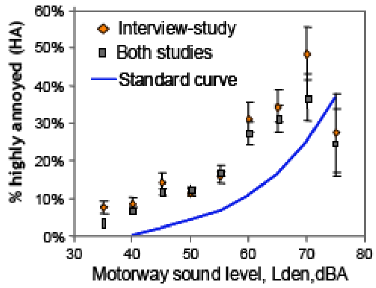
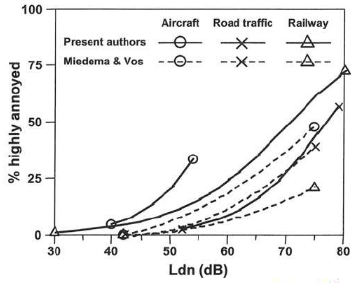
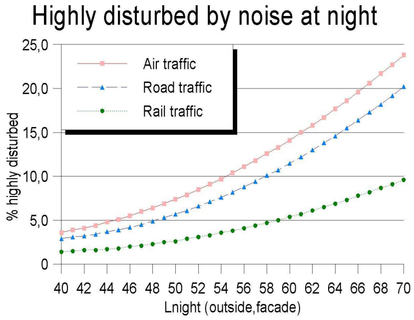
The railway noise bonus

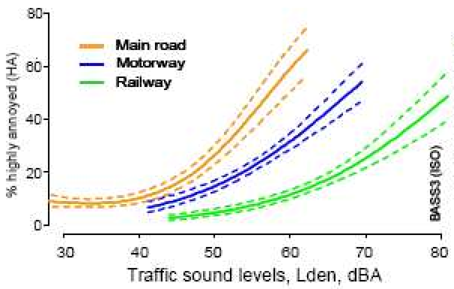
Discussion paper on the noise annoyance correction factor

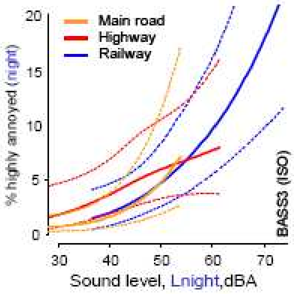
Final Report

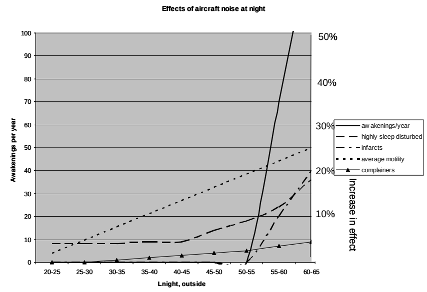












International Union of Railways, UIC
November 2010

This report has been realised by DHV B.V for the International Union of Railways.

ISBN 978-2-7461-1903-1

Printed by
International Union of Railways
16, rue Jean Rey 75015 Paris - France
November 2010

Table of content

EXECUTIVE SUMMARY

When people are exposed to environmental noise, a range of adverse effects may occur. In case of excessive or incidental noise, people tend to complain. In daily life, people can be disturbed in their activities, such as working, communicating or sleeping. In the long turn, these effects may cause annoyance. Annoyance could affect health, because it may lead to irregular hormone secretion, stress, high blood pressure and cardiovascular problems. Excessive noise during the night may disturb healthy sleep patterns and could lead to awakenings.

Most of these effects occur only after a long time exposure to noise. Therefore, the long term average noise level, expressed for instance in the European common indicator L_{den}, is the preferred quantity to express the exposure. From this exposure, the effects can be predicted using dose response relationships. These relationships are based on field or laboratory surveys. Such surveys have been carried out from the 1970s. From the 1990s different survey results have been combined in large databases. Analysis of these databases has demonstrated, that at equal exposure, railway noise leads to a lower percentage of annoyed people than road traffic noise. This difference can be expressed in decibels and is often indicated as railway bonus. In this report however we prefer to use the more neutral term “noise annoyance correction factor”, further indicated as NACF.
There is a large amount of evidence that the NACF assumes values of 5 dB or more for the majority of common noise exposure levels. Only for very low levels, the NACF may approach to zero.

With the growing concern about new and extended railway lines and traffic increase on existing lines in sensitive areas throughout Europe, the justification of this NACF has been questioned over and over again. The repeated criticism triggered new surveys and new analyses, which in most cases confirmed the previous NACF. Particularly for general annoyance and Lden the evidence is overwhelming, even for special cases such as high freight traffic intensity. For particular elements of general annoyance, in particular sleep disturbance, the results are more widespread. In the majority of cases, a positive correction factor was found, but certainly when different exposure indicators are used, results show a wide spectrum. More standardization in research approach is required when it comes to sleep disturbance and health effects research.

The term “rail bonus” and the way it is implemented in the legal framework has provoked critical reactions from people who think that there is a political bonus for the railway as a transport system. Clearly this is not the case. A better explanation is required, particularly with respect of the implementation of the NACF into the legal framework.

RESUME

L'exposition à un environnement bruyant peut entrainer toute une série d'effets négatifs. La présence d'un bruit excessif ou fortuit tend aussi à générer des plaintes et le bruit peut gêner les activités quotidiennes telles que le travail, les communications ou le sommeil. A long terme, ces effets peuvent se transformer en nuisances susceptibles de dégrader la santé en raison de sécrétions hormonales irrégulières, du stress, de l'hypertension artérielle et des problèmes cardiovasculaire qu'ils peuvent induire. Les rythmes normaux du sommeil peuvent aussi être perturbés par un bruit nocturne trop important pouvant provoquer des réveils.

La plupart de ces effets ne se produisent qu'après une longue période d'exposition au bruit. C'est pourquoi le paramètre privilégié pour exprimer cette exposition est le niveau de bruit moyen à long terme que traduit, par exemple, l'indicateur européen commun L_{den}. Partant de cette exposition, on peut prévoir les effets qu'elle induit en utilisant des relations doses/réponses elles-mêmes basées sur des études réalisées sur le terrain et en laboratoire. De telles études sont effectuées depuis les années soixante-dix et les résultats d'un certain nombre d'entre elles ont été combinés depuis les années quatre-vingt-dix pour constituer des bases de données de grande envergure. Or l'analyse de ces bases a montré qu'à exposition égale, le pourcentage de personnes perturbées par le bruit ferroviaire est inférieur au pourcentage de celles qui sont perturbées par le bruit routier. Exprimable en décibels, cet écart est souvent appelé "bonus ferroviaire". Toutefois nous avons préféré utiliser dans le présent rapport l'appellation plus neutre de "facteur de correction des nuisances sonores" (NACF).
Il est largement prouvé que le NACF atteint 5 dB voire davantage dans la majorité des niveaux habituels d'exposition au bruit et c'est seulement à des niveaux de bruit très faibles qu'il peut tendre à disparaître.

Cependant la légitimité de ce NACF n'a cessé d'être contestée au fur et à mesure que montaient les inquiétudes face à la construction et au prolongement de lignes ferroviaires et devant l'accroissement du trafic sur les lignes existantes dans les régions sensibles sur l'ensemble de l'Europe. La répétition des critiques à conduit à réaliser de nouvelles études et analyses qui ont, le plus souvent, confirmé les valeurs de NACF que l'on connaissait déjà, en particulier pour les nuisances sonores en général et l'indicateur L_{den}, y compris dans les cas spéciaux de forte intensité de trafic de fret. Les résultats sont, en revanche, plus dispersés pour des éléments particuliers de nuisance d'ordre général tels que les troubles du sommeil. Un facteur de correction positif a été constaté dans la majorité des cas mais il est certain qu'en présence d'indicateurs d'exposition plus élevés les résultats se répartissent sur un spectre plus large. Quoi qu'il en soit, la recherche sur les troubles du sommeil et les impacts sur la santé nécessitera une standardisation plus poussée des méthodes d'investigation.

L'expression "bonus ferroviaire" et la manière dont celle-ci a été mise en œuvre au niveau juridique ont suscité les critiques de ceux qui pensent qu'elle traduit un bonus politique pour le rail en tant que système de transport, ce qui, à l'évidence, n'est pas le cas. Une meilleure explication s'impose donc, surtout dans la perspective d'une utilisation du NACF dans le cadre juridique.

