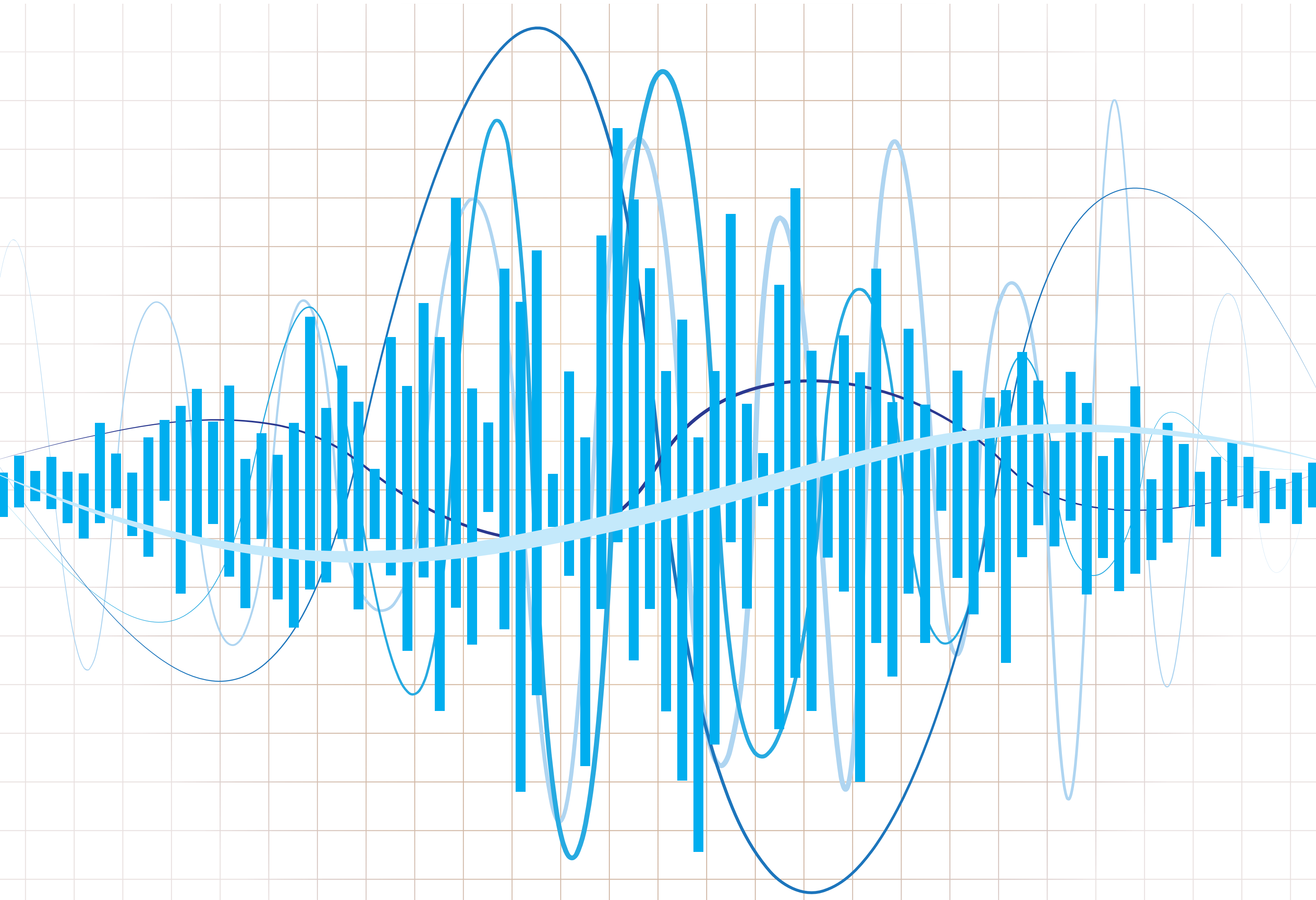
INTERNATIONAL UNION
OF RAILWAYS

Exploring bearable noise limits and emission ceilings for the railways

Part II: Cost and benefit study for different noise limits

UIC Project 'Bearable limits and emission ceilings'



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Summary

The question 'What are bearable limits for environmental noise?' is discussed regularly on a national scale and on a European level. A systematic evaluation of all aspects in what 'bearable' could consist was always missing. With this study UIC is in the position to propose for the first time a well-balanced noise reception limit that considers both disturbance of line side residents and realistic possibilities for the railways. Findings in this report are based on an extensive study.

A bearable value of noise reception limits for the night (L_{night}) is not lower than around 55 dB. More stringent limit values are not effective because:

- For values above 55 dB railway noise is the dominant source for sleep disturbed persons in urban areas near railway lines. For values lower than 55 dB, it is more effective to spend money on measures for road traffic noise. This will generally result in more reduction of the overall sleep disturbance.
- Below 50 dB, results show a large increase of cost Noise limits until 55 dB are effective.

Results are based on a 202 km railway line sample Rotterdam – Venlo and extrapolation to the ERTMS corridors.

Results in costs for noise measures and reduction of sleep disturbed persons

The results of this follow-up study give a better understanding of the effects of noise limit scenarios by studying different noise reception limits. These limits are 40, 50, 55, 60, 65 or 70 dB L_{night}. The results answer the following questions:

1. What costs on noise measures are expected depending on these noise limits.
2. What are the benefits in terms of reduction of sleep disturbed persons at these noise limits.

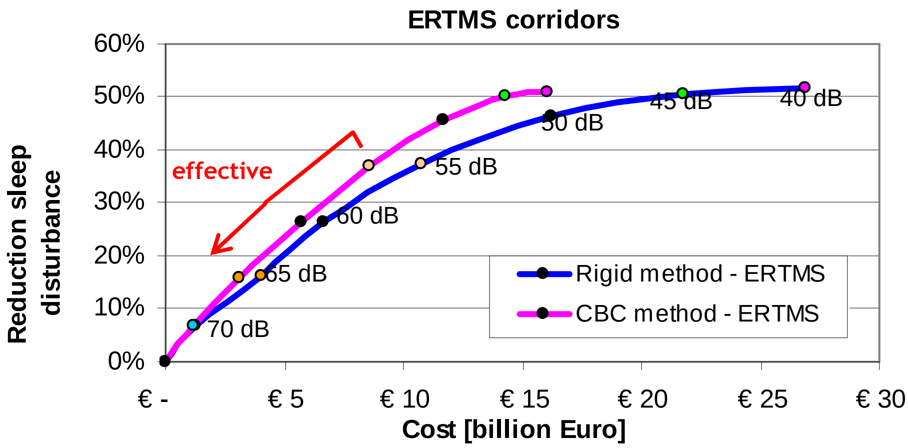

Figure 1 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB for the 15 000 km ERTMS corridors.

A L_{night} noise limit of 55 dB (WHO's Interim Target) would cost for the 15 000 km ERTMS corridors around 10.8 billion euro (Rigid method). This ERTMS corridors transports 43% of the total European freight.

A reduction to 8.6 billion euro is possible if noise measures are mainly placed in densely populated areas. This can be achieved by a decision support method called a CBC method (cost-benefit criterion). More stringent L_{night} noise reception limits will significantly increase costs. The additional benefit of a 5 dB more stringent noise limit becomes less and less, while additional costs increase. Therefore more stringent noise reception limits become less efficient.

With this CBC method it is possible to prevent noise measures in situations where costs are unacceptable high, relative to the number of dwellings that benefit. With the CBC method the focus on additional noise measures is in urban areas. Figure 1 shows the impact of variations of the limit values.

Sleep disturbed persons dominated by road traffic for L_{night} railway of 55 dB or less

A reduction of railway noise is only effective until a certain limit. To profit from low noise limits for railway noise, additional measures to urban road traffic noise are necessary. Without measures for urban road traffic noise, costs for reduction of railway traffic noise, towards stringent values, do not contribute to a reduction of sleep disturbed persons.

Noise annoyance rail correction factor reduces costs with € 3.3 – 3.7 billion[1],[2]

Quite some countries have different noise legislation limits for road and rail traffic noise. This difference is sometimes called 'noise annoyance rail correction factor '. The costs with noise annoyance rail correction factor decrease by 14 - 27% for the 40 dB limit value. For the 70 dB limit value this decrease is up to 89%.

100% retrofitting reduces costs with € 3.3 – 3.7 billion[2]

On a 100% retrofitted freight wagon fleet, the cost reduction of noise measures is between 14 – 27% for the 40 dB limit value and around 89% for the 70 dB limit value. Unlike the local effects for barriers and rail dampers, noise reduction by retrofitting is everywhere along the railway line.

Use of cost benefit criterion gives possible cost reduction of 2.2 billion[2]

With almost equal effects on reduction of sleep disturbed persons, the use of a cost benefit criterion (CBC) makes it possible to reduce costs between 7 and 37%. Or with equal costs a more stringent L_{night} noise limit is possible. This reduction is obtained due to the focus of the CBC method on urban areas.

The combination of the noise annoyance rail correction factor, 100% retrofitting and cost benefit criterion reduces cost with 7.7 billion.

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[1] *1 000 000 000 = a billion (one thousand million)*

[2] *Headlines focus on the Lnight noise limit of 55 dB (WHO's Interim Target)*

Contents

1 Introduction

In April 20111 dBvision finalized the reported on ‘Bearable noise limits and ceilings’. This report [2] focused on the question ‘What are bearable limits for environmental noise?’. The report shows the results of a costs and benefits study on different limits for railway noise.

Aim of this follow-up study

The aim of this follow-up study is to provide a better understanding of the effects of various noise limit scenarios by studying a variation of noise reception limits. The results of the new study will answer the following questions:

3. What costs on noise measures are expected depending on noise reception limits of 40, 50, 55, 60, 65 or 70 dB L_{night}.
4. What are the benefits in terms of reduction of sleep disturbed persons at noise reception limits of 40, 50, 55, 60, 65 or 70 dB L_{night}.

Content of this report

Chapter two describes the sample of the 202 km long railway model that is used for the calculation and analysis. In this sample an existing railway line is used and combined with a traffic volume of a heavy freight line. Also details are given about the method of cost and benefit calculation.

Chapter three presents results on terms of costs and benefits for this sample. At the end a decision support method is described that prevents noise measures for situations with high costs for noise measures for relatively a few benefitting dwellings. The method and the effect on costs and benefits is described on this 202 km long sample.

Chapter four presents a catalogue of variations on this sample. The effect on the costs and benefits is described for the following variations:

- existing/no existing noise measures in the initial situation,
- noise annoyance rail correction factor,
- retrofitting that helps to reduce noise creation levels,
- lower traffic volume, so there is less noise exposed,
- other constraints in the decision support method that prevents additional noise measures to be taken in situations with high costs for relatively a few dwellings,
- other noise indicators than L_{night},

- influence of railway traffic on the total number of sleep disturbed persons by noise in urban areas.

Chapter five extrapolates the results of the effects of a L_{night} noise limit on an European scale. For this extrapolation the focus is on the15 492 km long ERTMS freight corridors that provide the main freight traffic by rail.

2
Cost-benefit calculations 202 km freight line

2.1 Description of the railway model

For the noise calculations an acoustical model of a 202 km long railway line is created. This railway line and its environment are taken from the existing Dutch railway line Brabantroute[3] between Rotterdam harbour and Venlo. Venlo is a town near the Dutch-German border. This railway line crosses several cities and also rural areas with only a few dwellings. Figure 2 shows a graph of the railway line.

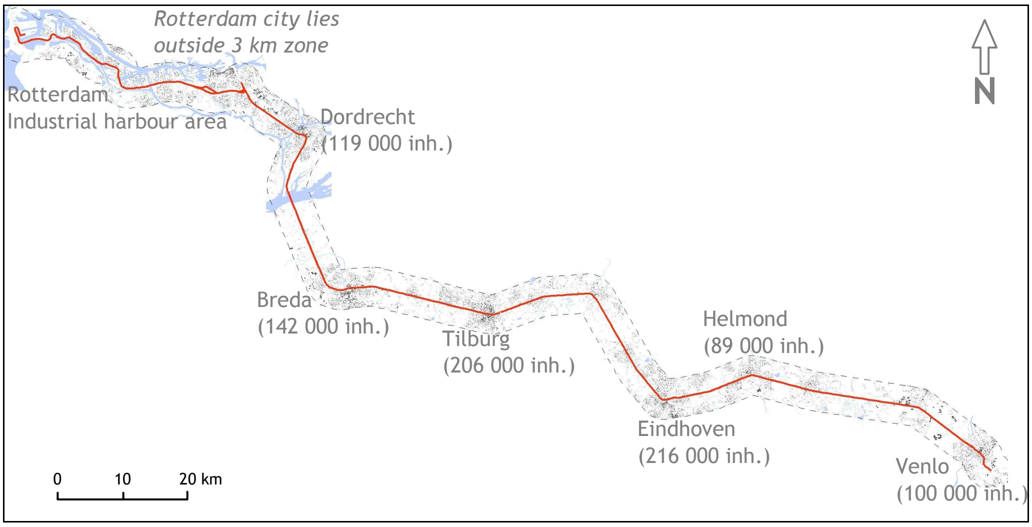

Figure 2 **The *Brabantroute*, a 202 km railway line used for the model calculations. Dwellings and waterways within 3 km distance from the line are shown. The given number of inhabitants refers to the total number per city (also outside the 3 km zone).**

For this noise calculation no existing noise barriers along the railway line is assumed. This assumption is chosen because for the final extrapolation of the results to a European scale, situations without existing noise barriers dominate. Chapter 4 ‘Effects on results in different cases’ present additional results for the situation with existing noise barriers at places where they are at present.

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[3] *The Brabantroute is a Dutch freight connection from Rotterdam Harbour to Venlo (German border). It shares the starting point Rotterdam with the Betuweroute, but it then bends to the south and passes mid-size cities like Breda, Tilburg, Eindhoven and Venlo (while the Betuweroute runs only through rural area).*

As this study concentrates on the night-time situation with mostly freight trains, the traffic in the model is set to 12 freight trains per hour during the night. Each train consists of 30 wagons equipped with cast-iron blocks. This corresponds to the planned situation on the Dutch Betuweroute that goes from Rotterdam to the Dutch-German border near Zevenaar[4]. This study use equal number of trains like the Betuweroute, but doesn't use geographical properties of the Betuweroute. This because the Betuweroute is a new build special purpose freight railway line that is recently opened (2007). The Betuweroute is not representative for a general European situation where mainly existing railway lines are upgraded for an increasing number of freight trains.

The freight connection Brabantroute[2] runs through industrial areas, rural areas and urban areas. Buildings and dwellings up to a distance of 3 000 m are included in the model. This distance is relevant because of noise limits down to 40 dB L_{night} are investigated in this study. Noise effects of 40 dB L_{night} for such heavy used freight railway lines do occur up to 3 000 m from the railway line. There are 278 000 dwellings within this area of 202 km railway line and 3 000 m on both sides.

2.2 Seven noise limit scenarios with L_{night} target levels between 40 and 70 dB

This study shows results and analyses in terms of costs (for measures) and benefits (less sleep disturbed persons) for a set of various L_{night} noise limits. Effects are calculated for limit values of 40, 45, 50, 55, 60, 65 and 70 dB. The L_{night} value of 40 dB equals the WHO Night Noise Guideline. The value of 55 dB equals the WHO Interim Target for night noise.

2.3 Benefits: Method to calculate sleep disturbed persons around dwellings

The Environmental Noise Directive (END) gives L_{night} as the indicator for sleep disturbed persons. The number of sleep disturbed persons is used as a benefit indicator. The report 'Elements for a position paper on night-time transportation noise and sleep disturbance' [4] presents relationships between L_{night} and sleep disturbed persons for road and rail traffic noise sources. The report 'Night noise guidelines for Europe' [5] presents relationships between L_{night} and sleep disturbed persons for aircraft traffic noise sources. The relations represent self-reported sleep disturbance when no other factors are taken into account. These relationships are given in Figure 3.

