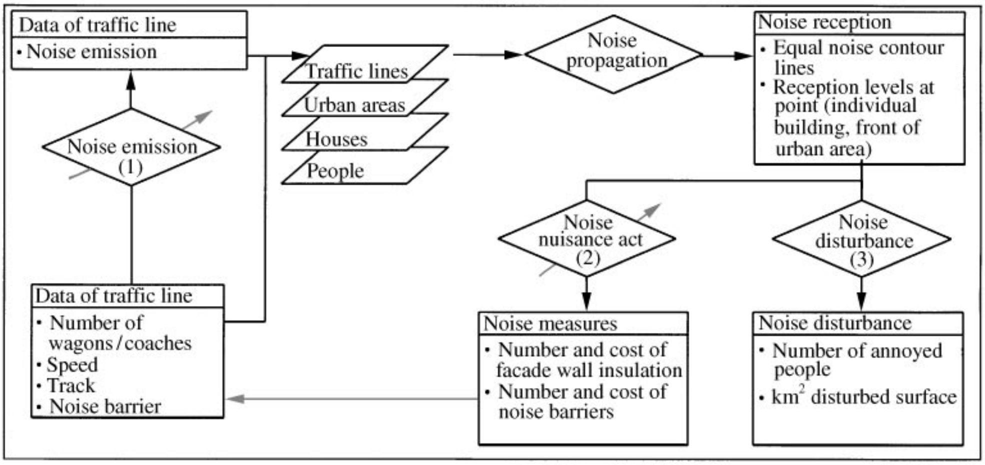

Figure 3. Components of Gerano98.

3.2. NOISE CALCULATION METHOD

Gerano98 contains the noise emission formulae of the SRM I method. Definition of future scenarios for new (low noise) train types can be carried out easily by changing the constant *a* and *b* (see Table 1) in the software. The same can be performed for new (silent) tracks. The noise propagation of an individual line is calculated using SRM I. The noise reduction of finite barriers is calculated by simplified formulae of SRM II and a representative spectrum for railway noise. As with the SRM II method, Gerano98 is able to calculate the total reception level of different kinds of railway lines. The main features of the noise calculation formulae of Gerano98 are summarized in Table 1. Main restrictions of the calculation method are:

- the combination of high-speed trains (with elevated noise sources) and noise reduction by barriers; as a result of the noise source being placed at 0.25 m, the noise reduction will be overestimated.
- the accuracy of the calculated reception levels behind the first row of buildings of an urban area; a general reduction will be calculated for the noise reduction of the urban area. In reality, this reduction varies from location to location.
- the combination of noise reduction of urban areas and noise reduction of noise barriers; in this calculation method both the reduction of the barrier and the urban area is taken into account. In reality, only the noise reduction of the barrier (high barrier and low buildings in urban area) or the urban area (low barrier and high buildings in urban area) can be dominant. Noise reduction by this combination is overestimated.

3.3. CALCULATION METHOD FOR DISTURBANCE AND MEASURES BASED ON THE SIMULATION OF THE NOISE NUISANCE ACT

Gerano98 can express the environmental impact in terms of two quantities:

- number of square kilometres within noise contours;
- number of annoyed people.

TABLE 1

Overview of noise calculation formulas used by Gerano98

Noise emission (1)	
$E = 10\log\left(\sum_{c=1}^{10} 10^{Enr,c/10} + \sum_{c=1}^{10} 10^{Er,c/10}\right)$	$E_{r,c}$ noise emission of trains of category c with brake *off*
	$E_{nr,c}$ noise emission of trains of category c with brake *on*
$E_{r,c} = a_{r,c} + b_{r,c}\log v_{r,c} + 10\log Q_{r,c} + C_{b,c}$ $E_{nr,c} = a_{nr,c} + b_{nr,c}\log v_{nr,c} + 10\log Q_{nr,c} + C_{b,c}$	a constant for initial strength of noise emission b constant for relation between speed and noise emission v speed Q number of coaches/wagons per hour C_b additional bonus for track construction
$E_s = 10\log\left(\frac{1}{127}\sum_{i=1}^{n} \phi_i 10^{Ei/10}\right)$	ϕ_i angle of reach of line with equal noise emission (from reception point) n number of lines with equal noise emission within observation area
Noise propagation	
$D_{geo} = 10\log(r)$	r distance between reception point and railway line
$D_{air} = 0.016r^{0,9}$	
$D_{ground} = 3B^{0,5}(1 - e^{-0,03r})(1.25e^{-0,75(0,6hrail+0,5)} + e^{-0,9hrec}) + 1.6B - 1.8 - 3(1 - B)(1 - e^{(-0,01r)/(hrail+hrec+0,4)}$	
$D_{meteo} = 3.5(1 - e^{-0,04((r/(hrec+0,6hrail+0,5))-5)})$	h_{rail} height of the rail h_{rec} height of the reception point
$0 \leqslant D_{urban} \leqslant 5$	Constant value for reception point in urban area
D_{screen}	Based on Maekawe and works with the Fresnel number and a standard spectrum for railway noise
Noise reception	
$L_{Aeq} = E_{s,day} - D_{geo} - D_{air} - D_{ground} - D_{meteo}$	