ZUSAMMENFASSUNG

Wenn Menschen Umweltlärm ausgesetzt sind, kann dies eine Reihe von Beeinträchtigungen mit sich ziehen. Bei übermäßigem oder zufälligem Lärm werden in der Regel Beschwerden laut. Im täglichen Leben kann der Mensch in seinen Tätigkeiten, z.B. beim Arbeiten, Kommunizieren oder Schlafen, gestört werden. Langfristig stellen diese Einflüsse möglicherweise eine gesundheitsschädliche Belastung dar, da sie eine unregelmäßige Hormonausschüttung, Stress, Bluthochdruck oder kardiovaskuläre Probleme verursachen können. Übermäßiger nächtlicher Lärm kann gesunde Schlafmuster stören und ein Aufwachen verursachen.

Die meisten dieser Folgen treten nur nach einer dauerhaften Lärmbelastung auf. Daher ist der langfristige, gemittelte Lärmpegel, der z.B. mit dem gemeinsamen europäischen Indikator L_{den} ausgedrückt wird, die bevorzugte Größe, um die Belastung auszudrücken. Ausgehend von dieser Belastung lassen sich mit Hilfe von Dosis-Wirkungs-Verhältnissen die Folgen prognostizieren. Diese Verhältnisse basieren auf Feld- oder Laboruntersuchungen, die seit den 1970er Jahren durchgeführt wurden. Ab den 1990er Jahren wurden verschiedene Untersuchungsergebnisse in großen Datenbanken zusammengeführt. Eine Analyse dieser Datenbanken hat ergeben, dass Schienenlärm bei gleicher Ausgesetztheit prozentual weniger Menschen belastet als Straßenlärm. Diese Differenz kann in Dezibel ausgedrückt werden und wird oft als Bahnbonus bezeichnet. In vorliegendem Bericht wird jedoch vorzugsweise der neutralere Ausdruck „Korrekturfaktor Lärmbelastung“ (*noise annoyance correction factor*, im Weiteren mit NACF abgekürzt) verwendet.
Es liegen zahlreiche Hinweise vor, dass der NACF bei den meisten gängigen Lärmbelastungsgraden Werte von 5 dB oder mehr ausmacht. Nur bei sehr geringen Lärmpegeln kann der NACF im Nullbereich liegen.

Angesichts der europaweit wachsenden Vorbehalte gegenüber Neu- und Ausbauten von Bahnstrecken sowie steigender Verkehrsvolumen auf den bestehenden Strecken in lärmempfindlichen Bereichen wurde die Berechtigung dieses NACF immer wieder in Frage gestellt. Die wiederholte Kritik führte zu neuen Untersuchungen und Analysen, die in den meisten Fällen den bestehenden NACF bestätigten. Die Beweislast ist insbesondere für die allgemeine Belastung und den Lden überwältigend, selbst in Sonderfällen wie bei einem hohen Güterverkehrsaufkommen. Die Ergebnisse zu Sonderaspekten der allgemeinen Belastung, insbesondere Schlafstörungen, sind breiter gefächert. In den meisten Fällen wurde ein positiver Korrekturfaktor ermittelt; die Ergebnisse decken jedoch sicherlich ein breites Spektrum ab, wenn unterschiedliche Belastungsindikatoren verwendet werden. Bei der Erforschung von Schlafstörungen und gesundheitlichen Auswirkungen müssen die Forschungsansätze stärker standardisiert werden.

Der Begriff „Bahnbonus” und seine Umsetzung im rechtlichen Rahmen haben kritische Reaktionen derjenigen hervorgerufen, deren Ansicht nach die Bahn als Verkehrssystem über einen politischen Bonus verfügt. Das ist eindeutig nicht der Fall. Hier sind bessere Erläuterungen erforderlich, vor allem hinsichtlich der Umsetzung von NACF im rechtlichen Rahmen.

1. The noise annoyance correction factor (NACF)

Noise in the living environment provokes adverse reactions from people. Some of these reactions may be biological or physiological, for instance: loud noise leads to stress hormones being produced. Some other reactions are more psychological and lead to external actions, such as the submission of complaints. One of the reactions is annoyance. Annoyance by definition is self reported and can be measured only through field surveys. The amount of annoyance is usually expressed as the expectation or observation that a certain percentage of people feel annoyed or seriously annoyed.
This amount of annoyance clearly depends on the noise itself the subjects are exposed to.

There are numerous parameters that one might suspect to have an influence on the annoyance, such as:

- the intensity and loudness of the noise,
- its duration,
- the repetition of its occurrence,
- the time of its occurrence (day, evening or night)
- the frequency content,
- its tonality,
- its information content,
- its level variation with time (e.g. continuous, intermittent, incidental),
- its time constant (impulsive or not).

The amount of annoyance is equally dependent on the peculiarities of the group of exposed people, and again a large range of potential influence factors arises, such as:

- the location of the exposure (outside or inside the dwelling)
- whether windows are open or closed,
- the activities during the exposure,
- the personal sensitivity to noise,
- the personal attitude towards the cause of the noise,
- the personal awareness

The relation between noise exposure and annoyance is indicated as dose response relationship or dose response curve. Different noise sources may lead to different reactions, even when the noise exposure level is identical. A clear example is pure tone noise (where a single frequency is dominating such that the noise is observed as a whistling or howling sound), which is considered more annoying than broad band noise.

The **noise annoyance correction factor** is a number, expressed in dB, which indicates:

- the difference in terms of the long term average noise exposure level from two different sources, which leads to the same identical effect in terms of annoyance.

When the noise exposure levels from two different sources have identical values and identical effects, the noise annoyance correction factor is equal to zero.

The noise annoyance correction factor is based on field studies of noise annoyance caused by different sources, where the exposure is expressed in the same quantity. In principle, situations are compared where the noise exposure has the same strength, but the resulting annoyance is different. The correction factor is then used to differentiate between different legal limits for different sources of noise.

From a theoretical point of view, the relation between noise exposure and noise annoyance[1] may have the shape of an S-curve. This is based on the assumption that some people will feel annoyed, no matter how low the noise exposure is. On the other hand, not every resident will feel annoyed, even if the noise exposure is extremely high. This leads to the following, hypothetical curve.

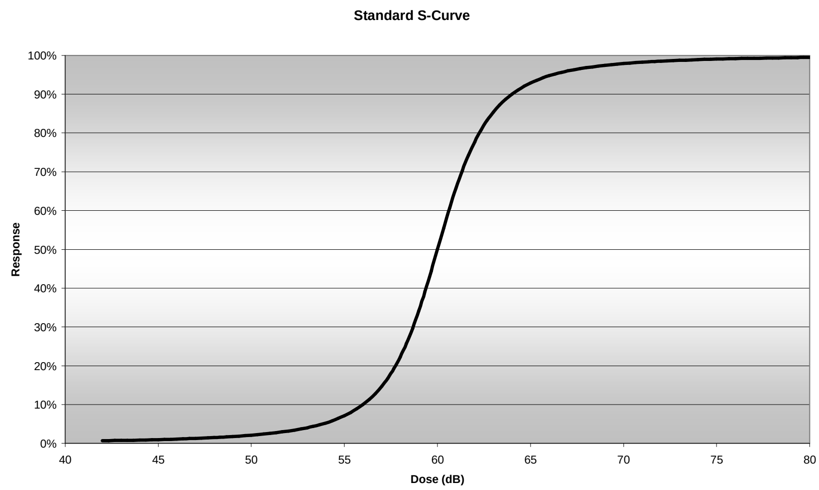


Figure 1: Hypothetical relation between noise exposure and response on the basis of an ideal standard S-curve

Most of the dose response curves presented in literature only show the middle part of this curve. In addition, it is unlikely that a real relation, e.g. on the basis of population surveys, will be consistent with the ideal S-curve.

An example of how to assess the noise annoyance correction factor from two hypothetical sources is presented in the following graph.