[4] *For comparison: the hourly number of freight trains along the real Brabantroute varies between 2 and 4 during night-time. In the Rhine Valley about 15 freight trains per hour are expected in the future.*

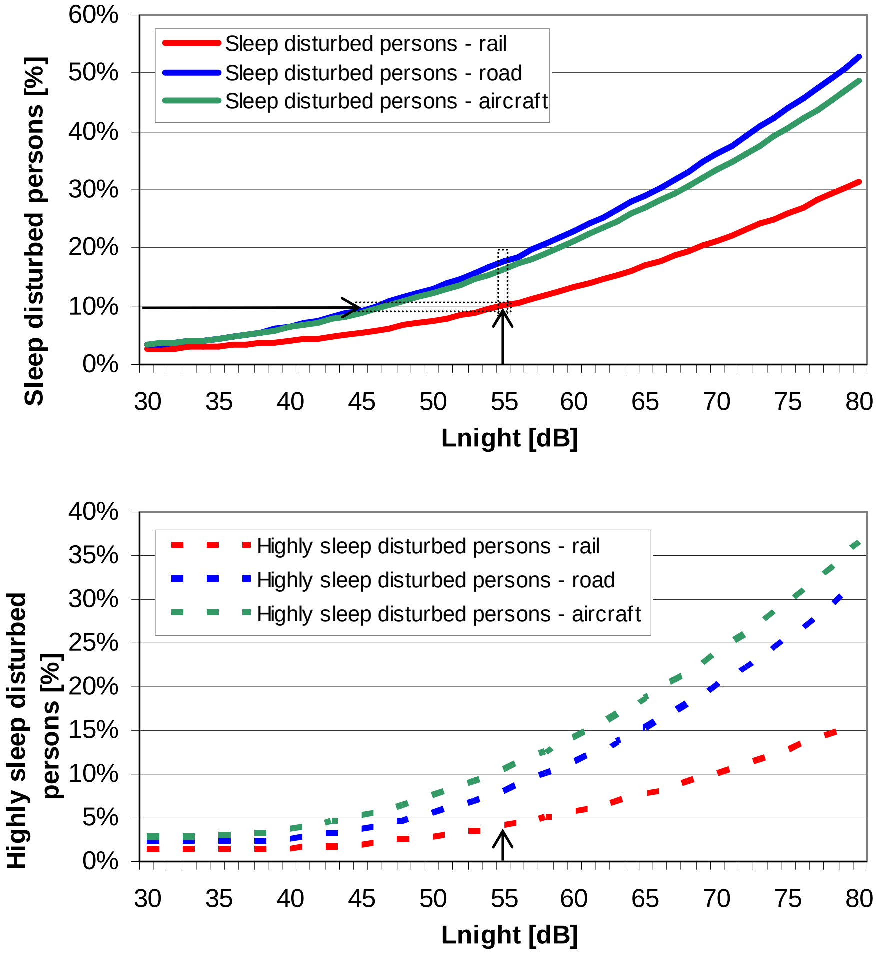


Figure 3 Sleep disturbed persons as a function of the L_{night} level for different noise sources.

Figure 3 shows in the graph of sleep disturbed persons that for a L_{night} value of 55 dB 10% of the persons is sleep disturbed. With the same value of 55 dB for road traffic noise 18% of the persons is sleep disturbed. For aircraft noise this is 16%.

Figure 3 shows that even for very low values of L_{night} (for example 40 dB) some people are (highly) sleep disturbed. Therefore in modern society with motorised transport in combination with large industrial areas, it is not possible to achieve a situation without people that are (highly) sleep disturbed. If for example a situation is acceptable with 10% of sleep disturbed persons one would have a limit value for railway noise of 55 dB. The limit value for road- and aircraft noise would be 46 dB and 47 dB. By acceptance of the same percentage of sleep disturbed persons one would allow a less stringent limit value for railway noise relative to road- and aircraft noise.

Sleep disturbed persons is estimated by the percentage of inhabitants being sleep disturbed. To calculate the number of inhabitants an general number of 2.5 inhabitants per dwelling is used. This number is a European average (see Appendix 2). The total amount of sleep disturbed persons is calculated by the sum of the sleep disturbed persons for each noise category. For example:

- Assume an initial noise reception level of 69 dB for 300 dwellings and of 56 dB for 200 dwellings. The percentage of sleep disturbed is 20% for 69 dB and 11% for 56 dB. The total amount of sleep disturbed is calculated by (2.5 x 300 x 20%) + (2.5 x 200 x 11%). This makes therefore a total of 205 (155 + 55) sleep disturbed.
- With the 50 dB L_{night} target level scenario the noise will be reduced to 50 dB for both groups of dwellings. The percentage of sleep disturbed is 8% for both groups. The total amount of sleep disturbed is calculated by (2.5 x 300 x 8%) + (2.5 x 200 x 8%). This makes a total of 100 sleep disturbed.

The benefit of the noise limit of 50 dB L_{night} is a reduction of 105 sleep disturbed (205 of the initial scenario minus 100 of the 50 dB L_{night} scenario).

2.4 Costs: Method to calculate costs for noise measures

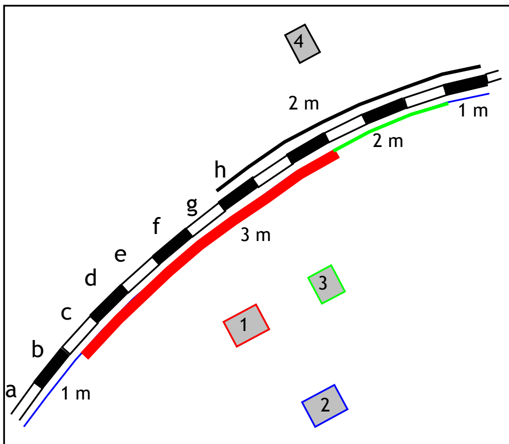
Barriers will be placed in situations where dwellings have noise reception levels above the target value (40 dB, 45 db, …, 70 dB). To derive the number of noise barriers per target value the next procedure is used:

A. For each dwelling the effect on noise reception is calculated with an additional noise measure of
   1. 1 m high barrier.
   2. 2 m high barrier.
   3. 3 m high barrier.
   4. 4 m high barrier.
   5. 5 m high barrier.
   6. 6 m high barrier.
   7. 6 m high barrier and rail damper.
B. For each target limit scenario and individual dwelling, the first noise measure is derived that brings the noise reception level below the noise target level. An example is given in Table 1. This example describes how to find noise measures that bring noise reception levels down to the target level of 55 dB or less. For dwelling 1 a 6 m high barrier is needed to reduce noise levels to 55 or less. For dwelling 2 no additional measures are needed and for dwelling 3 a 2 m high barrier is needed.

Table 1 **Example of noise reception levels for different noise measures.**

Dwelling no.	Noise limit	Noise reception level with							
		No additional	1 m	2 m	3 m	4 m	5 m	6 m	6 m + rail damper
1	55	73	70	65	61	58	56	54	52
2	55	55	50	46	44	42	40	38	36
3	55	60	57	54	51	49	47	45	43
..									
278 000	55	55	50	46	44	42	40	38	36

C. Now the noise measure per dwelling is known, for each dwelling the noise measure that needs to be installed is projected to the railway line (see Figure 4). Therefore the railway line is divided into segments. The final noise measure per segment that is taken into account, is the highest measure that is needed for the dwellings. For example: To meet the noise limit for dwelling number 1, segments c-j need a 6 m high barrier. Dwelling number 2 already meets the noise limit without noise barriers. To meet the noise limit for dwelling number 3, segments a-n need a 2 m high barrier. Segment e-j needs a 2 m high barrier for dwelling 3 and a 6 m high barrier for dwelling 1. Therefore segment e-j will have a 6 m high barrier.



rigid barrier result table
(one new table for each target level)

segment number	height Left	height Right
a	0 m	1 m
b	0 m	1 m
c	0 m	3 m
d	0 m	3 m
...	...	...
g	0 m	3 m
h	2 m	3 m
...	...	...

Figure 4 **Rigid method. For example, the required barrier height for a certain target L_{night} value for segment 'c' is 1 m for dwelling no. 2 and 3 m for dwelling no. 1. The table lists the maximum value.**

D. The total barrier costs for each target value (40 dB, 45 db, …, 70 dB) is found by adding up all barrier lengths of a specific height and multiplying this with the height-related barrier price[5], see Figure 5.

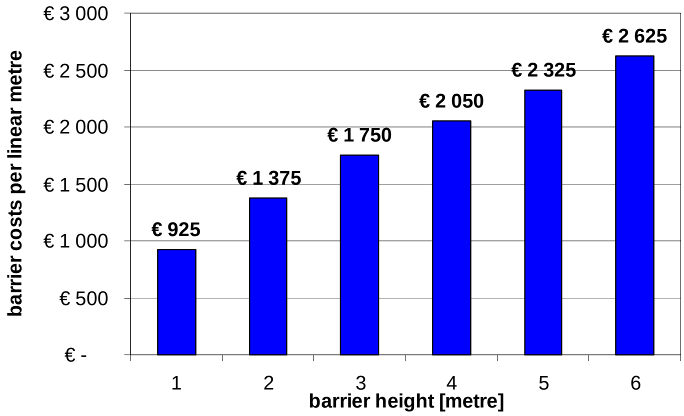


Figure 5 Barrier prices.

[5] *Unit prince used by the Dutch railinfra manager ProRail for the noise abatement programme in 2010.*

3 Results for sample of railway line

For the 202 km freight line costs and benefits are calculated. Paragraph 3.1 shows the impact of variations of the limit values from 40 until 70 dB L_{night}. Paragraph 3.2 shows the effect on costs and benefits, if generally barriers will be placed in urban areas with a high density of dwellings.

3.1 Results in terms of costs and benefits

Figure 6 shows the impact on costs and benefits of noise measures with L_{night} noise limits ranging from 40 to 70 dB. The results show that L_{night} noise limits significant influence the cost for noise measures and reduction on sleep disturbed persons (benefit). The increase of cost is significant. For different L_{night} noise limits ranging from 40 to 70 dB, the range of costs is a factor of 14 and the range of benefits is a factor of 6. Because the increase of cost is significant and the range of results is so wide, decision makers have a choice indeed.

For a 60 dB L_{night} limit value the costs are € 1,5 million per km railway line and the reduction of sleep disturbed is 27%. With L_{night} limit values of 50 dB and lower there is a small additional reduction of sleep disturbed persons but a significant increase of cost.

The price of an additional benefit increases when the L_{night} limit value decreases. This can be seen in the slope of the graph in Figure 6. Average costs of € 1 million per km give about 20% reduction of the number of sleep disturbed persons relative to the current situation. An additional € 1 million per km give about an additional 17%. An additional increase of € 1 million per km on top of the € 4 million per km gives an additional reduction of 2% only.

The benefit range a factor of 6: A limit value of 70 dB reduces the number of sleep disturbed persons by 9% and a limit value of 40 dB makes a 52% reduction possible, as can be seen in Figure 6. In this study the costs are between 0.35 million euro per km railway line for a 70 dB L_{night} limit value and 4.9 million euro per km railway line for a limit value of 40 dB. This is the equivalent of a factor of 14.

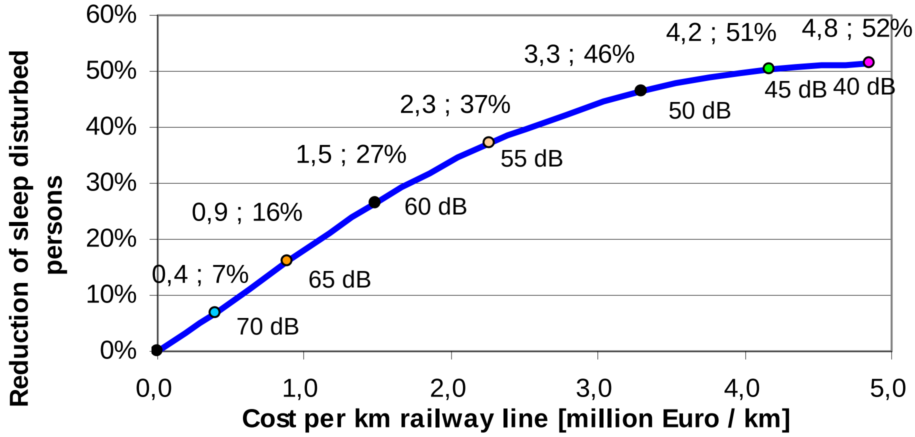


Figure 6 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB.**

The dots in Figure 6 have different colours. For example: The green dot is the result for the 45 dB limit value and the blue dot for the 70 dB value. In the other graphs of this report these coloured dots (for the corresponding limit values) are used also in the other graphs.

Figure 6 show that even with a 40 dB limit value there is not a reduction of sleep disturbed persons with 100%. This is because noise measures, like barriers up to 6 m of height and rail dampers, will not reduce noise until 40 dB for any situation. Noise reduction by these measures is limited and even not always effective. It is not always effective for situations with high buildings close to the track. For these situations noise barriers hardly reduce noise. The reduction of these measuresin general is also limited to about 20 until 25 dB. Therefore even these measures are not enough tot reduce noise levels to 40 dB for situations with initial noise levels above 60 until 65 dB.

3.2 Mainly noise measures for areas with high density of dwellings (CBC method)

Barriers will generally be placed in urban areas with a high density of dwellings. In rural areas with a low density of dwellings, barriers could be relative expensive. Situations occur where noise barriers can cost € 0.1 to 1.0 million per dwelling. Figure 6 shows the results of a method where noise measures are placed no matter how dense the dwellings are situated. Therefore noise measures are placed also in rural areas. This is called the ‘Rigid method’. This paragraph shows results of noise measures and noise exposure for an alternative method (see Figure 7). In this alternative method, noise measures are placed only for situations where the costs for these measures are acceptable, relative to the total number of dwellings that profit. This is called the cost-benefit criterion method (CBC method). This CBC method uses a cost-benefit criterion that is described in more detail in Appendix 1. This method is used in different ways in various countries. Figure 7 illustrates a pictogram with the effect of the variation. The effect is relative to the situation described before. The green pictogram means a cost reduction and the red pictogram means an increase of costs.

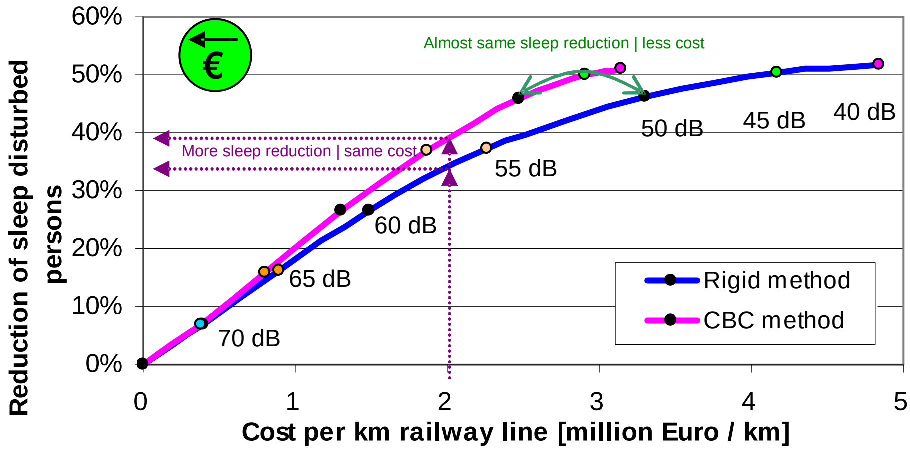


Figure 7 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures.**

Almost the same reduction of sleep disturbed persons with less costs: The use of a CBC method will reduce the number of noise measures in rural areas. This gives a cost reduction between 5% (70 dB limit value) and 35% (40 dB limit value). Because of the reduction on noise measures, the benefits decrease also. The decrease is for all noise limit values small (1%). Therefore the use of a CBC method has a significant effect on cost and a relative small effect on the benefits.

More reduction of sleep disturbed persons with same costs: This result can also be seen in another way. Imagine a situation with a limited budget of about € 2 million per km. With this budget a limit value of about 56 dB is possible with the rigid method (see Figure 6). This gives a benefit of 37%. With the CBC method a more stringent limit value of 53 dB is possible. This gives a benefit of 42%. Therefore the use of a CBC method makes more stringent noise limits bearable and results with a larger reduction of sleep disturbed persons.

In the next chapter continues with the results of both the rigid method and the CBC method.

4 Effects on results in different cases

4.1 Introduction

This chapter presents a catalogue of variations on the 202 km long sample. The effect on costs and benefits is described for variations in:

- existing/no existing noise measures in the initial situation,
- a noise annoyance rail correction factor that corrects the calculated noise reception levels with a certain value,
- retrofitting that helps to reduce noise creation levels,
- lower traffic volume, so there is less noise exposed,
- other constraints in the decision support method that prevents additional noise measures to be taken in situations with high costs for relatively a few dwellings and
- other noise indicators than L_{night}.

Also the influence of railway traffic on the total number of sleep disturbed persons by noise in urban areas is analysed.