The number of annoyed people is based on research formulas by Miedema [2]. The relation between noise reception levels and the number of (seriously) annoyed people is given in Figure 4.

The method of the calculation of measures based on the simulation of the noise nuisance act is described by Janssen [3].

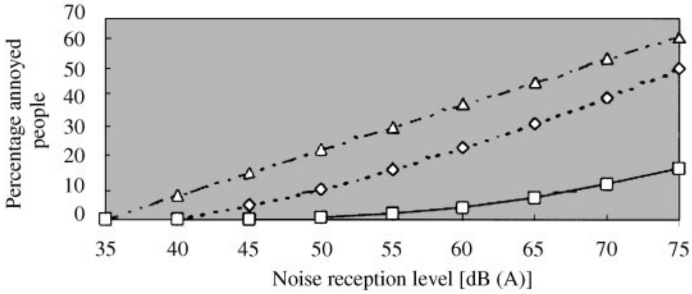

Figure 4. Relation between the noise reception level at the facade wall and the number of (seriously) annoyed people: – –△– –, moderate; ----◇----, normal; ——□——, seriously.

4. EXAMPLES OF THE APPLICATION OF GERANO98

4.1. THE HANZELIJN

During the development of the railway network between Amsterdam and Zwolle, NS Railinfrabeheer (Infrastructure Management) is concerned with ranking different options (see Figure 5). One option is to modify the existing line between Amsterdam-Amersfoort–Zwolle; another option is a choice of new lines between Lelystad–Zwolle. The final ranking is based on a weighted sum of noise, other environmental aspects, and the additional value for the rail transport system and costs.

The calculation of noise quantities (1) number of square kilometres within equal decibel lines; and (2) number of seriously annoyed people, is based on future scenarios of the traffic density lines. The number of annoyed people in the noise reception is calculated at an individual point with unique zip code. The number of people for each zip code is based on information from the local authorities. The position of urban areas (for noise reduction behind the first row of building of this area) is based on digital topographical maps. In addition to the calculation of noise, the impact of vibration is calculated by counting the number of people within an equal distance contour.

The results of the noise and vibration impact of the development of the rail network between Amsterdam and Zwolle are given in Figure 6 [4,5].

4.2. EFFECTS OF LIMIT LEVELS AND THE INTRODUCTION OF NOISE-EMISSION QUOTA

On behalf of the Ministry of Housing, Spatial planning and the Environment, a group of experts can establish a noise emission quota. A noise emission quota establishes the maximum noise emission for a particular section of track. Change of the current noise legislation and the limitation of the noise emission levels is required since a small but steady creep of noise pollution along existing lines is currently disregarded.

This study provides an insight into the effects of the noise levels and the introduction of noise emission quota. The work is carried out by NS Technisch Onderzoek in co-operation with the National Institute for Health and the