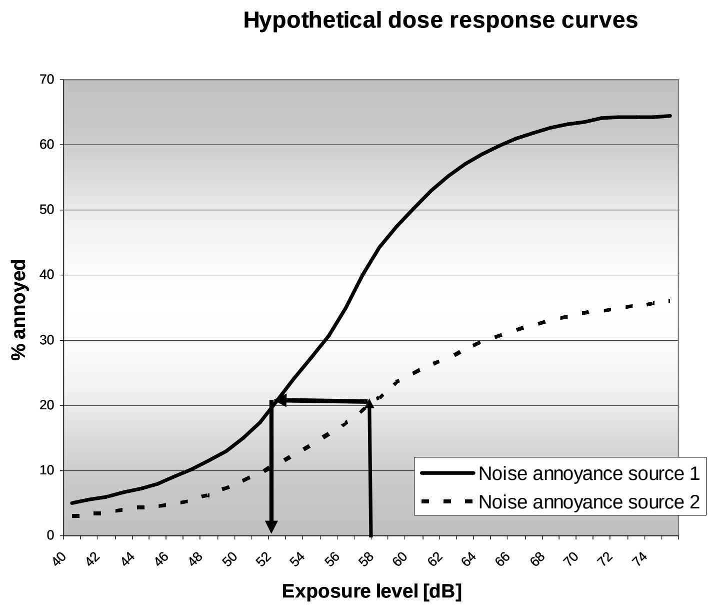


Figure 2: Illustration of the noise annoyance correction factor for two hypothetical sources. Source 2 causes 20% of annoyed people at an exposure level of 58 dB. Source 1 causes the same annoyance at an exposure level of 52 dB. The noise annoyance corrrection factor in this example is 58 – 52 = 6 dB.

[1] More about the background of noise exposure response curves can be found in chapter 4.

From the example in figure 2, it can be seen that the Noise Annoyance Correction Factor may depend on the actual level. This is illustrated in figure 3 below.

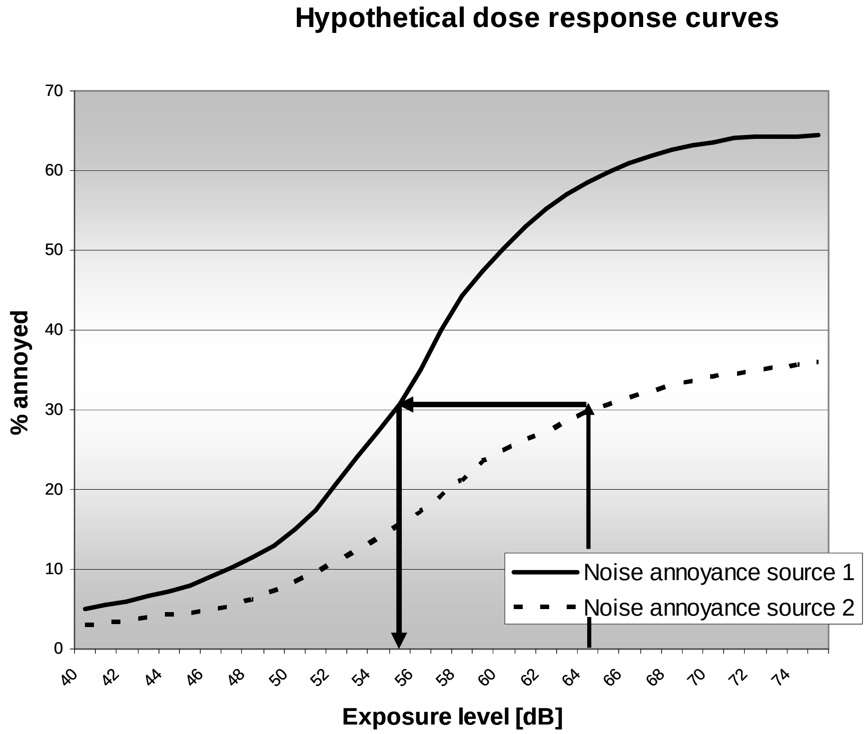


Figure 3: Illustration of the noise annoyance correction factor being dependent of the absolute level. In this case, source 2 causes 30% annoyance at 64.5 dB. Source 1 causes the same annoyance at 55.5 dB. The Noise Annoyance Correction Factor in this case is 9 dB.

Noise annoyance correction factors have been assessed for common sources of environmental noise, particularly transportation noise sources. They have been implemented in different ways in noise policy making and legislation. In chapter 2 of this report, the various ways of interpretation and application of the correction factor have been listed, with a discussion of the justification.

The best known correction factor is the one indicating the difference between road traffic noise and rail traffic noise. This correction factor is often referred to as the **railway noise bonus**, indicating that, at the same identical noise exposure level, railway noise tends to lead to lower noise annoyance figures than road traffic noise.

In hindsight, the name ***Railway Noise Bonus*** *was an unlucky choice. The name suggests that there is a certain advantage for the rail modality in comparison with the road modality. To the general public, particularly to residents along busy railway lines, the supposed advantage is probably the main reason to protest against the application of the railway noise bonus. The arguments against the railway noise bonus are discussed in chapter 5. For reasons of neutrality, in this*

Currently, there is an increasing amount of criticism with respect to the railway noise bonus. The main arguments put forward have been listed and discussed in chapter 5.

The scientific background of the railway noise bonus and a historical overview of its emergence are presented in chapter 4.

2. Application of NACF in legal procedures

2.1 Implementation in legal limits

One important application of the NACF is the differentiation in legal limits. This differentiation is current practice in some countries. The reasoning behind this practice is as follows:

Setting a legal noise limit is a political decision, based on the assumption that there is a given effect of noise which is politically acceptable, whereas the effect is not acceptable when it exceeds this effect.

In the early days of noise legislation, policy makers in various member states have decided that a certain percentage, for example 10%, of highly annoyed people in a population, was acceptable. Any percentage exceeding this number would be considered not acceptable, or only acceptable under certain conditions.
In doing so, and using the exposure annoyance curve, the setting of an acceptable limit for the percentage of annoyance leads to the setting of an acceptable limit in terms of exposure.

In this method, the NACF works out as a differentiation in noise limits. After all, the same politically acceptable level of *annoyance* leads to different acceptable levels of *exposure* for different sources.

Various national governments have implemented the NACF in the way described above. The consequence is a difference between noise limits for road traffic, rail traffic and possibly air traffic.
Some examples of such differences are given in the table below.

Table 1: Example: Difference in noise limit for road and rail in Austria and The Netherlands

Country	Daytime, Road traffic	Night time, road traffic	Day time, rail traffic	Night time, rail traffic
Netherlands (lower limit)	50 dB L_{den}		55 dB L_{den}	
Netherlands (upper limit)	65 dB L_{den}		70 dB L_{den}	
Austria	60 dB	50 dB	65 dB	55 dB

(1) Besluit Geluidhinder, decree of 20 October 2006, amending the Noise Annoyance Law
(2) Dienstanweisung Lärmschutz an Bundesstraßen/ Schienenverkehrslärm-Immissionsschutz-Verordnung (SchIV, 1993 BGBl. Nr. 415/1993)

As shown in these examples, the NACF equals +5 dB both for the lower levels and for the higher levels.

In addition to the data already known, a small questionnaire was sent out to experts in the EU Member States. A response was received from approximately 50% of the national experts. The results are presented in the following table.

Table 2: Results of questionnaire on the current application of NACF in EU countries

Member state	Noise legislation in place?	Noise annoyance correction factor in legal limits?	If yes, what is its value? (rail limit – road limit) in dB
Austria	Yes	Yes	+ 5 dB
Belgium	No info		
Czech Republic	No info		
Denmark	Yes	Yes	+ 6 dB
Estonia	No info		
Finland	No info		
France	Yes	Yes	+ 3 dB for conventional speed, 0 dB for high speed
Germany	Yes	See chapter 2.2	+ 5 dB
Hungary	No info		
Ireland	No info		
Italy	Yes	No	
Latvia	No info		
Lituania	No info		
Luxemburg	No info		
Netherlands	Yes	Yes	+ 5 dB
Norway	Yes	Yes	+ 3 dB
Poland	Yes	No	
Portugal	No info		
Romania	Yes	No	-
Slovenia	Yes	No	
Spain	Yes	depends 3)	
Sweden	No info		
Switzerland	Yes	Dependent on traffic intensity, see chapter 2.2	
UK	No info		

3) In Spain, there is a difference in indicators; road traffic is limited by L_{den}, $L_{evening}$ and L_{night}, for new rail infrastructure there is an L_{max} limit in place. There is no general conclusion which is higher.

In the questionnaire, national experts were asked what the basis for a possible NACF was. A few respondents referred to ISO 1996 [5]. Part 1 of this ISO standard specifies a railway related NACF of “3 to 6 dB” but restricts its application to trains with speeds less than 250 kph. Denmark referred to the Danish EPA Environmental Project 42/1982, referenced in a famous 1988 paper by John Walker [83]. More recent recommended noise limits in Denmark are based both on calculations of the expected differences between L_{Aeq} (using the original prediction methods) and L_{den} as a yearly average (using the recent NORD2000 method), ensuring no intended change of the protection against noise, and on the results from Miedema [2].