4.2 Existing noise legislation and existing noise measures

In the sample of the railway line described in chapter 2 and 3 a combination of an existing railway line, no existing noise measures and a high volume of freight traffic is used. This paragraph answers the question 'what is the effect of existing noise on the costs and benefits?'. The situation tested in this paragraph is an existing railway line with noise barriers that fit regular use and current Dutch noise legislation in combination with an expected high volume of freight traffic.

This means that the barriers are in some places but not everywhere. And the barrier height doesn't fit the noise limits for the expected high volume of freight traffic. The situation is based on the Dutch noise legislation in the period 1990 until 2010. This legislation contains railway noise limits for new lines only and for existing lines for the moment that they will be adapted. The Dutch noise legislation does limit growth of railway traffic on existing lines in a mild way.

Similar situations occur also in various other European countries. In such countries there are some existing noise barriers that (partly) help to reduce noise levels to the limit value. The number of noise reduction measures that have to be placed in these countries will therefore be lower. On the other hand with existing noise measures there are situations where the height of existing noise measures is not enough and higher barriers need to be placed. There are additional costs for the disassembly and removal of existing barriers.

The costs for countries without existing noise barriers increase by 0 - 1% for the 40 dB limit value or 13 - 15% for the 70 dB limit value, compared to the reference situation with existing noise measures considered in the previous chapter. Figure 8 shows both the results for countries without existing noise measures and countries with existing noise measures.

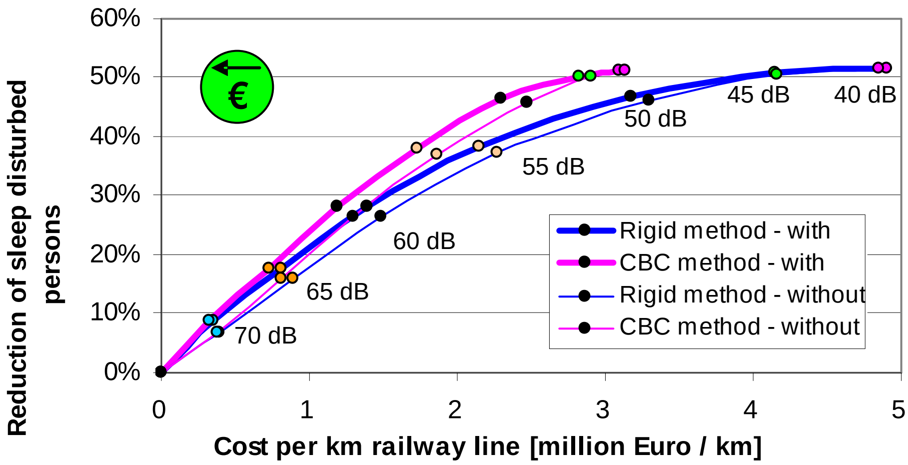


Figure 8 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures for a situation without existing noise measures.

The next part of this report will show results for countries without existing noise barriers only. The graph 'Rigid method – without' and 'CBC method – without' is placed in all graphs as a reference. The word 'without' is replaced by 'ref'. In this way it is easy to see the effect of different variations relative to the reference situation.

4.3 Noise annoyance rail correction factor

Quite a few countries have different noise legislation limits for road and rail traffic noise. This difference is sometimes called 'noise annoyance rail correction factor ', see section 1.2.2 'Health and annoyance research' of [2]. This correction factor is studied in [3] and [4] and also reported [5]. Some countries add the noise annoyance rail correction factor as a correction factor to the calculated noise reception levels, before comparing this level to the noise reception limit. Other countries have different noise reception limits for road and rail traffic noise.

There is no noise annoyance rail correction factor included in the calculation for this 202 km freight line. This means that a limit of 40 dB L_{night} in this study corresponds directly to the Night Noise Guideline of 40 dB (which is recommended by WHO regardless of the source type). If a noise annoyance rail correction factor is subtracted from the calculated noise reception levels the costs for noise measures will decrease. Figure 9 shows the effect of a 5 dB noise annoyance rail correction factor for both the rigid and the CBC method.

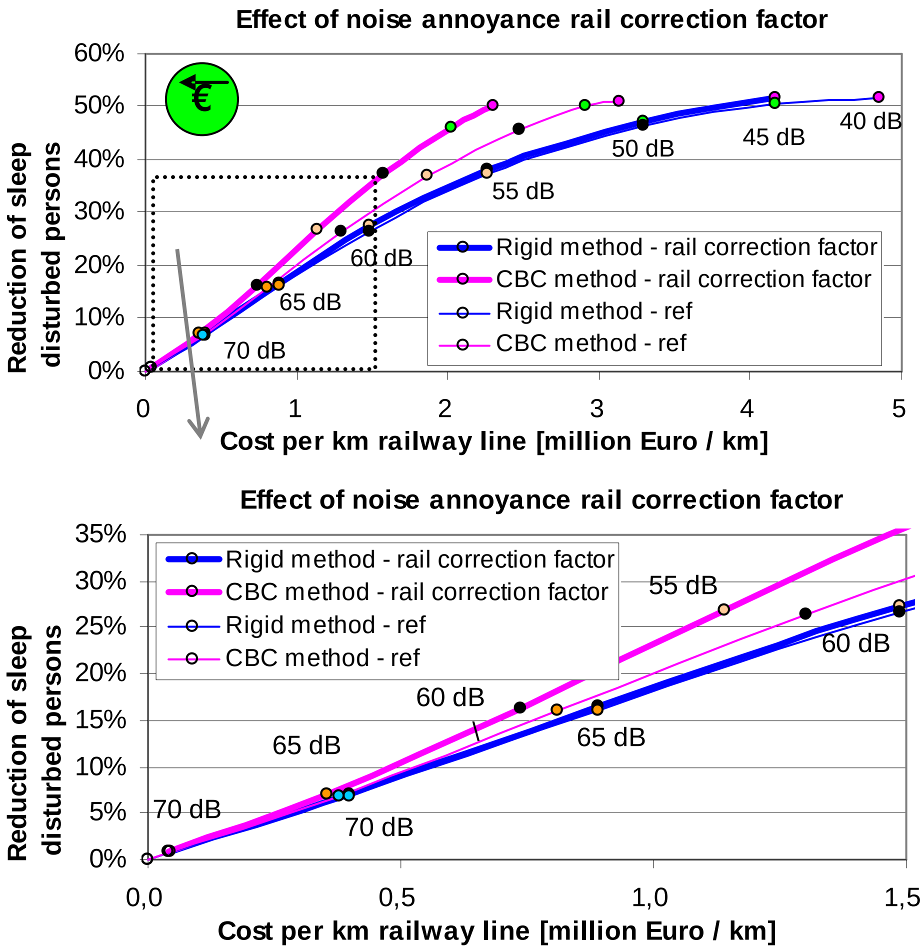


Figure 9 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB with a 5 dB noise annoyance rail correction factor included in the noise reception levels.**

The costs with noise annoyance rail correction factor decrease by 14 - 27% for the 40 dB limit value. For the 70 dB limit value this decrease is up to 89%. Because of the reduction of noise measures with the noise annoyance rail correction factor, the reduction of sleep disturbed persons is less. The relative difference for sleep disturbed persons is 0 – 2% for the 40 dB limit value. For the 70 dB limit value this decrease is up to 88 - 89%.

4.4 Retrofitting

Many international initiatives are taken for retrofitting the freight wagons with composite brake blocks. Several individual countries are also studying or implementing different means of promoting retrofitting. The Netherlands have introduced noise differentiated track access charges. Switzerland directly subsidises the retrofitting of the freight fleet in addition to using noise differentiated track access charges. Germany has initiated the project ‘Leiser Rhein’ (Silent Rhine) to reduce noise at the source. Two main elements of this ‘Leiser Rhein’ project are retrofitting of up to 5 000 freight wagons with K- and LL-blocks and definition of a practical approach for the use of LL-blocks [6].

Retrofitting of freight trains is an alternative way to reduce noise creation levels. There is no linear effect between noise reduction and the percentage of wagons that are retrofitted. The noise reduction of the last 10% of the wagons is more effective than the first 10%. This is shown by Figure 10. These examples assume a (relatively modest, thus safe) noise reduction of 5 dB by retrofitting a freight wagon relative to a non-retrofitted one.

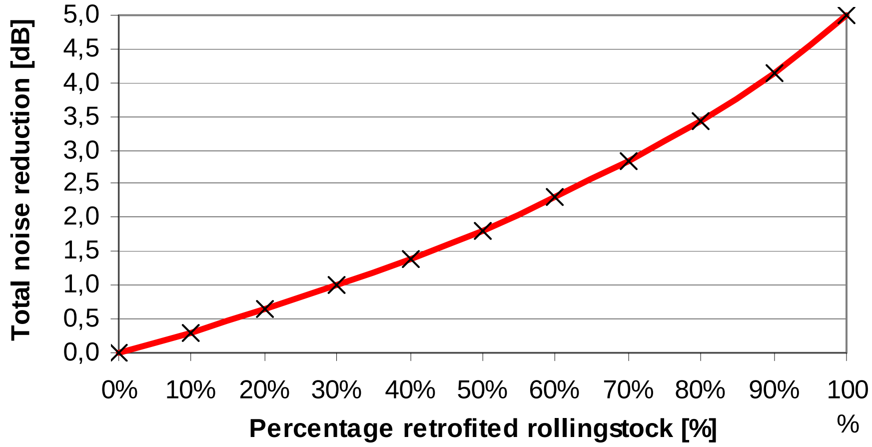


Figure 10 Total noise reduction when a part of the total freight wagon fleet is retrofitted. A 5 dB effect of retrofitting on the noise creation of a freight wagon is assumed.

Retrofitting of 25% on the freight wagon fleet has 0.8 dB effect on the total noise creation. The effect of this 25% on the cost benefit figure is shown in Figure 11 (Rigid method) and Figure 12 (CBC method). In these figures the reduction of sleep disturbed persons due to the retrofitting only, is included in the results of the reduction by noise barriers and rail dampers. The cost of retrofitting is not included. Unlike the local effect for barriers and rail dampers, noise reduction by retrofitting is everywhere along the railway line.

On a 100% retrofitted freight wagon fleet, the cost reduction of noise barriers is between 14 – 27% for the 40 dB limit value and 89% for the 70 dB limit value. For the CBC method reduction of costs is similar.

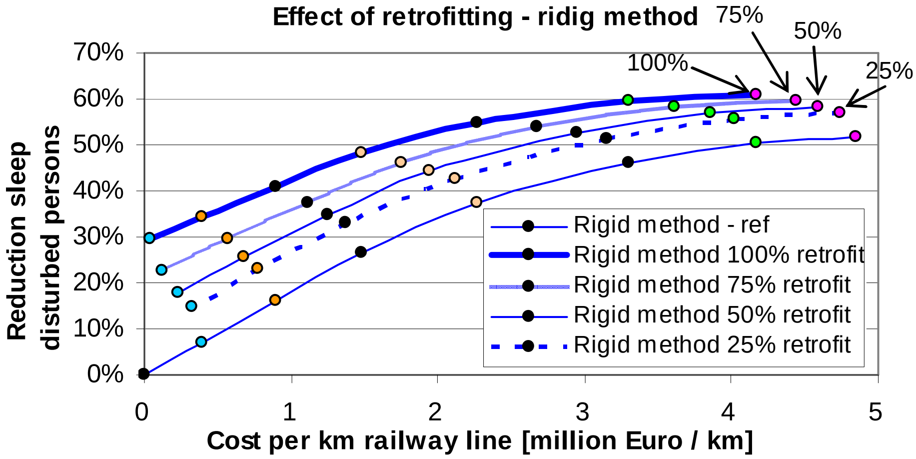


Figure 11 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB with a 100, 75, 50 and 25% retrofitted fleet of freight wagons for the rigid method.**

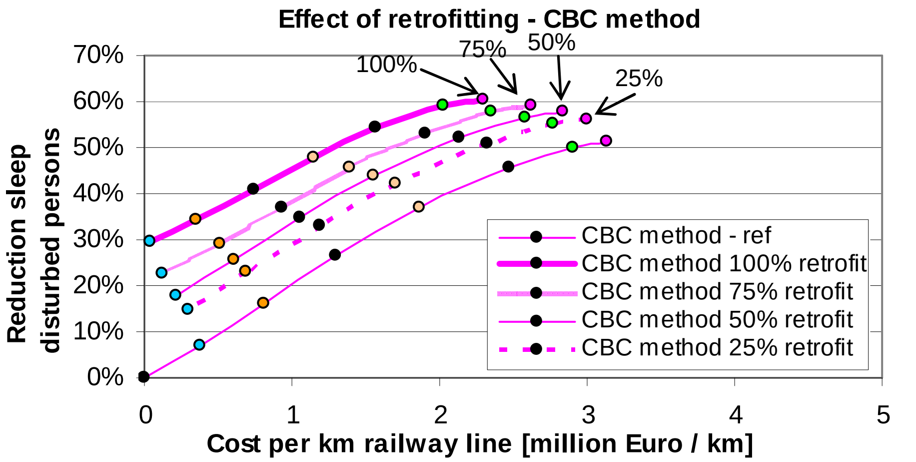


Figure 12 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB with a 100, 75, 50 and 25% retrofitted fleet of freight wagons for the CBC method.**

4.5 Lower traffic volume

As described before, the traffic composition on the line is 12 freight trains per hour. Railway lines with a lower traffic volume are less noisy. Therefore it is easier to meet the limit value of 40, 45, 50, 55, 60, 65 or 70 dB. A line with 50% less freight (relative to the reference line) produces 3 dB less noise. Figure 13 shows the noise difference for a line with less freight traffic.

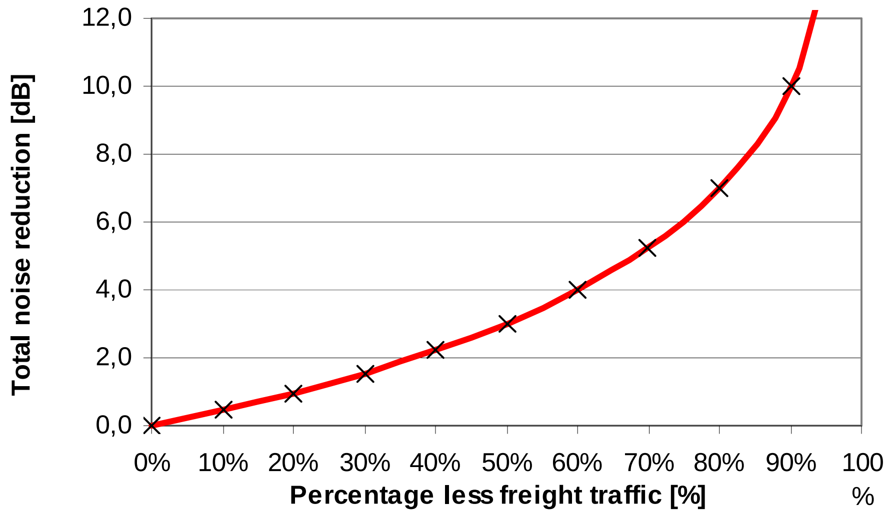


Figure 13 Total noise difference for railway lines with less trains than the assumption of 12 freight trains per hour for the reference line.

The effect of this 50%, 75% and 90% less freight traffic on the cost benefit figure is shown in Figure 14 and Figure 15. The reduction of sleep disturbed persons is relative to the situation with lower traffic (50, 75 or 90%) and without noise limits. The noise reduction because of lower traffic is therefore not included in the reduction of sleep disturbed persons.

The reduction of costs for noise measures on a line with 50% less freight traffic is 8% for the 40 dB limit value and 65% for the 70 dB limit value (rigid method). For the CBC method cost reduction is between 16% and 65%. The reduction of costs for noise measures on a line with 90% less freight traffic is 32% for the 40 dB limit value and 100% for the 70 dB limit value (rigid method). For the CBC method cost reduction is between 48% and 100%.

The efficiency of noise measure investments is lower for lines with lower traffic. Figure 14 and Figure 15 both show that the number of people that benefit from the noise measures for each invested Euro decreases for lines with lower traffic.