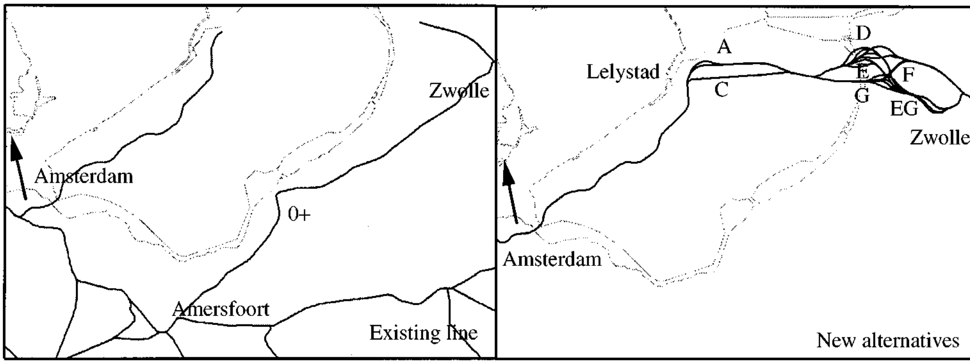

Figure 5. Alternative of the development of the railway network between Amsterdam and Zwolle.

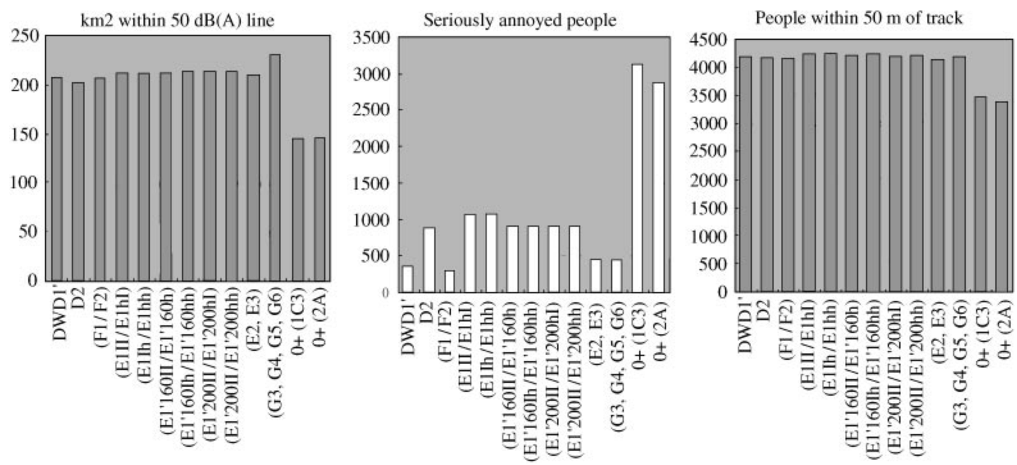

Figure 6. Noise and vibration impact of the development of the rail network between Amsterdam and Zwolle.

Environment (RIVM) on behalf of the Ministry of Housing, Spatial planning and the Environment, NS Railinfrabeheer (Infrastructure Management) and Railned (Rail Capacity Manager).

The reference emission level for the introduction of the noise quota is the emission level for the year 1997. The reference situation for the long-term effects is the predicted situation for 2010. A prediction of the volume of traffic has been made specifically for 2010, which includes the growth of rail traffic predicted and desired by the government. Two scenarios are considered with regard to the composition of the rolling stock fleet in and track constructions in 2010:

- The rolling stock fleet and track constructions are comparable to the current situation with regard to the acoustic properties.
- The passenger stock consists entirely of quiet trains (in other words, trains with "smooth" wheels which means a reduction of 7 dB(A) as compared with the old passenger trains) and 80% of the freight wagons being 7 dB(A) quieter than the current freight wagons. In addition, the wooden sleepers are replaced by concrete sleepers which are approximately 2 dB(A) quieter.

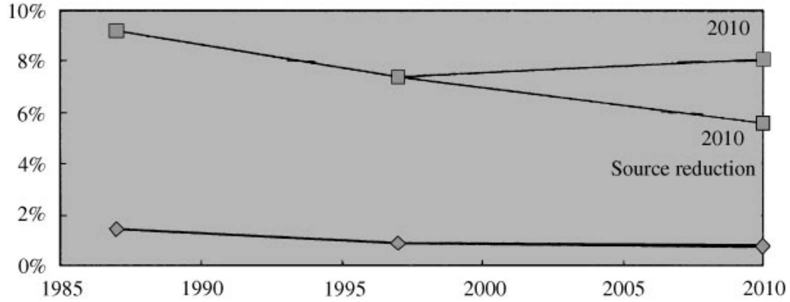

Figure 7. Noise impact of the introduction of noise emission quota (situation 1997) and the effect of noise reduction at the source.