Outside Europe, the American Standard ANSI 12.9 refers to the same dose response relationship as ISO 1996, but it does not specify a railway related NACF.
Although this was not mentioned explicitly by the respondents, we can assume that certain documents have played a significant role in setting the stage for a NACF. One important reference is a meta-study by Moehler in 1988 [43], presenting the following table:

Table 3: Differences between levels of road and railway noise for equal disturbance reaction [43]

Study	Disturbance reaction	Noise level differential dB(A) LAeq, 24 hours or LAeq,night
Daytime effects		
Holzmann (1982)	Interference during day	+5 dB to + 10 dB
	Communication	Negative
Heintz et al (1980)	Communication	Negative
Peeters et al (1983)	Communication	Negative
PBO (1983)	Interference during day	0 dB to + 4 dB
	Communication	- 4 dB to – 1 dB
Knall et al (1983)	General disturbance, day	0 dB to + 4 dB
	Communication	-4 dB to 0 dB
	Disturbance, outdoor leisure	-1 to 0 dB
Moehler (1985)	Communication indoors, windows closed	-16 dB to – 7 dB
	Communication indoors, windows open	-5 dB to 0 dB
	Communication outdoors	-2 to + 2 dB
	Indoor rest and leisure, windows closes	0 dB to + 4 dB
	Indoor rest and leisure, windows open	+ 5 dB to + 12 dB
Moehler et al (1986)	General disturbance, day	+ 1 dB to + 7 dB
	Communication	-4 dB to – dB
	Disturbance, outdoor rest and leisure	- 1 dB
	Disturbance, indoor rest and leisure	+ 1 dB to + 7 dB
Night time effects		
Holzmann (1978)	Interference at night	+ 6 dB to + 11 dB
Heintz et al (1980)	Interference with sleep	+ 4 db to + 20 dB
PBO (1983)	Interference at night	+ 9 dB to + 11 dB
Vernet et al (1983)	Interference with sleep	Positive
Knall et al (1983)	Disturbance to sleep	+ 12 dB to + 14 dB
Moehler et al (1986)	General disturbance, night	+ 7 dB to + 8 dB
	Disturbance to sleep	+ 12 to + 14 dB

In the UK, the Mitchell report [53], prepared for the Department of Transport, has most likely been a basis for setting the national noise standards. The report lists the arguments why there is a basis for a noise standard for railway noise that is somewhat higher than the standard for road traffic noise. Finally the report cites the conclusion of the committee of experts as follows:

"The committee believes that the fairest way to equate road and rail noise is to set a standard that allows a daytime noise level … which is 2 dB(A) above the daytime 18 hour noise level …. for roads".

The committee has not advised to set a standard for night-time noise, as there was no such standard for road traffic noise at the time either.

Similar arguments in other countries have lead to the value presented in table 2.

2.2 Implementation in prediction methods

A different way of implementing the NACF has been applied in Germany and Switzerland. In these countries the limit values for road and rail are identical. The NACF was implemented as a correction into the noise prediction scheme for railway noise. In doing so, the prediction of railway noise levels leads to a resulting noise level which is lower than without this correction. The prediction scheme for road traffic noise does not have such a correction included.

In Germany, according to the 16. BImSchV (Federal Immission Protection Ordinance), in a purely residential area and for new and substantially altered tracks, a limit value of 59 dB(A) during the day and 49 dB(A) during night time applies to all types of traffic noise. According to paragraph 3 and Annex 2 of the 16. BImSchV, a reduction of 5 dB(A) is to be applied to rail roads with the exception of railroads with a significant amount of freight trains.

In Switzerland, a planning limit of 55 dB during day (45 dB during night), a limit value of 60/50 dB and an alarm value of 70/65 dB are to be applied to purely residential areas. In calculating the levels, a correction factor K1 shall be applied. K1 is comparable to the NACF and is defined in annex 4 of the Noise Protection Ordinance, as follows:

Table 4: NACF in Swiss legislation

K1	- 15 dB	If N< 7,9
K1	10.log(N/250)	If $7{,}9 \leq N \leq 79$
K1	-5	If N > 79

In this table, N is the number of train passages per day (6.00 – 22.00 hours) or night (22.00 - 6.00 hours) period.
K1 assumes a value between 5 and 15 dB, where the higher correction applies to railway lines with very low traffic intensity (less than 1 train per hour).

The function is presented in the following graph:

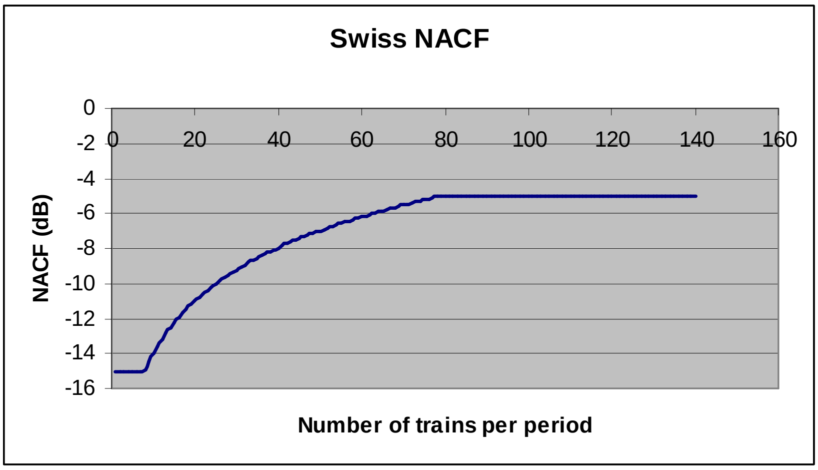


Figure 4: Swiss Noise Annoyance Correction Factor in function of the number of trains passing per period (day of night)

2.3 Application in the END

The Environmental Noise Directive (49/2002/EC) came into force in 2002. It requires member states to produce, every 5 years, strategic noise maps of the major infrastructure (roads, railways and airports) and of agglomerations. The maps should be focused on noise levels that are potentially hazardous. The lower limits for noise mapping, defined in the END, are 55 dB L_{den} and 50 dB L_{night}.
For these lower limits, there is no differentiation between the different sources of noise addressed in the END.

In producing strategic noise maps, the assessment methods defined in Annex II of the Directive should be applied. These methods do not include any Noise Annoyance Correction Factor. Evidently, the noise maps for the railway network in Germany do not either.

This leads to the effect that residents in Gemany may find themselves confronted with two different results:

- One result from a legal procedure for railway noise, including the NACF,
- One other result, 5 dB higher, from strategic noise maps of railways.

Obviously, this requires explanation to the citizen. So far, not many citizens have used this argument in their protests against railway noise, but one should be aware that there is this difference between legal procedures and noise mapping.

The END does not have the objective to set acceptable noise limits applicable throughout Europe. It is left to the responsibility of the Member States competent authorities to set limits and decide upon necessary actions. Consequently, it is also left to the member state whether or not to include a NACF in the setting of acceptable limit values for noise action plans in the frame of the END.

In chapter 3, the issue of multiple exposure is raised. This situation is applicable to the urban areas in most European countries. It is shown in chapter 3 that ignoring the NACF in EU noise mapping may lead to inefficient decisions when drafting the action plans.

2.4 Discussion

In general, the acceptance for new initiatives in road and rail networks is decreasing. Residents feel that their rights are not sufficiently protected by the current legal limits. Their concern is mainly about the increasing traffic flow on existing lines, which is usually not considered to be a legal ground for noise mitigation.
In their concern, residents question not only the legal limit values, but also the quantities in which these limits are expressed. The use of long term average levels is often put to the quest, as residents argue that peak levels would better represent their exposure.
The Noise Annoyance Correction Factor represents an important element in this discussion. After all, its existence is often explained by the fact that railway noise, as opposed to road traffic noise, has a distinct structure of relatively long pauses and relatively short peaks. Therefore, people feel that the use of a long term average is particularly faulty when judging railway noise.

Summarizing, this leads to the following complications:

(1) In the communication with citizens, it is usually difficult to explain why the legal noise level is a long term average level. Citizens are inclined to have more confidence in measured values of the instantaneous level than in computed long term levels. As these computed levels can not directly be checked against measured values, they feel that the computed level could be manipulated. In the German and Swiss approach to the NACF, this is even more complicated, because the calculated level includes the NACF, whereas the measured level does not include it. This could lead to the (erroneous) interpretation that the railway noise level is manipulated, whereas the road traffic noise level is not.