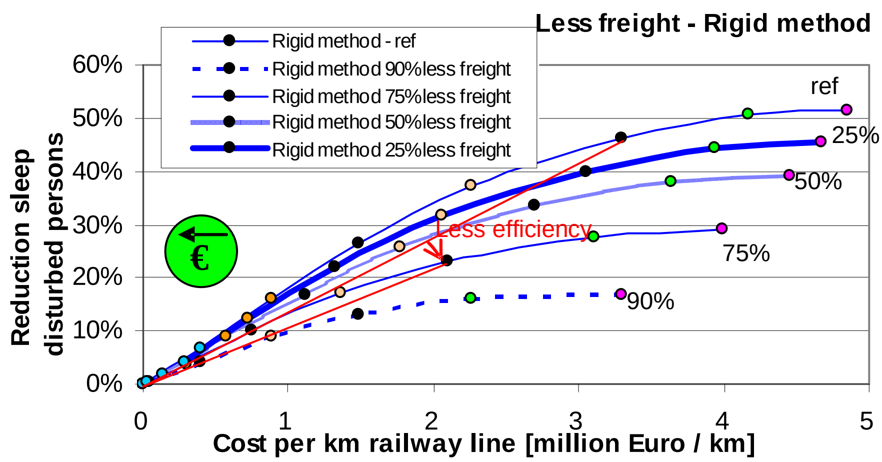


Figure 14 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB with a 90, 75, 50 and 25% lower traffic volume of freight wagons for the rigid method.

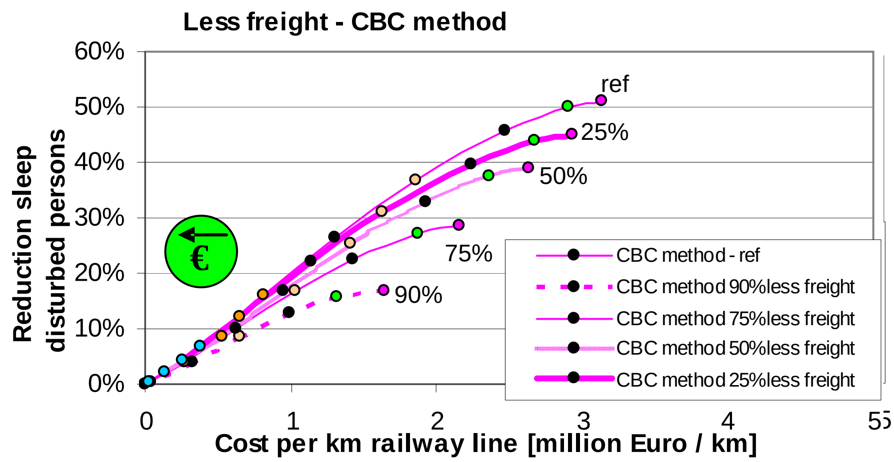


Figure 15 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB with a 90, 75, 50 and 25% lower traffic volume of freight wagons for the CBC method.

4.6 Cost-benefit criterion

With a cost-benefit criterion for noise measures it is possible to avoid taking measures on spots where measures are expensive in relation to the number of residents that benefit from them. Figure 6 showed that the CBC method allows for a cost reduction in rural areas. With almost equal effects on reduction of sleep disturbed persons, cost reduction is possible between 7 and 37%. Or with equal cost a more stringent L_{night} noise limit is possible.

The effects of the CBC method are studied here in more detail. The CBC method is fully described in appendix 1. The method basically consists of a virtual budget (in euro) per dwelling to be spent on noise measures if the noise limit at the façade of the dwelling is exceeded. Noise measures are only taken if the budget of all nearby dwellings is sufficient to finance a local noise barrier. The height of this barrier is determined by the size of the budget (unless the noise limit is reached before the budget is spent).
Figure 16 shows the costs per dwelling (in the situation of Figure 6) in relation to the density of dwellings. The density of dwellings is expressed here as the number of dwellings per 25 m segment of the railway line. For example, a density of 10 dwellings per segment refers to those segments that effectively contribute noise to 10 dwellings[6].
Figure 16 shows that with the rigid method average cost per dwelling increase much more for a situation with 10 dwellings or less per segment. These situations occur in rural areas. With a cost-benefit criterion noise measures are generally not installed in these areas.

[6] *These 10 dwellings can still be hundreds of meters away from such a segment.*

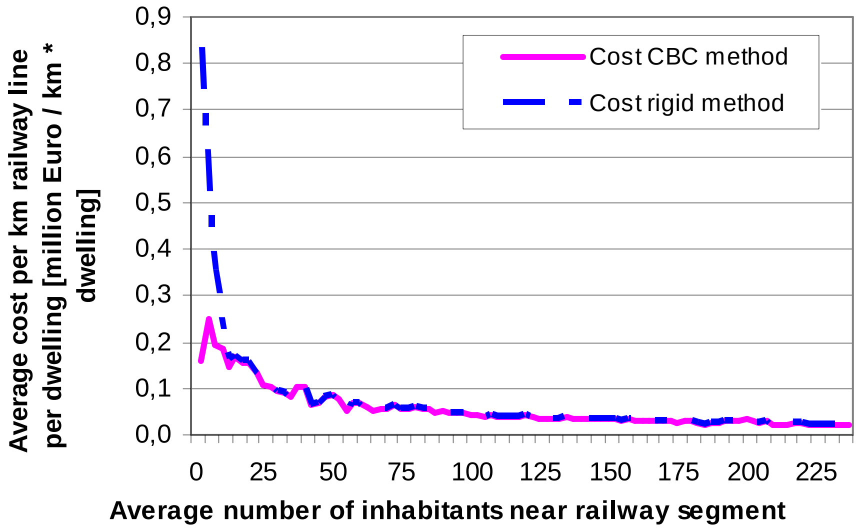


Figure 16 With the applied CBC method cost reduction take place for railway segments with low density of dwellings around the railway line (less than 6 dwellings per segment). In this study and in most EU countries, a low density of dwellings is found along the majority of the railway sections.

The average cost per railway segment is shown in Figure 17. The black line in this figure shows the share of segments with respect to the total amount of segments (right-hand axis). For example, along 15% of this 202 km railway line, 0 dwellings per segment occur. Situations with a low dwelling density appear to occur along the largest part of this railway line.

A detail of Figure 17 is amplified in Figure 18. The three figures also show that the cost-benefit criterion applied in this study is most effective in areas with 6 or less dwellings per railway segment. Between 6 and 10 dwellings per segment, there is a small effect. Within urban areas, the results of the rigid method and the cost-benefit criterion method are equal.

By adjusting the cost-benefit criterion (virtual budget per dwelling, Figure 36) one can adapt the minimum density of dwellings required to apply noise measures. This minimum can be moved towards higher densities than 10 by reduction of the virtual budget per dwelling. On the other hand this point can be moved towards lower densities than 10, by extending the virtual budget per dwelling. By implementation of a cost-benefit criterion into a (national) legislation, one can choose the weight factor of these virtual budgets per dwelling.

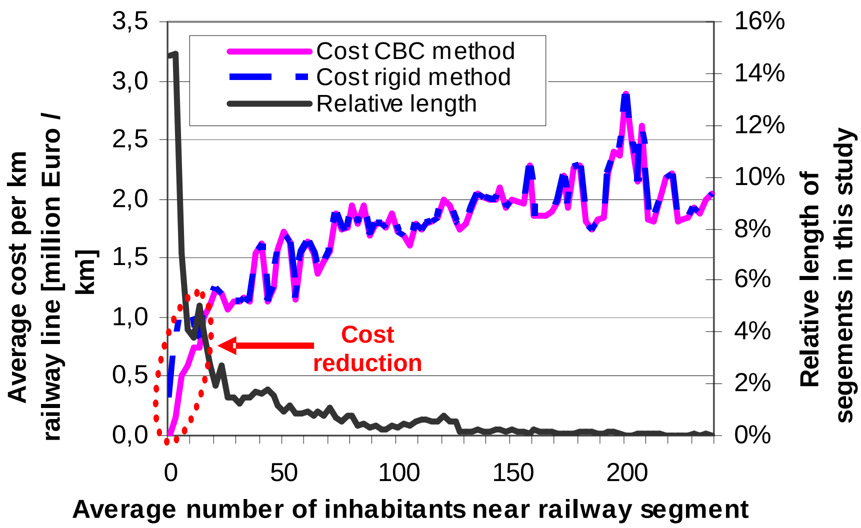


Figure 17 With the applied CBC method cost reduction take place for railway segments with low density of dwellings. Low density of dwellings occurs along a relative large part along the railway line (black line).

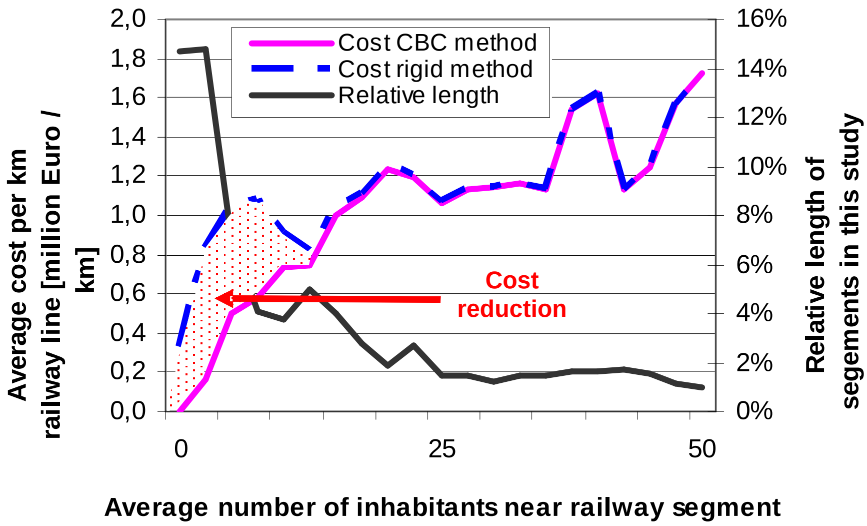


Figure 18 With the applied CBC method cost reduction take place for railway segments with low density of dwellings. A low density of dwellings occurs along a relative large part of the railway line (black line). The red dotted area is the situation with cost reduction.

4.7 Other indicators than L_{night}

Besides noise limits based on L_{night}, countries may (also) have noise limits based on indicators $L_{Aeq,6\text{-}22h}$ or L_{den}. For countries with other indicators the results in this report can be converted. To get an indication about the conversion one has to know the difference between L_{night} and these other indicators at a certain location along the railway line.

This difference depends on the traffic volume during the day and during the night. This study concentrates on the main freight corridors. The average difference will be about 6 dB, hence $L_{den} \approx L_{night} + 6$ dB. This 6 dB is based on noise maps made at various railway lines in 2007 within the framework of the END, see Table 2.

This difference of 6 dB between L_{den} and L_{night} implies that $L_{Aeq,6\text{-}22h}$ must have approximately the same value as L_{night}. This follows from the L_{den} weighting formula.

Table 2 Estimated differences between L_{night} and either L_{den} or $L_{Aeq,6\text{-}22h}$[7].

Country	Freight corridor	Line	$L_{den} - L_{night}$	$L_{Aeq,6\text{-}22h} - L_{night}$
France	Corridor D	Tarascon-Sète	6	0
	Corridor C	Lyon-Dijon	6	0
Germany	Corridor A	Koblenz-Mainz	6	0
	Corridor A	Basel-Karlsruhe	6	0
	Corridor B	Hamburg-Hannover	6	0
Netherlands	Corridor C	Dordrecht-Breda	7	2,5
	Corridor A	Utrecht-Arnhem	7	2,5
Belgium	Corridor C	Brussels-Arlon	7	2,5

Because limits for $L_{Aeq,6\text{-}22h}$ generally have higher values than L_{night} limits (see Appendix 1 of [2], the value for $L_{Aeq,6\text{-}22h}$ will in most cases not be decisive for noise measures. To obtain a first impression of the effects of various noise limits expressed in L_{den}, simply add a value of 6 dB to the L_{night} limits of this scenario study, thus yielding a L_{den} range of 46, 51, 56, 61, 66, 71, 76 dB. The result is given in Figure 19 (L_{den}) and Figure 20 ($L_{Aeq,6\text{-}22h}$).

[7] *Sources: carto1.wallonie.be/cigale/viewer.htm?APPNAME=BRUIT; www.rhone.equipement.gouv.fr/cartes-de-bruit-du-reseau-national-r266.html; laermkartierung.eisenbahn-bundesamt.de/; www.prorail.nl/internetresources/geluidskaart/geluidkaart.htm*

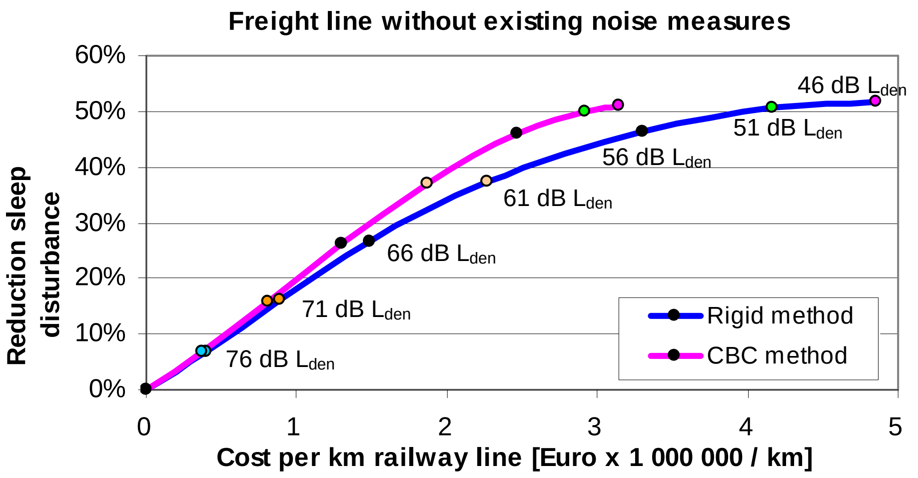


Figure 19 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 46, 51, 56, 61, 66, 71 and 76 dB L_{den}.

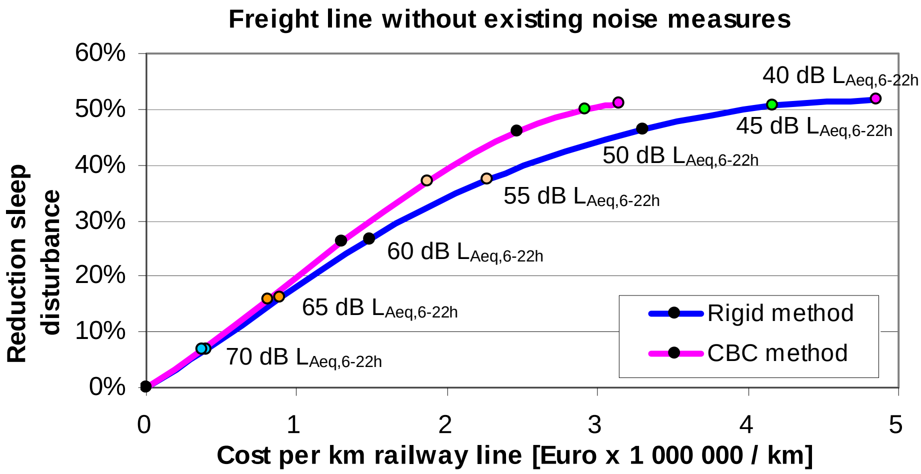


Figure 20 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB $L_{dAeq,6\text{-}22h}$.

4.8 Annoyance by rail and road traffic in city centres

In urban areas railway noise is not the only source that influences the number of sleep disturbed persons. Also other sources, like road traffic and industrial noise, determine the amount of sleep disturbed people. To achieve a reduction of the total number of sleep disturbed persons, it is important to reduce all relevant noise sources and not only railway noise.

This section shows results of the comparison of the contribution of road traffic and rail traffic to the number of sleep disturbed persons in a medium-sized urban area (Eindhoven, 216 000 inhabitants). The rail traffic is based on the 12 freight trains per hour during the night. The road traffic is based on the situation of 2006. Figure 21 presents the L_{night} noise levels of road and rail traffic separately. Rail traffic noise is concentrated around the railway line. Road traffic noise is spread throughout because of a traffic network throughout the city.