At the same time, an indication is given of developments on the rail network during the past 10 years by comparing the 1997 situation to the 1987 situation.

The noise impact of the introduction of noise emission quota and the effect of noise reduction at the source is given in Figure 7 [6].

Noise reduction at the source requires less noise barriers to be used along the 3000 km long railway network in The Netherlands. Introduction of the noise emission quota (situation 1997) with future scenario 1 (comparable rolling stock) requires an addition of 600 km noise barriers and 2000 insulated houses. The cost of these measures is approximately 850 million ECU. If it is possible to realize the future scenario 2 (noise reduction at the source) this can be reduced to 65 km of noise barriers and 90 insulated houses. The cost of these measures is then approximately 80 million ECU. The cost of the noise reduction at the source is not quantified. An additional study is presented in references [7,8].

5. NEW DEVELOPMENTS OF THE GERANO CONCEPT

To conclude, four new developments of the Gerano concept are described which have been finished recently or which will be carried out in the near future:

1. Extension of Gerano98 with a more detailed noise calculation method (started in September 1998).
2. Development of Eurano for noise calculation on a European scale. Eurano can be seen as a decision support system for cost-benefit analysis of railway noise control by a combination of reduction at the source and barriers on a European source (completed in May 1999).
3. Development of a noise simulation unit for communication with inhabitants near new line infrastructure (completed in November 1998).
4. Development of a similar prediction tool for large-scale environmental studies of road traffic noise.

5.1. ACCURACY UPGRADE OF THE CALCULATION METHOD

For basic large-scale environmental studies the Gerano98 calculation method provides ample effectiveness and accuracy. However, a simple data model in combination with a smart calculation model is required to reduce the time needed for data acquisition and calculation. The restrictions of the present Gerano tool described in Section 3.2 do not provide sufficient accuracy for calculation of the noise reception levels at an individual house, nor for the accuracy of the calculation of noise contours for the development of small urban areas.

To meet the requirement of a more accurate calculation method, the development of SRM II in Gerano is started in September 1998 and will be finished in 1999. With this method, calculations are performed for each octave band and for different heights of the noise sources. With the capacity of present computer systems this method is mainly effective for small and medium-scale studies (up to about 500 km railway line).

5.2. EURANO: CALCULATIONS ON A EUROPEAN SCALE

On behalf of the UIC and under the chairmanship of the SBB, NS Technisch Onderzoek started to develop the Gerano concept into Eurano99. Eurano99 is the software tool for the purpose of studies to gain insight into the results of noise reduction of railway traffic at source on a European scale. The study determines the costs and benefits of noise reduction at source. The current area of interest is the freight line Rotterdam (NL)-Milano (I) and a French freight line from Bettenbourg (B) to Lyon (F) (see Figure 8). In addition to the main features described in section 3, Eurano99:

- will have a user friendly geographical data input module and stores its railway line-related data in an easy accessible MS Access database.
- works either with the co-ordinate system of the four participating countries (CH, D, F, NL) or with a general map of Europe.
- calculates using one adapted calculation model with the possibility of defining 30 different types of trains. The noise characteristics of an individual train type

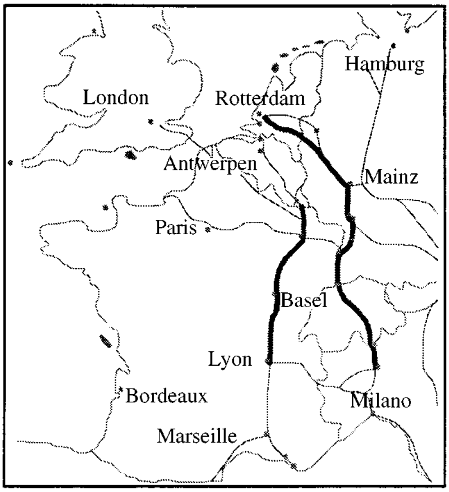

Figure 8. Calculation of the environmental impact of two mayor European freight railwaylines with Eurano99 for the UIC study 'Cost Benefit Analysis' and the ERRI project 'Economical studies'.

are defined by a set of train-type-dependent parameters such as *a* and *b* in the formulae in section 3.