(2) In the application of the END, strategic noise maps have been produced for the rail

and road network in Germany. As argued in the previous section, the levels presented in the noise maps do not include a NACF. This makes it difficult to compare noise mapping results with noise levels applied in any legal procedures. Generally, the noise maps show noise levels that are 5 dB higher than the levels used in legal procedures. Again, this leads to the (erroneous) conclusion that legal levels might be manipulated and that the END finally brings forward the "truth". Although this has not been used as an argument by residents, it represents a potential risk in the communication with citizens.

In comparison to these complications, the approach followed in several countries (re. table 2) with a NACF has more transparency, both for politicians and citizens. Also, there are no conflicting results when legal procedures are compared to the noise mapping results.

It should be emphasized that, for legal applications, there is no difference between an application of the NACF in the prediction scheme (German/Swiss approach) and the application of the NACF in the limit value (several other countries). This is illustrated in the following equations:

In general the following *legal requirement* applies:

$$\text{Assessment level} \leq \text{legal limit} \quad (1)$$

In the German/Swiss approach this reads:

$$\text{Assessment level} - \text{NACF} \leq \text{General legal limit} \quad (2)$$

In the approach in other countries (table 2) this reads:

$$\text{Assessment level} \leq \text{Railway limit} = \text{General legal limit} + \text{NACF} \quad (3)$$

where (2) and (3) are equal.

These equations show that there is no principal difference between the approaches in all the member states that apply a NACF. In most of these countries, the value of NACF is chosen to be 5 dB. However, the German/Swiss approach may lead to more community dispute because it tends to lead to the suspicion of manipulation.

3. Multiple source exposure and cumulative noise exposure

The application of a NACF is very relevant when it comes to assessing the impacts of multiple noise sources operating at the same time. This is illustrated by the following example.

In adding noise exposures from different sources, a weighted summation is highly recommended. An equal annoyance weighting can be derived directly from the dose response relationships provided in the Position Paper of the Working Group on the Assessment of the Exposure to Noise [1]. Usually, the noise exposure from a given source not being road traffic is translated first into an equal annoyance road traffic noise exposure. The resulting "weighted" noise exposure level can then be energetically added to the exposure from road traffic. Here, one has the choice to either use the curves for "percentage of people annoyed" or for "percentage of people highly annoyed".

The following example illustrates the method of cumulating noise exposure from a road and a railway line. All numbers are rounded to the nearest natural integer.

Road noise exposure level L_{den} = 62 dB
Rail noise exposure level L_{den} = 67 dB

Energetic summation of these two levels would result in 68 dB (62 ⊕ 67 = 68 dB, where the ⊕ sign indicates energetic or logarithmic summation). However, the noise exposure level of rail noise will cause 10,6% of highly annoyed citizens. The same annoyance score would have been achieved by road traffic noise with a level of 60 dB Lden. The "equal annoyance weighted' rail noise level is 60 dB L_{den}. The cumulative noise level then is 64 dB L_{den} (62 ⊕ 60 = 64 dB).

The relevance of this method emerges when one starts defining mitigation measures for this situation.
One would tend to start with the railway line, as it causes the highest exposure. A reduction of 5 dB of railway noise would cause an overall reduction from 68 dB down to 65 dB (62 ⊕ 62 = 65 dB), so an effective reduction of 3 dB.
However, in terms of equal annoyance, the 64 dB would be reduced to 63 dB (62 ⊕ 55 = 63 dB), so an effective reduction of only 1 dB.
In conclusion, it would probably not be the best decision, in this case, to start reducing at the railway only.

4. Background and basis of NACF

4.1 Annoyance caused by transportation noise, a historical review

4.1.1 The Schultz curve

The first comprehensive and often cited study into the annoyance effects of different sources was carried out by Theodore Schultz of Bolt, Beranek and Newman [75]. He started in 1976, in assignment of the USA Department of Housing and Urban Development. Schultz collected data from various so-called social surveys, originating from different researchers, different cities and even different countries, and tried to combine these. The surveys included aircraft noise and different surface transportation noise sources.
In such field studies, residents would be asked about their annoyance. They would score the amount of observed annoyance on a scale, and Schultz combined the different scales by defining that those residents who indicated a score within the higher 28% of the scale, whatever it was, were to be considered “highly annoyed”.
Schultz may have had similar difficulties with the exposure side of the relationship: many different exposure indicators were used. He used the L_{DN} or day-night level, which usually deviates only insignificantly from the L_{den}.

The original Schultz curve, i.e. the result of the 1976 study, is presented below. It shows the typical shape that has been introduced in the previous sections, although it differs at the higher exposure end.

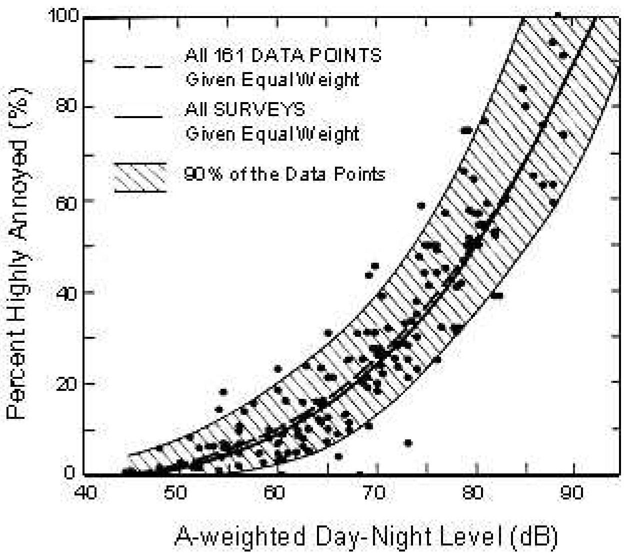


Figure 5: The curve showing data points from various field surveys, as collected and interpreted by Schultz [75]

Schultz’s work was a major breakthrough with respect to his choice for the dependent and independent variable, i.e. the *self-reported* annoyance and the *long term average* noise exposure. From the moment of his publication, there was much criticism with respect to this choice. Other researchers argued that other indicators of the effects of noise, such as sleep or speech disturbance, or even complaints, should have been used as the dependent variable. Comparable arguments were raised with respect to the choice for the long term average exposure. However, these criticasters did not find a similarly good correlation between exposure and effects as Schultz did.

The Schultz curve, for all noise sources, confirms the lower part of the theoretical S-shaped curve presented in figure 1, but obviously there is a large spread around the curve. In a later stage, Schultz concluded that he could improve the correlation if he split up those data according to the type of noise source involved. Thus, he produced different dose response relationships for different noise sources and in doing so introduced, for the first time, a basis for a Noise Annoyance Correction Factor.

In later years, the data from Schultz has been re-analysed, for instance by Fidell [18] distinguishing between different sources of noise. This has lead for example to the following graph.

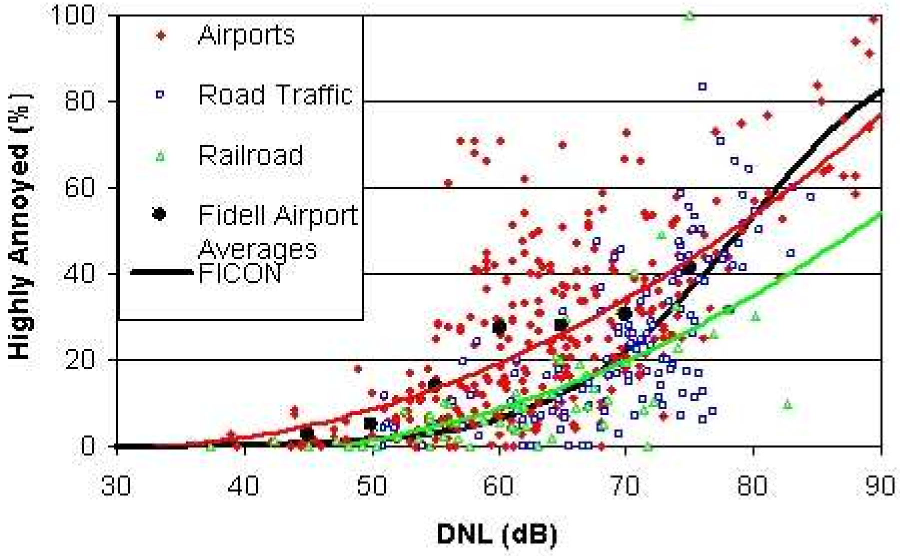


Figure 6: Re-analysis of aircraft and rail data by Fidell

The above curve suggests a NACF between rail and aircraft of about 10 dB for the majority of noise exposure levels. However, a different analysis of the same dataset and a different regression lead to a different NACF (black line).