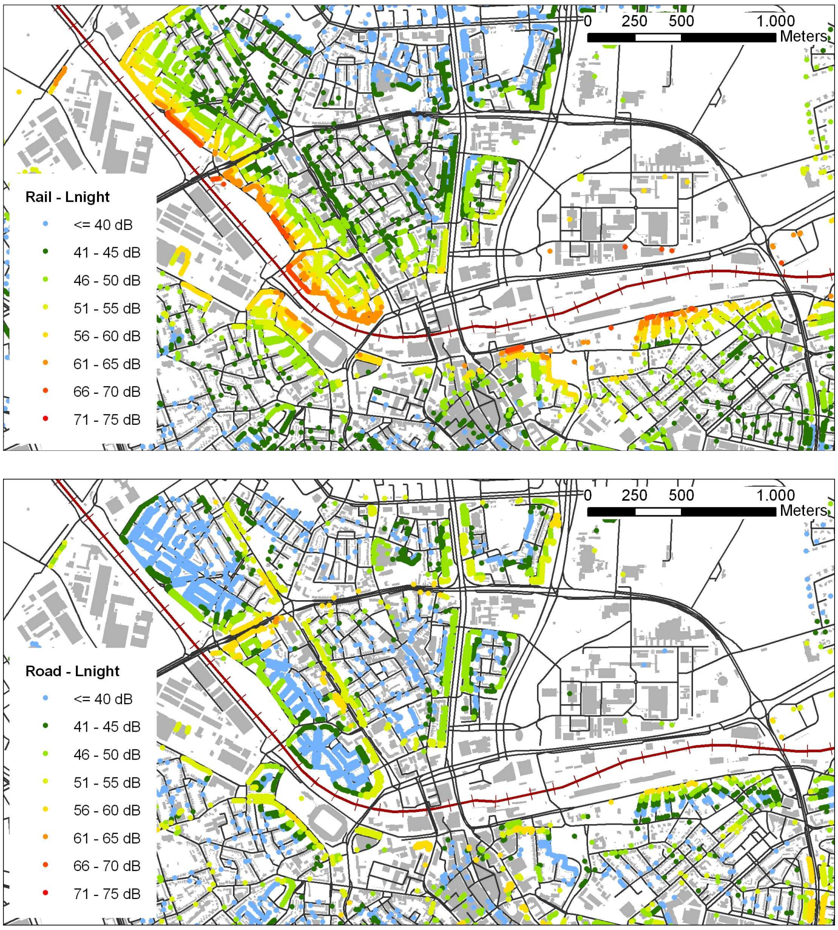


Figure 21 **L_{night} noise levels of rail traffic (upper part) and road traffic (lower part). The rail traffic is based on the 12 freight trains per hour during the night. The road traffic is based on the situation of 2006.**

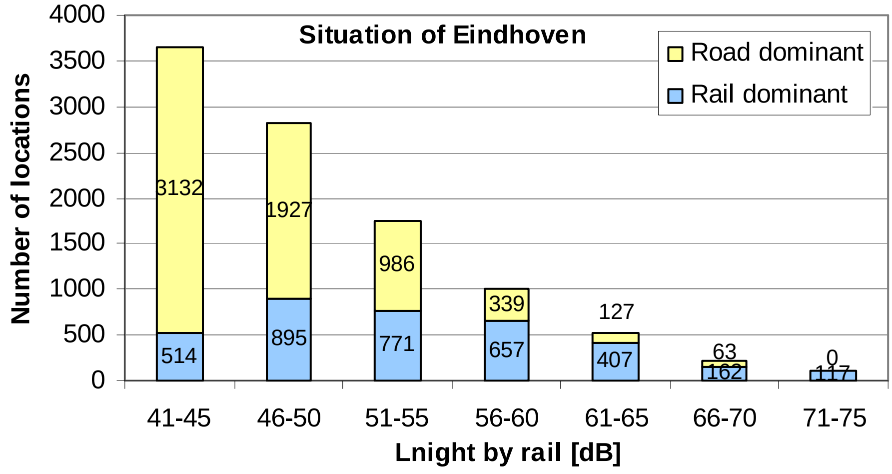


Figure 22 Number of locations where road or rail is dominant for the number of sleep disturbed persons. The results are for the situation of Eindhoven and are for different noise classes for L_{night} of railway traffic.

The results can be analysed in more detail. Figure 22 shows an overview of the number of locations that have road or rail as a dominant source. The results are for different noise classes. As can be seen from the figure the number of locations per noise class will increase with lower noise classes. There are 534 (127 + 407) locations with L_{night} by rail between 61 and 65 dB. The class between 56 and 60 dB has 996 (339 + 657) locations. The number will increase because lower noise classes occupy larger surface areas than higher noise classes.

The locations on the map of Eindhoven where railway traffic or road traffic is dominant for the number of sleep disturbed persons is illustrated in Figure 23a and 23b. The graphs present the results for situations without noise reduction for freight traffic and with 5, 10, 15, 20 and 25 dB railway noise reduction. With a 10 dB noise reduction only the locations that face the railway line are dominated by railway noise. The other locations are dominated by road traffic noise. After a 15 dB noise reduction there are almost no locations left where railway traffic dominates the number of sleep disturbed persons.

Figure 22 also shows that for L_{night} rail noise levels below the class of 56 until 60 dB, road traffic is more dominant than rail traffic. From the 1 757 locations between 51 and 55 dB, 986 locations are dominated by road and 771 by rail. For lower noise classes the dominance of road traffic will increase. Therefore the additional effect of a 5 dB more stringent noise limit on railway noise will decrease. With a very stringent limit of 40 dB, railway noise reduction is made at locations where road traffic is dominant.

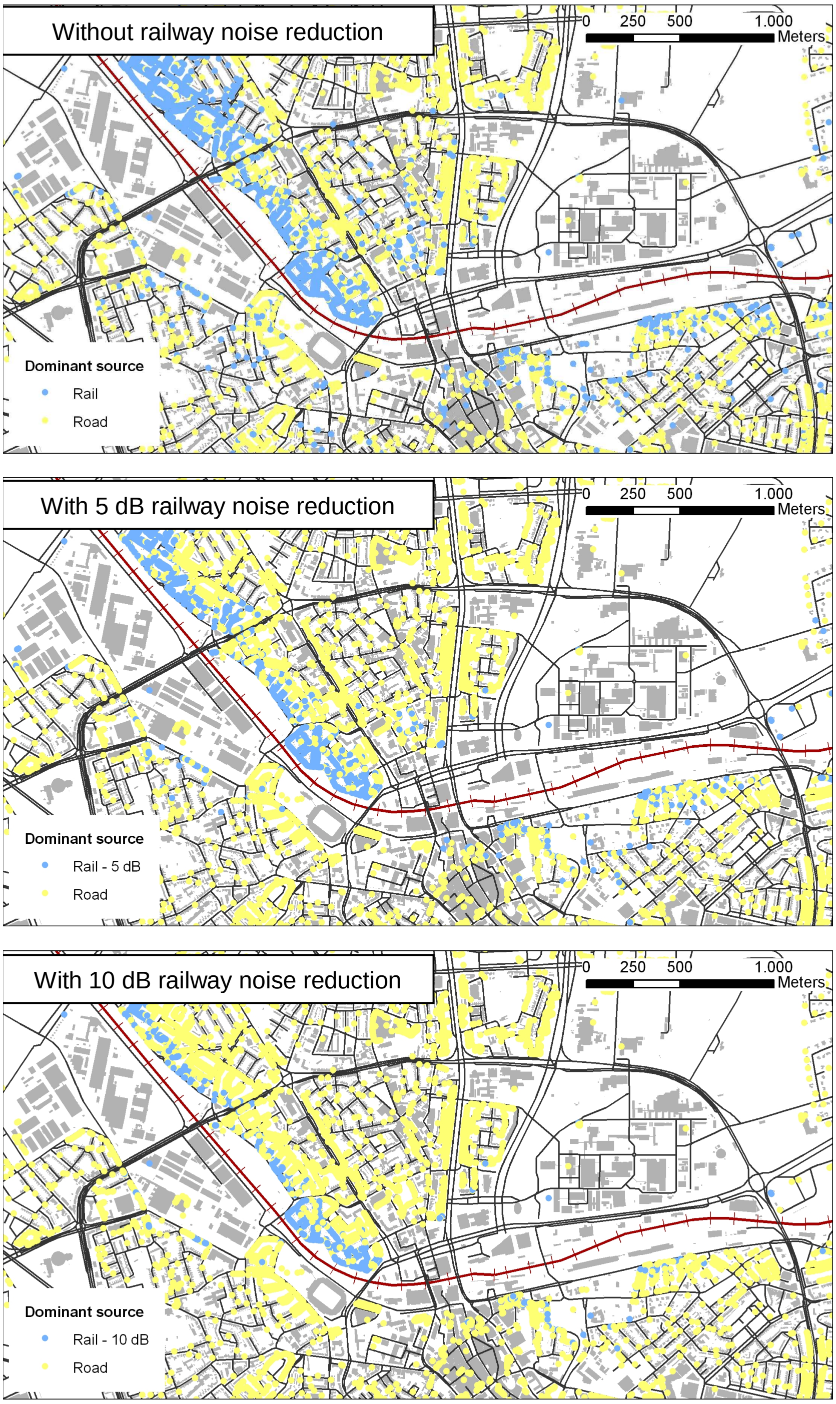


Figure 23a Dominant source for the number of sleep disturbed persons for the situation with 12 freight trains per hour (rail) and situations with 5 and 10 dB noise reduction.

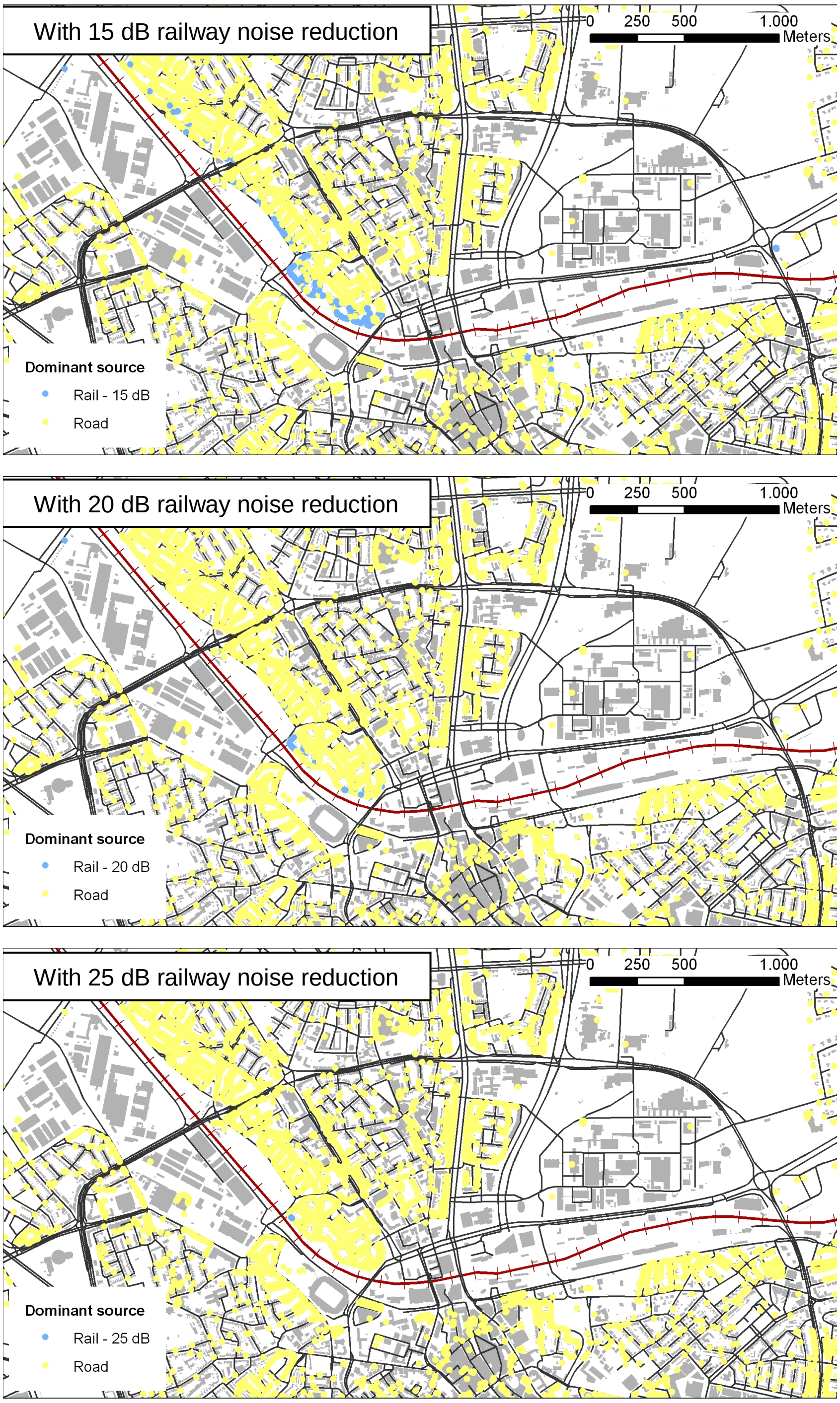


Figure 23b Dominant source for the number of sleep disturbed persons for situations with 15, 20 and 25 dB noise reduction.

To profit from low noise limits for railway noise, one could think of an additional strategy for road traffic noise in urban areas. If so, the number of noise measures for urban road traffic noise is limited. Potential measures to reduce road traffic noise in urban areas are:

- Hybrid and electric cars reduce noise with about 1 dB. The use of these cars is most effective near traffic lights, because of lower engine noise levels during acceleration,
- Low noise road surface reduce noise with 3 dB. These silent roads can not be placed near road crossings, because accelerating, braking en turning vehicles cause early damage. A damaged low noise road surface has no advantage in noise reduction. In urban areas these low noise road surfaces are practically only possible on longer straight parts of the network without road crossings.
- Silent vehicle tires reduce noise with 1 dB. In urban areas the effect is only 1 dB because at low traffic speed the engine noise dominates.

Noise barriers are in most cases not possible in city centres. Speed reduction below 50 km/h is only used in residential areas with a low traffic volume. Compared to railway traffic, the traffic volume of road traffic is not regulated. The potential total noise reduction for road traffic noise in urban areas is about 2 until 3 dB.

Therefore the total effective reduction of sleep because of stringent noise limits for railway noise is limited due to the potential noise reduction of road traffic noise. Figure 22 show that the turning point is around L_{night} railway noise levels between 51 and 55 dB. Reduction of railway noise to values of 50 dB or less is not effective.

These examples show that noise limits for railway noise need to be in balance with noise limits for road traffic noise. This balance needs to ensure that additional measures will be forced to the source that dominates the number of sleep disturbed persons or noise annoyed persons. A focus on very stringent limits on railway noise results in high cost for noise measures and low additional benefits.

5 Estimated costs on an European scale

5.1 Introduction

In this study the focus has been on a 202 km freight railway line. What are the effects on costs if the results are extrapolated to the EU railway network? This question is not easy to answer because traffic load and population density on and along the EU railway network are very diverse.

Nevertheless, this chapter attempts to estimate the costs for noise measures on the most relevant part of the UIC European Railway Infrastructure Masterplan (ERIM) network (see Figure 24) [7].

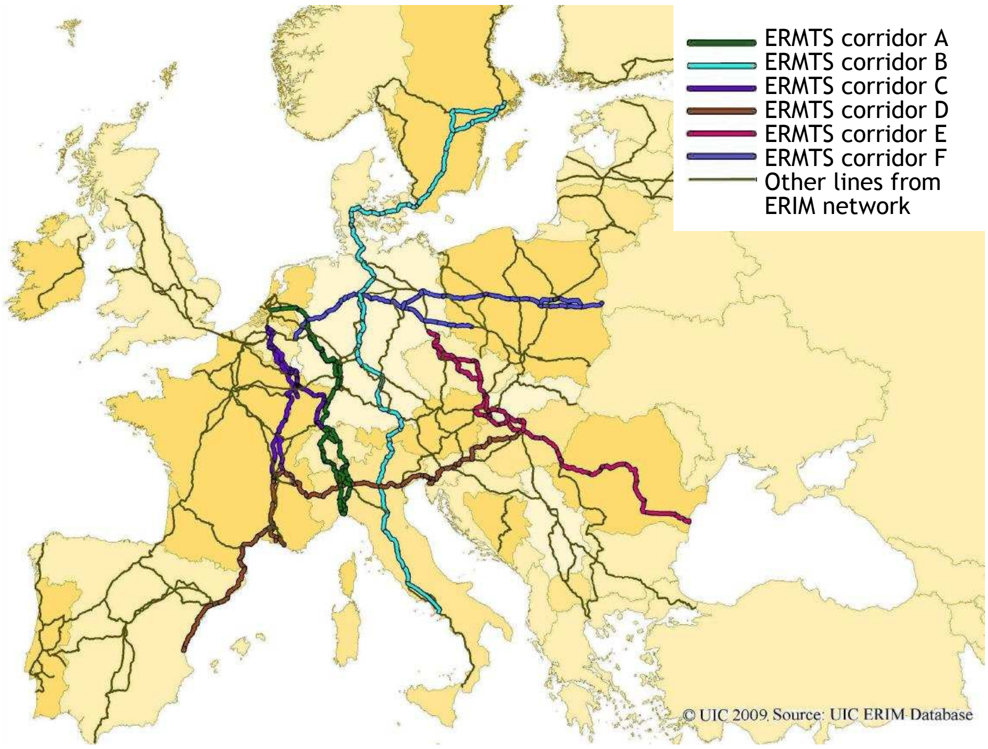


Figure 24 The UIC ERIM network of international rail corridors. This network is mainly for freight on which a European Rail Infrastructure Masterplan could be built on (UIC Atlas 2008 of Infrastructure in the ERIM Network).