From the study (Comparison of some prediction models for railway noise used in Europe), performed for ERRI [9], it can be concluded that for large-scale environmental studies the prediction models for the participating countries are comparable. The definition of the different models provides the possibility of applying the Gerano concept and defining a single calculation formula for the calculation of equivalent A-weighted noise levels.

Eurano99 will be used to calculate the environmental and economical effects of potential noise reductions. Together with the Silent Freight, Silent Track and Eurosabot research project, this study will be able to quantify the environmental effects. It will determine the best mix of noise control measures to meet more stringent legislation and possibly growing rail transport.

5.3. SIRANO: SIMULATOR OF RAILWAY NOISE FOR RESIDENTS NEAR NEW INFRASTRUCTURE

In order to communicate the results of a number of noise studies (for example the effects of adapting an existing line or constructing a new line) NS Railinfrabeheer asked NS Technisch Onderzoek to develop a noise simulator. This simulator is a combination of the noise calculation model and the sound reproduction module of the noise simulator, which was developed for the high-speed train from Amsterdam to Paris and the user interface and data (acquisition) model of Gerano. The simulator can be used for railway noise as well as for road traffic noise. The work was carried out by NS Technisch Onderzoek in co-operation with DHV in 1998. In January 1999 the first public simulations where performed for the new freight traffic link "Noord oostelijke verbinding" from the west end of the Betuweroute to Oldenzaal (NL).

With a user friendly interface using a topographical map, the data (acquisition) model of this simulator collects the data. The data calculations are performed with the detailed SRM II method with a simplified data input. This data includes the type of the train/traffic, the distance between the reception point and the railway track and the presence of noise barriers. In the database of the simulator, measured noise samples are stored for

- different individual trains (specific spectrum).
- with and without noise barriers (no noise barrier has more high frequencies).
- at different distances to the railway line (small distance has a fast decay).

Depending on the above parameters a particular noise sample is selected and automatically scaled to the desired noise level. In this way one is able to give the residents an impression of their current situation and possible different future scenarios.

5.4. THE DEVELOPMENT OF A LARGE-SCALE SOFTWARE TOOL FOR THE IMPACT OF ROAD TRAFFIC NOISE

At this moment a large amount of effort is spent to develop this software tool for the impact of rail traffic noise. Comparison of the calculation methods [1,10] show that the calculation method for rail and road traffic noise is very similar. The development of a software tool for the impact of road traffic noise can be performed relatively quickly. A software tool for this has been proposed by NS Technisch Onderzoek.

In this way a powerful software tool can provide insight into the impact of road traffic noise and the development of noise policy. The measures to be applied to reduce road traffic noise (for example maximum emission levels for power units of vehicles, reduction of tire/road noise and noise barriers) can be determined which has greater benefits or has lower overall cost. A combined software tool can take into account both the effects of railway and road traffic noise. This prevents the overestimation of the impact calculated by adding the results of individual studies on the noise impact of railway and road traffic noise.

6. CONCLUSION

Due to environmental impact regulations there is a demand for methods and tools which determine noise reception levels near railway lines. Currently, a wide variety of methods and tools is available. The most frequently used tools are able to calculate accurately the noise reception on a small scale, but because of the detailed data input, data acquisition is labour intensive and calculations are time consuming.

To fulfil the requirements of policy and decision makers, a tool (Gerano) has been developed which can predict the noise impact on a medium to large scale. The Gerano platform is suitable for complete railway and motorway networks, noise policy and noise legislation. Gerano makes use of a smart combination of different standard Dutch noise prediction methods with general noise calculation methods.

Gerano98 has been used successfully for two different projects. For the development of new railway infrastructure (the Hanzelijn) the use of Gerano ranked the different options. This global ranking results in a decrease of labour-intensive calculation with the detailed SRM II method and thus saved time and money. For the development of new noise legislation Gerano compares the effects of alternative noise reduction variants (source reduction or noise barriers). The results provide a new perspective relating to noise policy which stimulates (or exact) noise reduction at source.

The combination of the modular components in the Gerano platform makes possible an extension to different powerful noise tools. Currently, extension to road traffic is possible and a more detailed calculation method will be completed in 1999. A simulator for rail and road traffic noise and a European policy tool Eurano99 was recently completed.

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