Schomer [69] analysed the different methods for regression, for example the assumptions with respect to the zero values, and returned to the hypothetical S-shaped curve shown in chapter 2. He found good agreement with field study results (Figure 7).

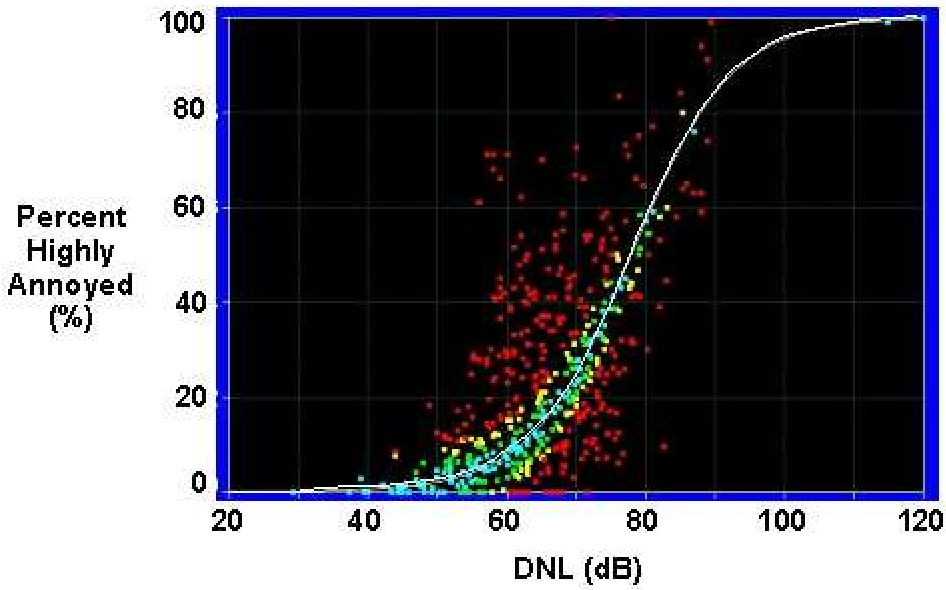


Figure 7: Re-analysis by Schomer, using the theoretical S-shape

From these studies we conclude, that it is feasible to predict, with good accuracy, the percentage of people annoyed or highly annoyed, from the long term average exposure level.

4.1.2. Annoyance research in Europe: the "Stuttgarter" study

In Europe, similar work was conducted for example by G. Heimerl and E. Holzmann, who published their findings as early as 1978 [22]. The study, which is often referred to as the Stuttgarter Study, was dedicated to assessing the annoyance ("Belästigung") of residents depending of the transport source and its traffic flow. The results have been summarized in the following abstract[2]

On the basis of a study including noise level measurements during the day and night and 1125 interviews with residents, it was found that railway noise creates less of a disturbance than street traffic noise. By far the largest majority of respondents experienced the greatest disturbance during the day. The difference in nuisance decreases as noise level rises.[3]

4.1.3 Annoyance research in Europe: the IF-study

As a follow up of this study, a large research project was launched in 1976 in Germany, under assignment of the Federal Ministry of Transport. This project is known as the "IF-study", the Interdisciplinary Field study. Its results were reported in 1983 by Planungsbüro Obermeyer.

In this IF Study, about 1600 residents were interviewed. For the disturbance by noise at night, a difference of 10 dB(A) was assessed to the advantage of railway noise compared to road traffic noise.

One year after the conclusion of this project, a "railway bonus" of 5 dB(A) was included in the Traffic Noise Control Act (Verkehrslärmschutzgesetz) in Germany.

4.1.4 Annoyance research in Europe: update of the IF-study

In the early 1990's a large number of legal procedures was carried out in relation to the planning of new and extended lines in Germany. This caused increasing criticism from residents with respect to the application of a NACF. Therefore, Deutsche Bahn initiated yet another large research initiative, carried out between 1996 and 2001. DB involved many other parties, such as the German Federal Transport Ministry, the Federal Environmental Agency and the Federal Railway Agency, and other railway operators from Austria and The Netherlands. This research program included, among others, special studies into the effects of awakenings ("Aufweckstudie"), the effects of high speed rail noise and the differences between passenger and freight rail traffic. More than before, a lot of attention was given to selecting residents with the same level of noise exposure in different circumstances.
Some of the results obtained from 1600 residents are cited below:

- In general, the studies confirm that the NACF of 5 dB(A) is justified and applicable even to the traffic circumstances representative for the 1990s.
- For requested awakenings, a difference of +13.6 dB(A) was found between railway noise and road traffic noise, indicating that the exposure from road noise would have to be 13.6 dB(A) higher than that of rail noise to create the same amount of awakenings.
- Another study registered motility of sleeping residents during the night. Also, performance tests were carried out in the early morning to detect effects of sleep disturbance. The results of this study were not published for reasons of too low confidence.

The surprising result for requested awakenings was further investigated in relation to the habit of having windows open or closed (the "window setting"). It was found that, particularly at high average noise levels, people near motorways would be inclined to keep their windows closed, whereas only a small percentage of the residents would keep their windows closed in situations along railway lines with similar noise exposure. This may explain the negative scores with respect to disturbance of communication and self reported awakenings.

---

[2] from Report no. NASA-TM-75414, Determination of traffic noise nuisance as a function of traffic type and density in a heavily populated area, 1979

[3] The quotation demonstrates the complexity of semantics: the American text uses "disturbance" and "nuisance" instead of "annoyance", whereas the original document speaks of "Belästigung" which is, to our opinion, best translated as "annoyance". Semantics are treated in Annex 1 to this report. .

Zeichart et.al. [70] reported the results of a study comprising 315 residents along a high speed line, which largely confirmed the NACF of 5 dB(A), even for lines with high speed traffic.

The origin of the criticism and some possible explanations for the results are discussed in chapter 5 of this report.

4.1.5 Annoyance research in Europe: The Netherlands

In other countries, like in Germany, the NACF was discussed and criticized. The main work, apart from Germany, was carried out in The Netherlands, clearly triggered by the planning of two new railway lines: a dedicated high speed line (HSL-South) from Amsterdam to the Belgian border and a dedicated freight line (Betuweroute) from the Port of Rotterdam to the German border at Zevenaar. In addition, some work was done in relation to magnetic levitation trains, triggered by the plan for a MagLev line from Amsterdam to Groningen.
In all cases, TNO addressed the issue whether or not a NACF should be included in the legal procedures for these new lines [50, 51]. For the high speed and MagLev lines, the conclusion can be summarized as follows:

- The level increase per unit time (the so-called cut-on) for *high speed trains* is steeper than for conventional trains, but at realistic distances from the track the difference is not such that it would lead to an entirely different disturbance of residents. In any case, the level rise is by far not as steep as it is for e.g. low flying aircraft noise. So there is no reason to assume that the exposure response relationship for high speed lines would be closer to that of aircraft noise. The conventional NACF can be applied to high speed lines.
- Results of analyses on existing data show no consistent differences in exposure-response relations between routes with a small or high proportion of freight trains, once the effects of different noise levels are removed. Thus these results do not support the need for special legislative provisions, not even for freight-only lines like the Betuweroute [78].

4.1.6 Annoyance research in Europe: the Miedema curves

In addition to these dedicated studies, more recent work was done by Miedema at TNO in 2002. Miedema followed the Schultz approach by collecting as much available data from surveys all over the world, and deriving exposure response relationships from this data. The database he used for his re-analysis eventually comprised data from 47 field studies and is probably the most extensive database ever used.
Eventually the conclusions were summarized in the EU’s Position paper on dose response relationships between transportation noise and annoyance [2]. The paper was prepared by a working group of noise experts set up by the European Commission in order to provide guidance on the dose-effect relations to be used for the assessment of numbers of people annoyed by noise.
The relationships presented in this paper are founded on the mentioned, extensive database. Algorithms have been derived to assess the relationships for annoyance and high annoyance for road, rail and aircraft noise.