The ERIM project focuses on a high-level infrastructure of major international rail corridors within and between 32 countries. These corridors are mainly used for freight traffic. Based on the current and the planned 2020 infrastructure provision, ERIM has proposed minimum upgrading targets for the existing and new installations. In order to analyse whether the planned 2020 infrastructure provision is sufficient to carry the future traffic volumes UIC has estimated (in collaboration with its Member Railways), the forecast traffic growth and the potential capacity utilisation by 2020. ERIM has established in [7] that cost for tackling all infrastructure issues would require about 200 billion euro for the entire ERIM network and about 60 billion euro for the six European Rail Transport Management System (ERTMS) corridors.

The ERIM network has a route length of 50 000 km through 32 countries. These countries have in total a network route length of 232 000 km. On this ERIM network the freight transport is estimated to increase from 267 000 million tkm[8] in 2007 to 479 000 million tkm in 2020 (+80%). In 2007 the ERIM network transported 55% of the freight on the total network [1].

Parts of the ERIM network are the ERTMS corridors (see Figure 24). These ERTMS corridors have a route length of 15 000 km. This is 31% of the ERIM network. It is expected that the ERTMS corridors will transport 43% of the total freight by 2020. The countries with the heaviest used ERTMS corridors are Germany, Switzerland, The Netherlands and Austria. These countries have corridors with a freight flow on a route of at least 20 million tonnes[9] per year (see appendix 3 and [1]). This equals to 5 freight trains an hour[10]. The maximum on those corridors is 8.5 freight trains an hour. Italy is not mentioned in this list of heaviest used ERTMS corridors, although lines in Italy are connected to the heavy lines in Switzerland and Austria. Numbers for traffic volume in [1] for Italy on corridors A and B seems to be low.

In many cases the corridors are not exclusive for freight only. Also the number of freight trains during the night period is not always equal to the year average. If 67% of the total freight trains run during the night, because daytime capacity is reserved mainly for passenger trains, the average of 5.1 freight trains per hour equals 10.2 freight trains per hour during the night. The maximum on those corridors is 17 freight trains an hour. Table 3 in appendix 3 gives more detailed information about these numbers.

5.2 Method of extrapolation

Estimating the effects on a European scale is roughly possible. To extrapolate costs the following corrections are made:

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[8] 1 tkm = 1 000 kg km

[9] 1 tonne = 1 000 kg

[10] 20 million tonnes equal 1 million wagons per hour (assuming one wagon has an average load of 15 tonnes). This equals 44 444 trains a year (assuming one train has 30 wagons) and 5.1 trains an hour.

- Costs per km: Additional information of costs for a traffic reduction of 25, 50, 75 and 90% is given in paragraph 4.5 (Lower traffic volume). First, an interpolated trend line (2nd order function) is derived. Based on this trend line, costs is calculated for different traffic volumes in Table 3 of appendix 3;
- Sleep disturbed persons km: Additional information of sleep disturbed persons for a traffic reduction of 25, 50, 75 and 90% is given in paragraph 4.5 (Lower traffic volume). First, an interpolated trend line (2nd order function) is derived. Based on this trend line, sleep disturbed persons is calculated for different traffic volumes in Table 3 of appendix 3;
- Route length: The route length of the corridor section is given in Table 3 of appendix 3. This length is multiplied with the costs / sleep disturbed persons per km to derive the total costs / sleep disturbed persons per corridor section;
- Density of buildings: The costs of noise measures / sleep disturbed persons is assumed to be linear with the density of buildings. The density of buildings is derived from the number of inhabitants and the land surface per country. Table 4 presents these values based on Wikipedia[11]. The last column in the table shows the scale factor. Since the study is based on a Dutch situation, the factor for The Netherlands is 100%.

5.3 Results

Costs for the ERTMS corridors are calculated, based on the described correction values and the main graph (Figure 7) without existing noise measures. The results are given in Figure 25. An L_{night} noise limit of 55 dB (WHO's Interim Target) would cost between 8.6 billion euro (CBC method) and 10.8 billion euro (Rigid method) on noise measures for the ERTMS corridors.

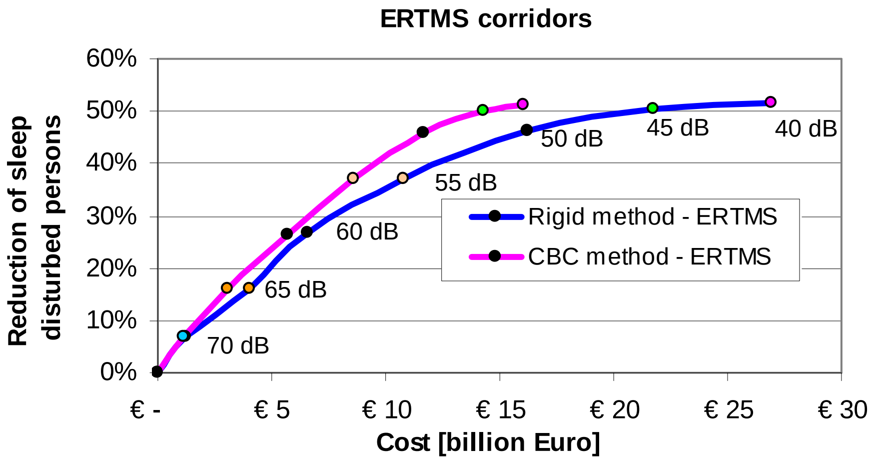

Figure 25 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures for the 15 000 km ERTMS corridors.

[11] http://en.wikipedia.org/wiki/Area_and_population_of_European_countries

The price for reduction of sleep disturbed persons is reported in various ways [2]. The report ‘Exploring bearable noise limits and emission ceilings for the railways’ give in Appendix 4 an example of monetary values. By using the Swiss values of Euro 5 800 for sleep disturbance, the value for sleep disturbed persons in Figure 26 can be calculated in a monetary value. The impact of various noise limits on cost and benefits both in a monetary value is given in Figure 29. The cost for noise measures is 5 – 9 times as high as the benefits for reduction of sleep disturbed persons (rigid method). The use of a CBC method will improve this ratio to 4 – 5 times as high. This ratio can be improved by optimisation of the CBC values for the virtual budget per dwelling given in Figure 36. In general: The lower the values for the virtual budget per dwelling, the stronger the focus of noise measures near densely populated areas and therefore the lower the ratio given in this paragraph.

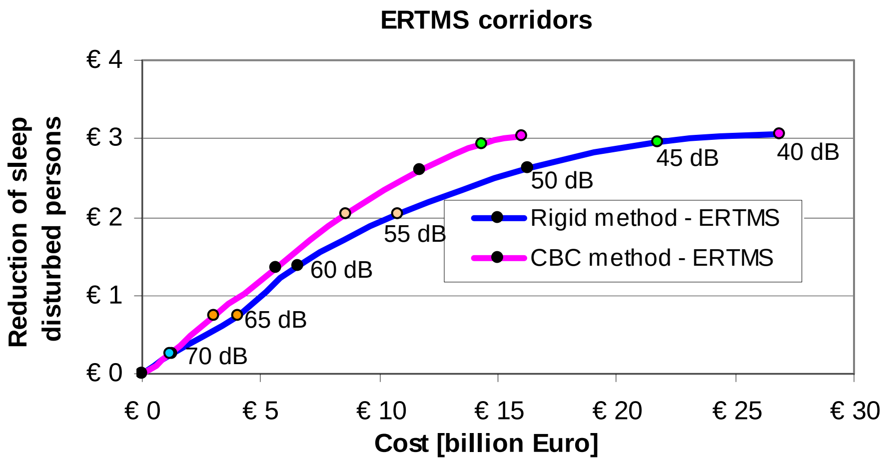

Figure 26 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures for the 15 000 km ERTMS corridors.

The number of sleep disturbed persons around the ERTMS corridors is significant. The number starts with 1.1 million people without a noise limit and can be reduced until 600 000 with a 40 dB L_{night} noise limit. The impact of various noise limits on benefits in the number of sleep disturbed persons is given in Figure 27. Figure 28 gives a bar chart of the impact of various noise limits on cost.

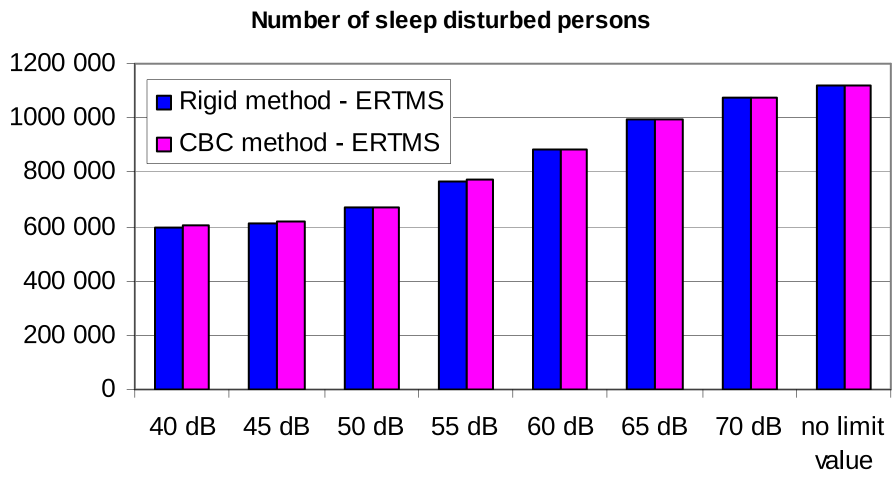

Figure 27 **Number of sleep disturbed persons for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures for the 15 000 km ERTMS corridors.**

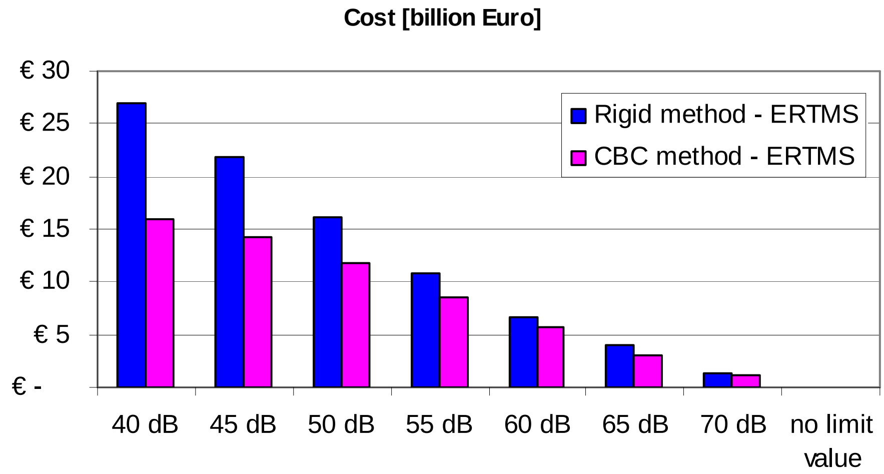

Figure 28 **Cost in billion Euro for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures for the 15 000 km ERTMS corridors.**

6 Conclusion

6.1 Introduction

The question 'What are bearable limits for environmental noise?' is discussed regularly in different forums on a national scale and on a European level. This report presents the impact on cost and benefit for different limits for railway noise. Noise limits until 55 dB are effective. More stringent limit values are not effective because:

- Below 55 dB, railway noise is not the dominant source for sleep disturbed persons in urban areas. If railway noise is reduces to 55 dB, measures on road traffic noise will have more impact on sleep disturbance.
- Below 50 dB, results show a large increase of cost and a small increase of benefits.

This study is additional to the report 'Bearable noise limits and ceilings' (dBvision, 2011).

Results in costs for noise measures and reduction of sleep disturbed persons

The results of this follow-up study give a better understanding of the impact of noise limit scenarios by studying a variation of noise reception limits. The results answer the following questions:

1. What costs on noise measures are expected depending on noise reception limits of 40, 50, 55, 60, 65 or 70 dB L_{night}.
2. What are the benefits in terms of reduction of sleep disturbed persons at noise reception limits of 40, 50, 55, 60, 65 or 70 dB L_{night}.

6.2 Results for the 202 km long sample

Large difference in costs and benefits for different L_{night} noise reception limits

Costs for noise measures per km railway line vary within a wide range. A 40 dB noise limit is 14 times as expensive as a 70 dB noise limit. Costs vary between 0.3 and 5 million euro per km railway line. The benefits of a 40 dB noise limit are expressed in a reduction of sleep disturbed persons. A 40 dB noise limit reduces the number of sleep disturbed persons by a factor of 6 comparing with a 70 dB noise limit. Reduction of the number of sleep disturbed persons varies between 9% and 52%.

Equal benefits and reduction of costs with focus on urban areas

A reduction of costs between 7 and 37% is possible, if noise measures are mainly placed in densely populated areas. This can be achieved by a decision support method, called a CBC method (cost-benefit criterion). With this CBC method it is possible to prevent noise measures being taken in situations where costs are unacceptable high, relative to the number of dwellings that benefit. The CBC method makes it possible to have the:

- Same reduction of sleep disturbed persons with less costs.
- More reduction of sleep disturbed persons with same costs.

The CBC method results in less noise protection for dwellings in rural areas.

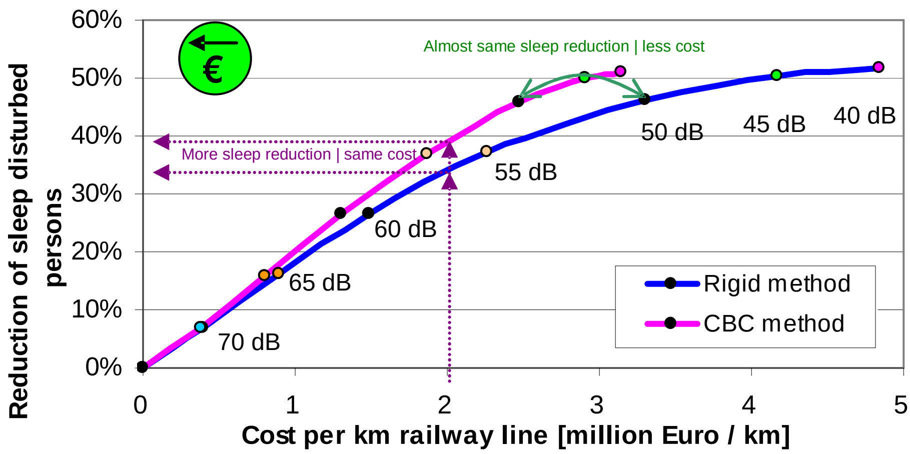

Figure 29 Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB and two different cost benefit criteria for noise measures.

6.3 Effect on results in different cases

The results will be influenced by variations in the assumptions made. The effects are discussed for variations in existing noise measures along the railway network, use of noise annoyance rail correction factor , retrofitting, lower traffic volume, other constraints in the CBC method and other noise indicators.

With existing noise measures costs decrease between 0 and 15%

Countries with a history of noise legislation will have some noise measures along their network. The costs in paragraph 6.2 decrease, for countries with existing noise measures, by 0 – 1% for the 40 dB limit value and 13 – 15% for the 70 dB limit value. There is a decrease in total cost because there are existing noise measures that help to reduce noise. On the other hand this decrease is partly compensated, because there are additional costs for removal of existing barriers that are not high enough for the new noise limit.

Correction of reception levels with the noise annoyance rail correction factor reduces costs between 7 and 55% Some countries have different noise legislation limits for road and rail traffic noise. This difference is sometimes referred as ‘noise annoyance rail correction factor ’. The costs with a noise annoyance rail correction factor decrease by 7 - 14% for the 40 dB limit value. For the 65 dB limit value this decrease is up to 53 - 55%.

Retrofitting of freight trains reduce costs between 14 and 89%
Retrofitting is an alternative way to reduce noise levels. On a 100% retrofitted freight wagon fleet, the cost reduction of noise barriers is between 14 – 27% for the 40 dB limit value and around 89% for the 70 dB limit value. For the CBC method reduction of costs is similar.

With decision support method it is possible to focus noise measures on urban areas
With the CBC method it is possible to prevent noise measures being taken in situations where costs are unacceptable high, relative to the number of dwellings that benefit from it. The chosen factors for the CBC method in this study, focus on groups of 10 dwellings or more that receive noise of a railway segment of 25 m. A focus towards smaller groups of dwellings or larger groups of dwellings is also possible. This can be done by adaption of the CBC factors in Figure 36. A change of these factors will influence the calculated costs and benefits.