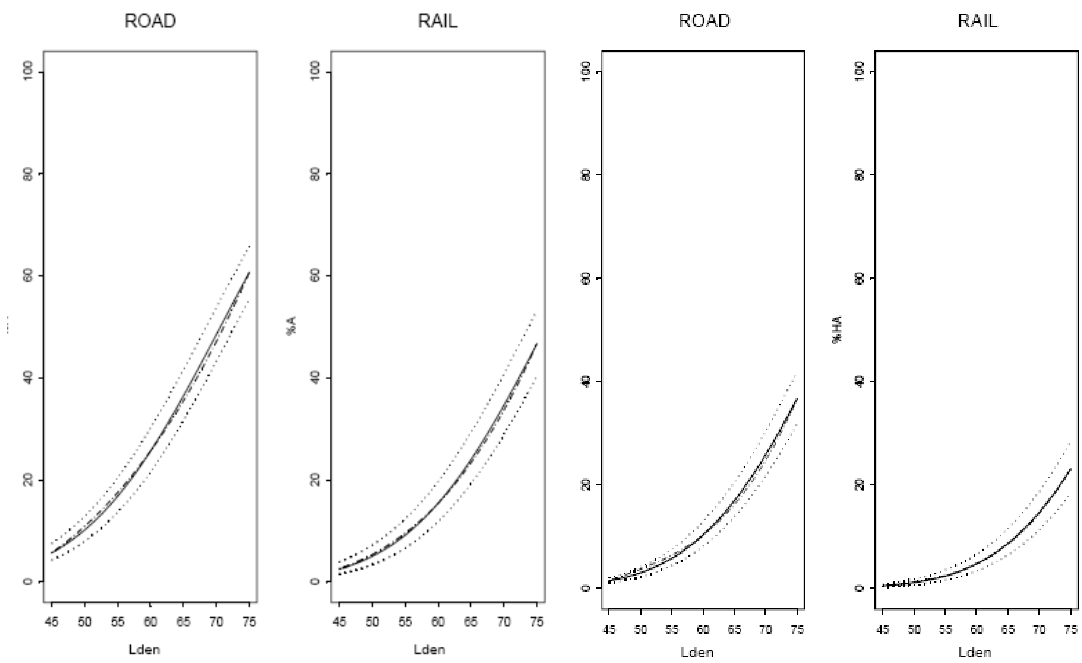


Figure 8: Dose response relationship curves from the EU position paper, showing %-age of annoyed (left two graphs) and highly annoyed (right two graphs) residents for road and rail noise exposure. The dotted lines are the 95% confidence intervals covering the 47 field surveys.

Figure 8 clearly shows that the annoyance caused by rail is substantially less than the annoyance caused by road traffic with the same exposure level. So, the curves confirm the existence of the NACCF, 25 years after Schultz's first publications. Further, figure 8 shows that the confidence intervals are substantially smaller than in the Schultz curve, which lead to the conclusion that there is a good correlation between exposure and effect and that the derived algorithms allow a fair prediction of annoyance once the exposure is known.

The two graphs presented below are derived directly from the exposure response relationships in this paper. They show the NACF for normal and high annoyance.
It can be seen from the curves, that for annoyance, +5 dB(A) is a low estimate for the average NACF between 48 and 75 dB(A) exposure level. For high annoyance, the difference is even more distinct.

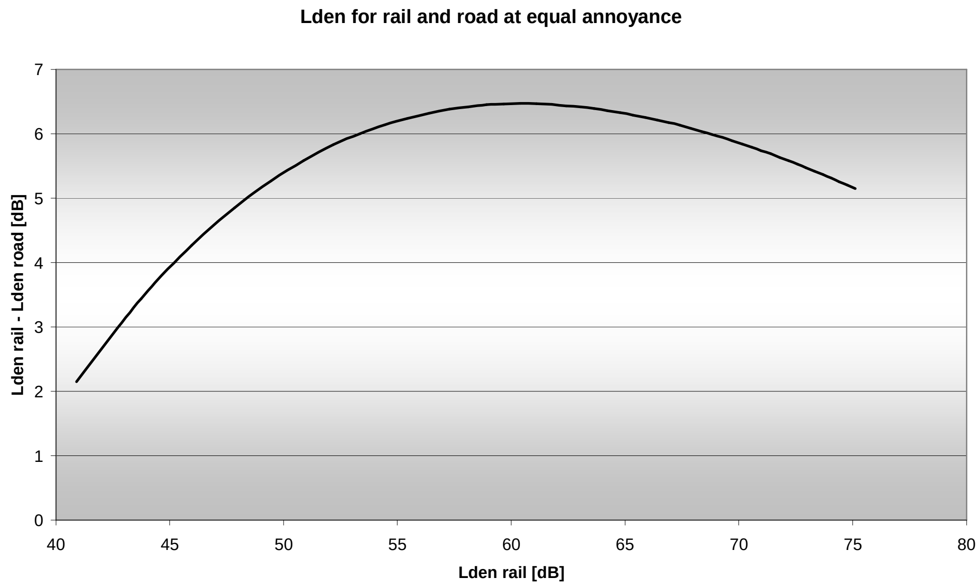


Figure 9: Difference between road traffic noise level and rail traffic noise level (in other words: NACF) at equal percentages of annoyance, derived from Miedema exposure response relationships.

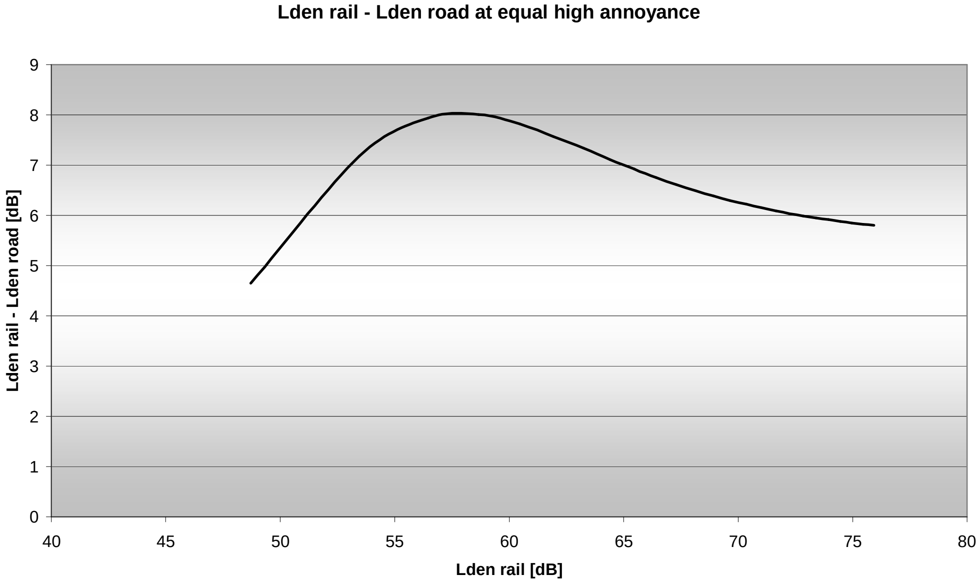


Figure 10: Difference between road traffic noise level and rail traffic noise level (in other words: NACF) at equal percentages of *high* annoyance, derived from Miedema exposure response relationships

Comparison between Miedema and Schultz

Although substantial time has passed between the Schultz 1976 study and the publication of the EC position paper the results are surprisingly unchanged. The following figure shows a comparison of the Miedema and Oudshoorn (2001) [52] function for road traffic noise (adopted by the EU) and the corresponding function suggested by ISO-1996 Part 1 [5], which is basically identical to the Schultz curve. The difference between the two reaches its maximum around L_{dn} 60 dB, where it amounts to about 3 dB.