With limit values for $L_{Aeq,6\text{-}22h}$ or L_{den} costs increase
Besides noise limits based on L_{night}, countries may (also) have noise limits based on other indicators or L_{den}. For countries with other indicators the results in this report can be converted. Results are given in paragraph 4.7.

Sleep disturbed persons dominated by road traffic for L_{night} railway of 55 dB or less
A reduction of railway noise is only effective until a certain limit. To profit from low noise limits for railway noise, additional measures to urban road traffic noise are necessary. Without measures for urban road traffic noise, costs for reduction of railway traffic noise, towards stringent values, do not contribute to a reduction of sleep disturbed persons.

6.4 Estimated costs on an European scale

A L_{night} noise limit of 55 dB (WHO's Interim Target) would cost for the 15 492 km ERTMS corridors around 10 800 million euro (Rigid method). This ERMTS network transports 43% of the total European freight. A reduction to 8 600 million euro is possible if noise measures are mainly placed in densely populated areas. This can be achieved by a decision support method called a CBC method (cost-benefit criterion). Other values for costs and benefits are presented in Figure 30.

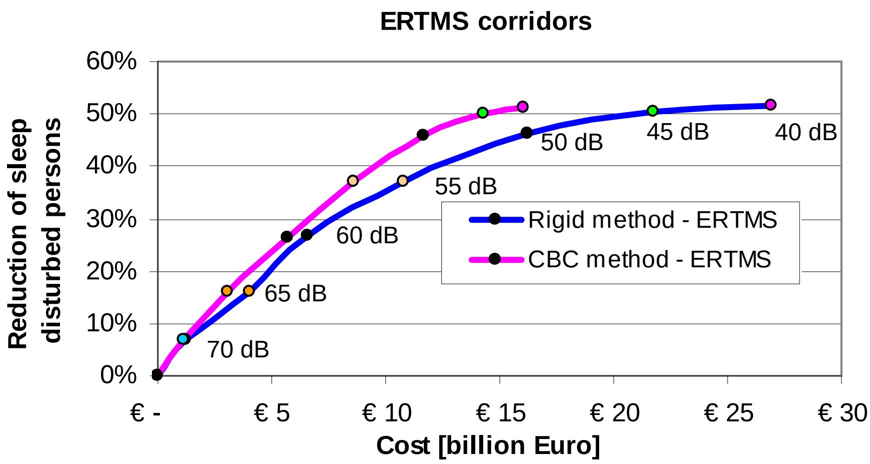

Figure 30 **Costs and benefits (reduction of sleep disturbed persons) for different limit values of 40, 45, 50, 55, 60, 65 and 70 dB for the 15 492 km ERTMS corridors.**

6.5 Concluding remarks and recommendations

Based on this study we have the following concluding remarks:

- A bearable value of noise reception limits for the night (Lnight) is not lower than around 55 dB. More stringent limit values are not effective because:
  - For values above 55 dB railway noise is the dominant source for sleep disturbed persons in urban areas near railway lines. Instead of spending money for noise measure to reduce railway noise to values lower than 55 dB, it is more effective to spend money on measures for road traffic noise. This will generally result in more reduction of the overall sleep disturbance.
  - Below 50 dB, results show a large increase of cost and a small increase of benefits.
- The cost-benefit criterion shows that significant reduction of costs is possible in combination with a low increase of sleep disturbed persons. This reduction is because of the focus for noise measures in urban areas. The average factor 'virtual budget per dwelling' (see Figure 36) is the important key to decide at what building density a group of dwellings is an urban area or not. Additional research can make effects of different scenarios for this factor possible. A lower average factor makes fewer areas an 'urban area'. By further analysing the effect of different factors, an optimisation is possible between 'cost reductions' on one side and 'secure noise protection of urban areas' on the other side.
- The cost-benefit criterion makes better protection for the higher noise levels possible. Figure 36 show a strong increase of the 'virtual budget per dwelling' above 60 dB L_{night}. The relative value factor 'virtual budget per dwelling' is the important key to decide above what noise levels dwellings get relative more

noise protection. Additional research can make effects of different scenarios for this factor possible. A strong increase at higher noise levels than 61 dB give fewer protection for dwellings with areas an 'urban area' above 61 dB. By further analysing the effect of different factors, an optimisation is possible between 'cost reductions' on one side and 'secure noise protection of the worst's situations' on the other side.

- Costs for noise measures are significant in terms of total cost for railway lines. Cost for noise measures for limits between 70 and 55 dB varies a factor 5 tot 6. Even with 100% retrofitting additional noise measures are needed to meet the noise limits between 65 and 55 dB. Reduction of sleep disturbance is also significant and varies a factor 5. The choice for a noise limit between 70 and 55 dB is therefore a political choice. The choice for each individual country depends on the economical power of the railway sector / country in combination with the importance for noise control relative to other national issues. Because of large national differences the value of a bearable noise limit is different for different European countries.
- There is a minimum noise limit value that is bearable for most of the European countries. With a better understanding about the impact on national level it is possible to get e better understanding about this minimum noise limit value.
- A combination of European noise limits and national noise limits seems to be possible. This combination secures a minimum protection against railway noise Europe wide. And makes more stringent noise limits and therefore a better an additional protection on a national scale possible. There is almost no additional cost for noise barriers and rail dampers with 100% retrofitting and a noise limit value of 70 dB L_{night}.

Appendix 1
Description of the railway model

For the calculations in this study the noise calculation model RINGS is used. RINGS is developed for strategic cost benefit analyses for the Dutch railway network. It supports ProRail and the Dutch Ministry of Infrastructure and the Environment with the development of noise legislation.

General features of RINGS

The RINGS software system contains a noise calculation algorithm in combination with data of:

- Railway network;
- Track construction (track superstructure type, bridges, noise barrier positions);
- Types of rolling stock, local train speed, numbers of trains;
- Position of dwellings (addresses);
- Geometry of buildings (for shielding);
- Ground absorption.

RINGS is capable of calculating the required noise measures in terms of noise barriers and/or rail dampers to satisfy a certain set of noise rules. These rules can be formulated as: 'all dwellings should be below 50 dB' or 'where the present level is over 60 dB it should be reduced at least by 5 dB'. The system can handle different scenarios regarding railway stock and track superstructure features, traffic volume developments, speed changes.
It is possible to set a boundary condition to the cost benefit ratio of the noise measures. This means that where noise barriers are too expensive in comparison to the number of residents that benefit from them, façade insulation is applied instead (or in addition to lower barriers).
Costs for replacement of existing barriers where higher barriers are necessary will be taken into account as well.

Model definition in this study

For the calculations in this study the following noise model has been created:

- A freight railway line of about 202 km length is regarded. This railway line and its environment are taken from the Dutch freight connection *Brabantroute*[12], see Figure 31.The line runs through industrial areas, rural areas and urban areas. Buildings and dwellings up to a distance of 3 000 m are included in the model. This distance is relevant because of the chosen noise limits down to 40 dB L_{night}

[12] *The Brabantroute is a Dutch freight connection from Rotterdam Harbour to Venlo (German border). It shares the starting point Rotterdam with the Betuweroute, but it then bends to the south and passes mid-size cities like Breda, Tilburg, Eindhoven and Venlo (while the Betuweroute runs only through rural area).*

in this study. Noise effects of 40 dB L_{night} for such heavy used freight railway lines do occur up to 3 000 m from the railway line.

- There are 278 000 dwellings in the model.
- For the purpose of this study, the traffic composition on the line is 12 freight trains per hour (6 trains per direction), each train consisting of 30 wagons with cast-iron braking blocks. This hourly number of freight trains (12) corresponds to a busy freight line[13].
- Besides this main scenario two alternative traffic scenarios could be calculated in the same run, without any extra effort. These scenarios are left unanalysed as they are beyond the scope of the project, but they are kept as spare situations for possible later use. These two scenarios are as follows:
  - A. 12 freight trains per hour (6 trains per direction), each train consisting of 30 wagons with cast-iron braking blocks and 12 passenger trains per hour (6 trains per direction), each train containing 10 disc-braked coaches;
  - B. Like situation A, but with only 1 such passenger train per hour (0.5 per direction).

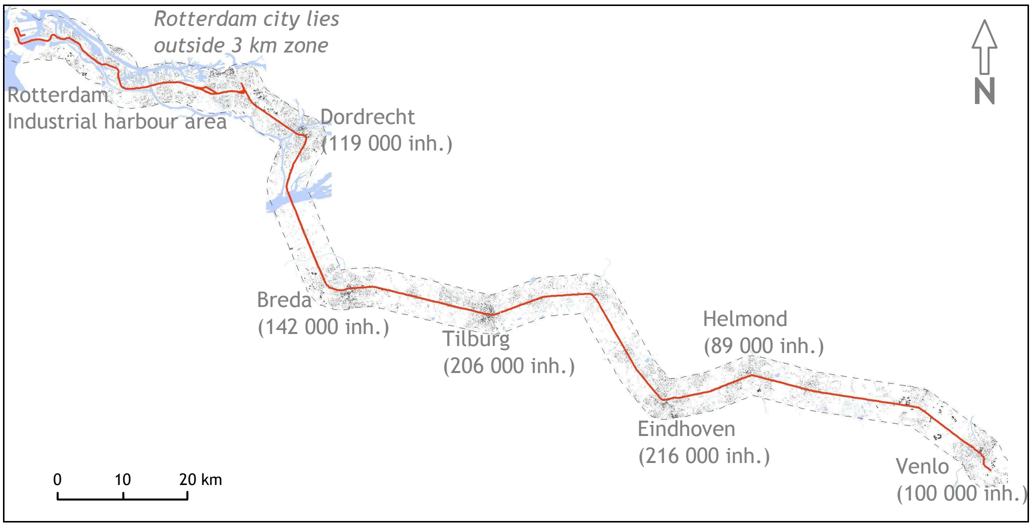

Figure 31 The *Brabantroute*, a 202 km railway line used for the model calculations. Dwellings and waterways within 3 km distance from the line are shown. The given number of inhabitants refers to the total number per city (also outside the 3 km zone).

Basic description of the noise calculations and post-processing

The analysis is done in two steps: (1) noise calculations using the RINGS software and (2) data post-processing processing using GIS software and databases. The noise calculations are made for 8 situations with and without noise barriers of different heights. The post-processing part of the analysis consists of constructing a

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[13] *For comparison: the hourly number of freight trains along the real Brabantroute varies between 2 and 4 during night-time. In the Rhine Valley about 15 freight trains per hour are expected in the future.*

database look-up table and algorithms that determine where barriers should be placed as well as which height the barrier should have to reach a certain target noise reception level. Both parts of the analysis are described in more detail below. Thereafter the cost-benefit algorithms are explained that allow for cost-optimized placement of barriers.

Noise calculations

The noise calculations consist of computing the L_{night} value at the dwellings in the present situation and in case noise barriers are installed of 1 m, 2 m, 3 m, 4 m, 5 m, 6 m height. In one additional case, the L_{night} is calculated for a situation where besides the 6 m barrier also rail dampers are installed (effect 3 dB at the source). All together, this makes 8 calculation runs. The result of the noise calculations is the *reception level database* with Lnight values at all 278 000 dwelling positions (receiver height is 7.5 m above track level, equal for all dwellings).

Post-processing

The post-processing part of the analysis contains all intelligence concerning the question where barriers should be placed and their height. In this part a look-up table is constructed that contains for each dwelling the specific track segments of which the noise creation contributes significantly to its L_{night} value, as illustrated in Figure 32. Track segments of 25 m length are defined. Using this look-up table and the reception level database, it is possible to derive the required barrier height and position to reach a certain target reception level, for each dwelling separately. The output of this stage of post-processing is:

- A set of noise measures (barriers and dampers) with various barrier heights between 1 and 6 m that are to be built along the railway line;
- Aa set of noise levels for all 278 000 dwellings in case these noise measures (barriers and dampers) are built;
- The number of annoyed people before and after applying the noise measures (barriers and dampers).

From the above information the total barrier costs and the total benefits in terms of reduced annoyance can be evaluated.

In order to calculate the total barrier cost, two different approaches are followed:

I. <u>Rigid method</u>: Target noise levels should be reached no matter what cost;
II. <u>CBC method</u>: Target noise levels should be reached up to a defined cost-benefit criterion.

The algorithms behind these methods are explained hereafter.

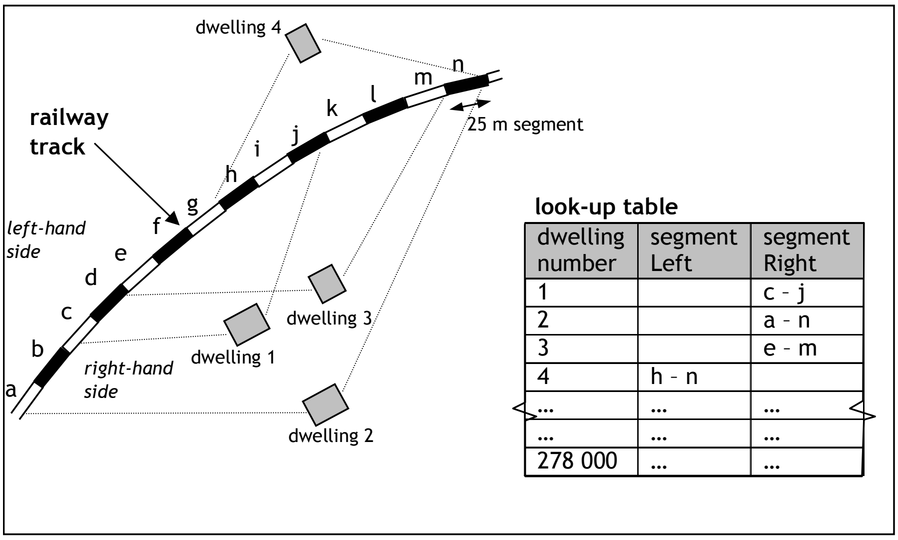
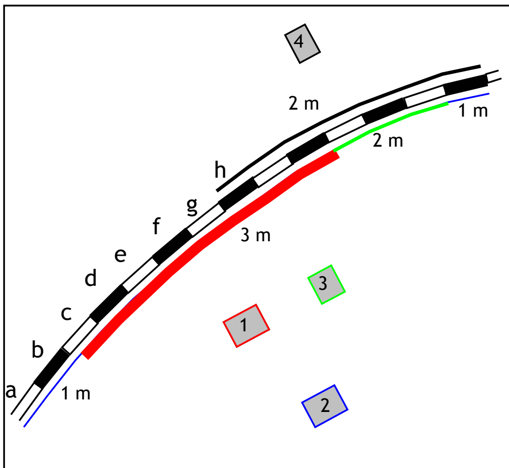


Figure 32 Setting up the look-up table that connects acoustically relevant track segments with dwellings. Segments within an aperture of about 130° are listed.

Rigid method

In this method the barrier height is chosen such that L_{night} at each dwelling will at least be equal to the target value, without any efficiency constraint. The resulting barrier height for a track segment in front of a group of dwellings, is the maximum barrier height (required by the most demanding dwelling) found via the look-up table. This is illustrated in Figure 33. The other dwellings within this group may end up with a level (slightly) below the target. As individual costs per dwelling are not taken into account in the rigid method, even a detached farmhouse at 250 m from the railroad may get a 1000 m long and 1 m high noise barrier (€ 925 000).



rigid barrier result table
(one new table for each target level)

segment number	height Left	height Right
a	0 m	1 m
b	0 m	1 m
c	0 m	3 m
d	0 m	3 m
…	…	…
g	0 m	3 m
h	2 m	3 m
…	…	…

Figure 33 **Rigid method. For example, the required barrier height for a certain target L_{night} value for segment 'c' is 1 m for dwelling no. 2 and 3 m for dwelling no. 1. The table lists the maximum value.**

The total barrier cost for each target value (40 dB, 45 db, …, 70 dB) is found by adding up all barrier lengths of a specific height and multiplying this with the height-related barrier price, see Figure 34. In some cases the height of existing noise measures are not enough and higher barriers need to be placed. In these cases additional cost of 25% is counted for the extra cost of disassembly and removal the existing barrier.

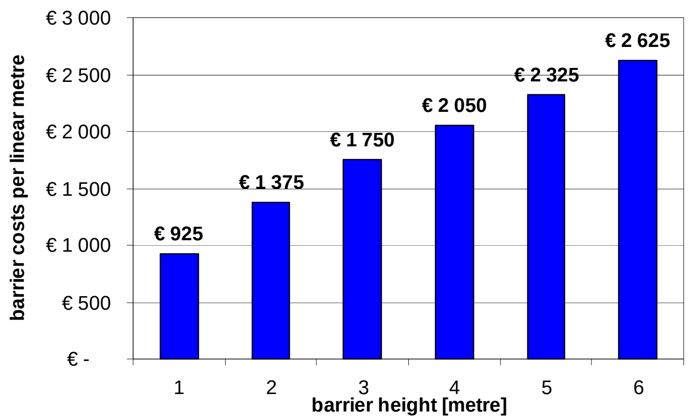


Figure 34 **Barrier prices.**

CBC method

In the cost-benefit criterion method, barriers will generally not be placed in rural areas where hardly any dwelling is found, because barriers are too expensive in relation to the number of residents that benefit from them. Situations occur that additional noise barriers can cost up to 1 million euro per dwelling. A cost-benefit criterion may then be used to decide if a barrier of a certain height is placed in a certain situation. This criterion leads to the 'optimal' noise measures, in the sense that as much residents as possible will benefit from the barriers, giving priority to the extremest cases. Some countries that apply a certain CBC will reduce the interior noise level of the dwellings that do not reach the target (façade insulation).

The criterion used in this study is an example of a possible criterion. Many alternatives are possible. The cost-benefit criterion is done is introduced just to show the potential effect on cost for noise measures and on annoyance.
The cost-benefit ratio could in general be based on the following premisses:

1. The higher the noise level (and the higher the health effects may be), the more resources should be allocated for noise measures;
2. The more people benefiting from a noise measure, the more cost-effective that measure will be.

These premisses can be combined in several ways into a decision tool or, if desired, into a mathematical formulation. The formulation followed in this study is based on the idea that is used in the Dutch noise legislation. First, a certain amount of money is allocated to each dwelling that is above the L_{night} target value. This amount only depends on the present L_{night} value of the dwelling. The higher the present value, the higher the resources per dwelling, see Figure 36. A step is made at 60 dB in the relationship between L_{night} and the budget per dwelling, in order to give special attention to highly exposed neighbourhoods[14].

The budget per dwelling in Figure 36 can be chosen different for individual countries. On both side there is a limit. The limits are related to the maximum amount of money (per dwelling) you want to invest to improve the situation. And the minimum amount of money (per dwelling) it is acceptable to invest to improve the situation.

- Budget per dwelling is too high: Noise measures like barriers and rail dampers are placed for cost that is close to or more than the value of the dwelling. For cases where this budget value is more than the value of the dwelling, building owners will prefer to accept the money and leave their house. In most cases in The Netherlands the maximum budget per dwelling is about 2 until 10 times lower than average values of dwellings.
- Budget per dwelling is too low: Noise measures like barriers and rail dampers are in many cases not placed. Even in situations where the noise reception value does not meet the limit and the relative cost per dwelling is low. In most cases in The Netherlands the minimum budget per dwelling is about 30 until 150 times lower than average values of dwellings.

[14] *In the Dutch cost-benefit criterion, which is based on L_{den} rather than L_{night}, this step is made at 70 dB L_{den}.*

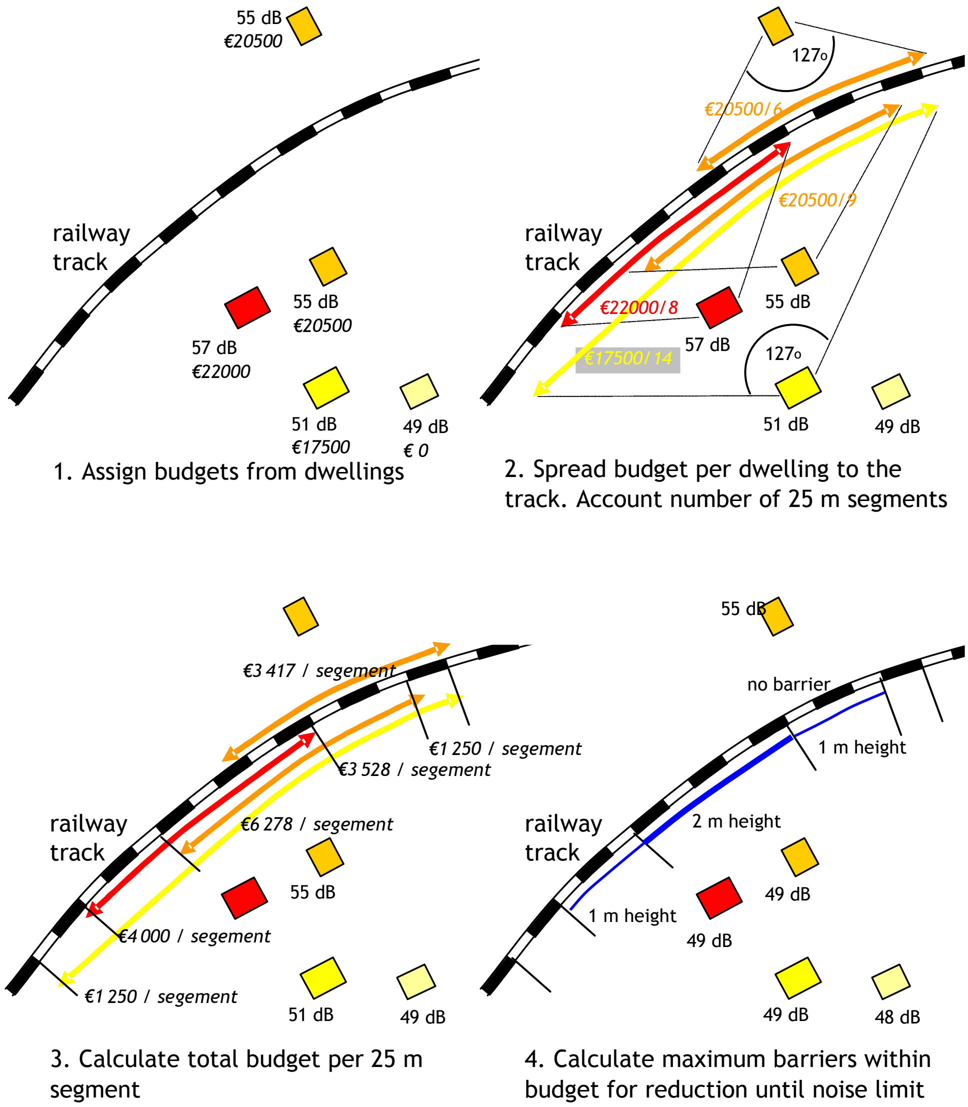


Figure 35 **Calculating the optimal set of barriers for a L_{night} target value of 50 dB. Though dwellings at 50 dB or less are not contributing to the barrier budget, they may still benefit from the measures.**

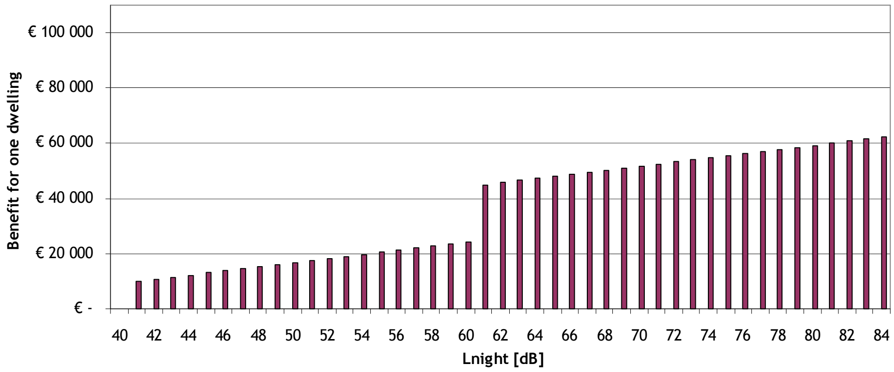


Figure 36 Virtual budget per dwelling, dependent of L_{night} in the present situation.

The budget of the dwelling is then assigned to the piece of track in front of it. For example, if the present L_{night} value for a certain dwelling equals 55 dB, its budget is € 20 500. This budget is equally distributed to all track segments listed in the look-up table (Figure 32) for this dwelling. The more dwellings are close to each other, the more budget is virtually assigned to the track in front of neighbourhood. Noise barriers are mainly placed where the budget is sufficient to build at least a 1 m high barrier. If more budget is available, higher barriers can be placed. Where there is not enough budget, no barriers are placed (the budget is not used then). In some countries, façade insulation is applied to those dwellings. If the noise barrier height is enough to meet the L_{night} target level and the budget allows even higher barriers, no further increase of barrier height is calculated. Further barrier increase is not necessary because the noise level is not above the L_{night} target level anymore.

Appendix 2
Number of persons per household

The average number of people living in a household is closely related to living standards. Western Europe has a lower number of people living in the average household (2.6) than Eastern Europe (2.7). Industrialised nations in Australasia (2.7) and North America (2.5) have similar rates. Figure 37 shows the development of these rates in the period 1977 until 2015.

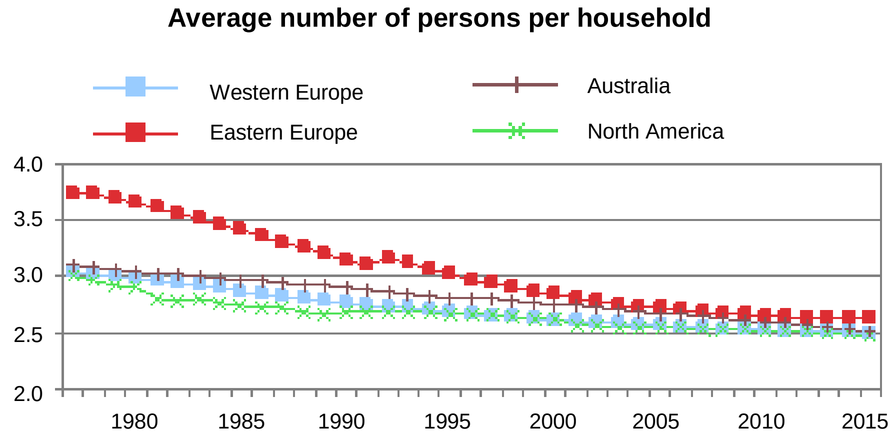


Figure 37 Average number of people living in a household (Source: Euromonitor International).

Other sources show similar rates within Europe. The European Environmental Agency made indicator sheets for the average number of people living in a household. They used the data source:

- Population data –Eurostat/NewCronos (24/03/2000);
- Household number: Euromonitor - European Marketing data and statistics 1997;
- 32nd edition + Statistical Compendium for the Dobris Assessment (table 26.1).

Figure 38 gives an overview of the number of persons per dwelling in the period 1980 until 1995. In 1995 the European average rate was 2.5 persons per household.

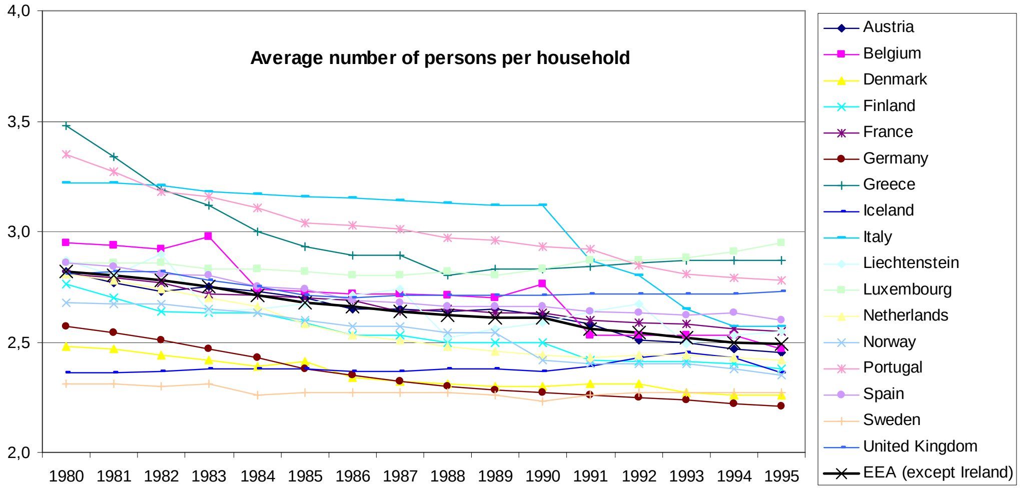


Figure 38 Average number of people living in a household (Source: European Environmental Agency).

Appendix 3
ERTMS corridors

The extrapolation of the cost to the ERMTS corridors is based on values of the network and characteristics of the country. The values used for this extrapolation are given in Table 3 and Table 4 of this appendix.

Table 3 Freight transport on the ERMTS corridors (source: UIC Atlas 2008 [1]). The number of trains per hour during the night is estimated.

Corridor	Country	Route length [km]	Freight [t km *10^6]	Trains per hour during the night
Corridor A	Germany	1 080	36 362	17.1
Corridor A	Italy	734	5 020	3.5
Corridor A	Netherlands	229	5 969	13.2
Corridor A	Switzerland	874	25 688	14.9
Corridor B	Austria	110	2 515	11.6
Corridor B	Denmark	350	2 414	3.5
Corridor B	Germany	1 205	34 860	14.7
Corridor B	Italy	903	1 513	0.9
Corridor B	Sweden	909	4 874	2.7
Corridor C	Belgium	532	3 677	3.5
Corridor C	France	1 084	13 765	6.4
Corridor C	Luxembourg	59	45	0.4
Corridor C	Switzerland	5	89	9.0
Corridor D	France	877	9 596	5.6
Corridor D	Hungary	283	259	0.5
Corridor D	Italy	628	3 000	2.4
Corridor D	Slovenia	447	3 546	4.0
Corridor D	Spain	535	2 856	2.7
Corridor E	Austria	167	1 803	5.5
Corridor E	Czech Republic	828	5 196	3.2
Corridor E	Germany	55	1 834	16.9
Corridor E	Hungary	502	3 981	4.0
Corridor E	Romania	865	3 187	1.9
Corridor E	Slovakia	297	2 471	4.2
Corridor F	Germany	980	24 593	12.7
Corridor F	Poland	954	7 932	4.2

Table 4 Density factor per country based on number of inhabitants and land surface. The factor is relative to The Netherlands (source: http://en.wikipedia.org/wiki/Area_and_population_of_European_countries).

Country	Inhabitants	Surface [km2]	Inhabitants per km2	Factor
Austria	8 404 252	83 858	100	25%
Belgium	10 918 405	30 510	358	89%
Czech Republic	10 532 770	78 866	134	33%
Denmark	5 560 628	43 094	129	32%
France	65 075 310	547 030	119	30%
Germany	81 751 602	357 021	229	57%
Hungary	9 986 000	93 030	107	27%
Italy	60 626 442	301 230	201	50%
Luxembourg	511 840	2 586	198	49%
Netherlands	16 654 979	41 526	401	100%
Poland	38 200 037	312 685	122	30%
Romania	21 413 815	238 391	90	22%
Slovakia	5 435 273	48 845	111	28%
Spain	46 152 926	505 782	91	23%
Sweden	9 415 570	449 964	21	5%
Switzerland	7 866 500	41 290	191	48%

Literature

[1] UIC Atlas 2008 of Infrastructure in the ERIM Netwerk, February 2009.
[2] Exploring bearable noise limits and emission ceilings for the railways - Part I: National and European legislation and analysis of different noise limit systems | UIC Project 'Bearable limits and emission ceilings', 25 October 2011, dBvision, Edwin Verheijen and Frank Elbers.
[3] The railway noise bonus; discussion paper on the noise annoyance correction factor – Final report, November 2010, UIC, Paul de Vos.
[4] Elements for a position paper on night-time transportation noise and sleep disturbance, January 2003, TNO Inro, Henk Miedema, W. Passchier-Vermeer and H. Vos.
[5] Night noise guidelines for Europe, 2009, World Health Organisation.
[6] Railway noise in Europe – A 2010 report on the state of the art, September 2010, UIC, Jakob Oertli and Peter Hübner.
[7] European Rail Infrastructure Masterplan (ERIM) – 2007 Final Report, January 2008, UIC, Aleksandra Perkuszewska, Annemarie Ebenberger.

Colophon

Title
Exploring bearable noise limits and emission ceilings for the railways
Part II: Cost and benefit study for different noise limits

Client
International Union of Railways (UIC)
Contract number: P000250/10.288

Coordinator and contact person: Lisette Mortensen
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Date
26 November 2011

Report reference
UIC001-01-23fe

Status
Final

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