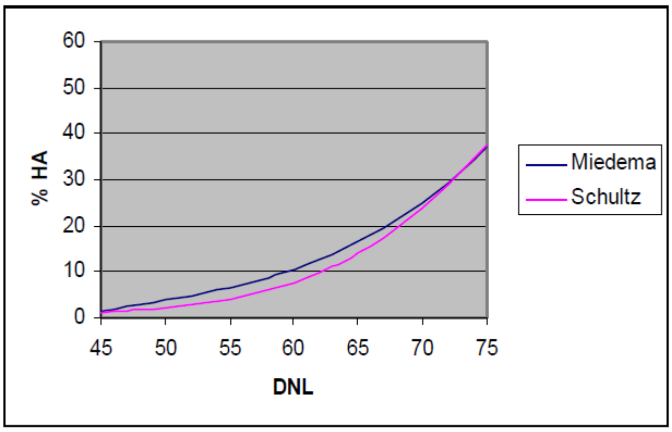


Figure 11: Comparison for road traffic noise between Schultz (1976) and Miedema (2002)

Changing 3 dB around 60 dB(A) exposure level in the curves 9 and 10 would not affect the conclusion that + 5 dB(A) is still a low estimate.

4.1.7 Conclusions on noise annoyance

The curves presented in the previous sections lead to the following conclusions with respect to the NACF:

- There is clear evidence that a NACF exists and can be verified in practice,
- Two comprehensive studies which are 26 years apart show more or less the same results,
- There is a difference between NACF based on annoyance or based on high annoyance; for high annoyance, the NACF is between 5 and 8 dB, for annoyance it is between 2 and 6 dB.
- At very low noise exposure levels, the NACF is typically small (down to 2 dB).
- For the majority of typical noise exposure levels, the NACF is larger than 5 dB

- At very high exposure levels, the NACF comes down to approximately 5 dB

The above points lead to the following, significant conclusion:

- The legal choice of 5 dB for the NACF between road and rail traffic noise is a conservative, but well justified average, both for annoyance and high annoyance. The value is confirmed by early field studies in the 1970s, but was reconfirmed in 2002 by an analysis of many studies that had been carried out in the years between 1976 and 2002. This leads to the conclusion that there is little change over time in the way residents respond to rail and road traffic noise.

4.2 Other effects of transportation noise

4.2.1 Annoyance and other effects

The exposure to environmental noise has many effects on human beings. Annoyance is probably the best described effect and most of the legal regulations set up in the 1980s and 1990s refer to the avoidance or reduction of annoyance as their primary objective.

Nevertheless, the effects of noise are more wide spread than general annoyance, although many of the effects are correlated. Over the past 10 years, there has been an intense interest into the health effects of noise, which are probably related to annoyance. The following graph presents a general overview of the effects of noise on human beings[4] and the interrelations between these effects.

From: Rainer Guski, Concepts and Methods of Noise Impact Research

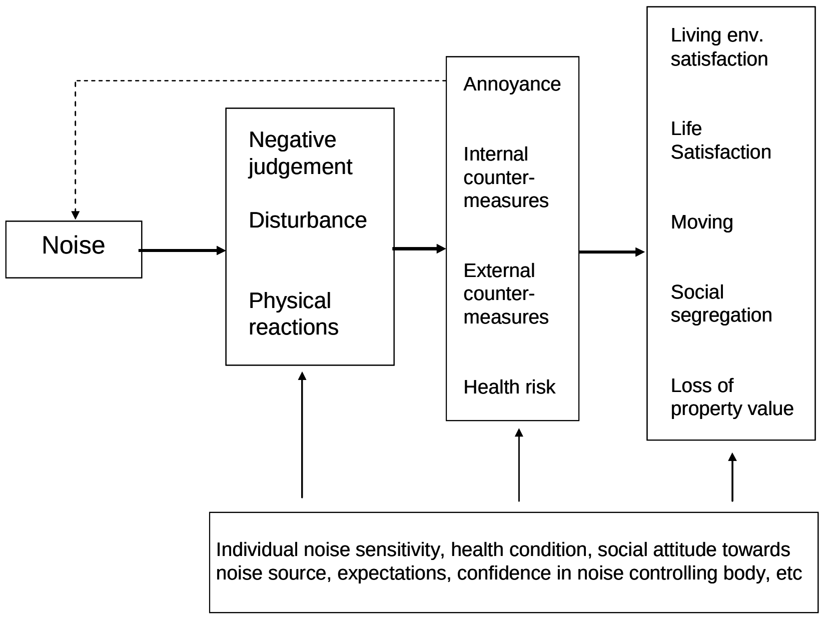


Figure 12: General overview of the effects of environmental noise

Babisch [12] presents a similar scheme with a slightly different interpretation of annoyance:

[4] Here: the effect on residents. Where it is said, in the graph, “negative judgment”, this indicates that the resident judge the noise as a negative element in their living environment

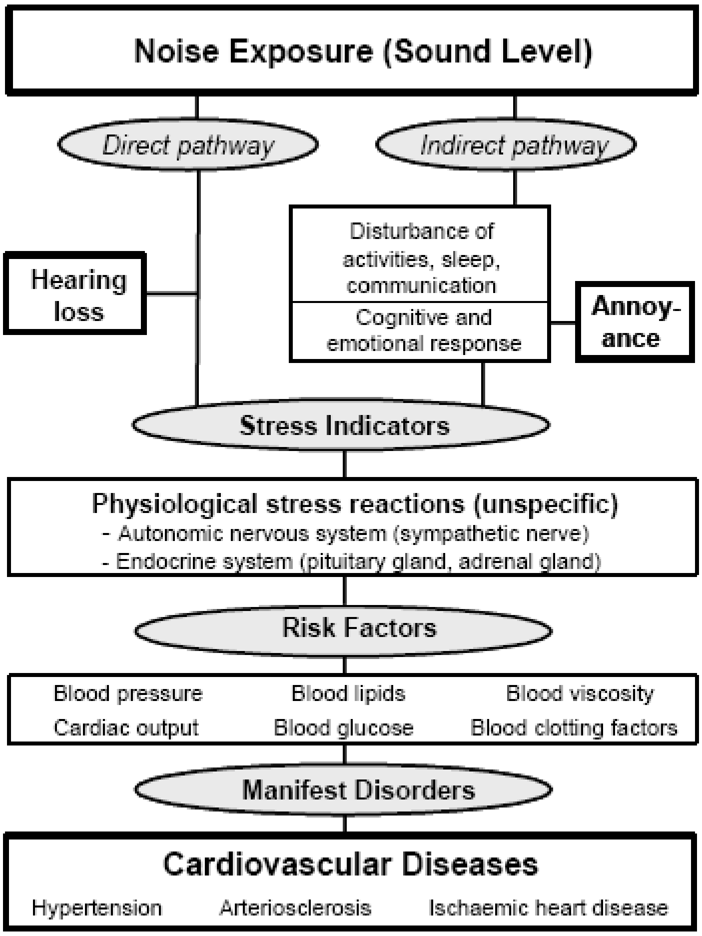


Figure 13: Scheme showing the causes and reactions for health effects of environmental noise [12]

Annoyance, in the context of the previous chapter, is a self-reported effect (requested in field surveys). Annoyance is often mixed up with the external counter measures involved in high noise exposure, namely complaints. In Guski's scheme, annoyance and complaints are in the same box. In some cases, complaints may be an expression of annoyance, but not necessarily an expression of health risks.

In Babisch's scheme, annoyance is a side effect of sleep and communication disturbance, two leading phenomena for health risks. Without further specification, *general* annoyance is a state of mind covering a wide range of different *specific* annoying factors, usually indicated as disturbances. Such disturbances can refer to communication (in conversation, in listening to music or spoken media, in making telephone calls, etc), but also to sleep.

The schemes underpin the strong interrelation between *the self reported effect* of annoyance on the one side, and on the other side many *physiological effects* such as stress hormone production, high blood pressure and sleep disturbance.

Annoyance as an indicator has the advantage, that there is a general consensus about the method to assess annoyance. This is not the case for e.g. sleep disturbance where the methods applied are more widespread.
Annoyance should be assessed, according to the ICBEN[5], by enquiries in field studies, setting an individual score on an annoyance scale, preferably from 1 to 10.

4.2.2 Sleep disturbance

The most prominent disturbance of sleep is waking up. Wake up reactions are usually self-reported. They can cause annoyance (as presented in figure 13) but may also lead to physiological effects (fatigue). Other effects of noise on sleep are rather physiological effects,

[5] ICBEN: International Conference on the Biological Effects of Noise

such as the disturbance of healthy sleeping phases and the increase of motility during sleep. These effects can be actually measured, for instance with bracelets sensitive to motion (so called actimeters) and with electro-encephalography, but this rather applies to laboratory situations than to real life.

As far as physiological effects like high blood pressure are concerned, annoyance may be an important cause of them. According to Ising and Kruppa [32], “severe annoyance persistent over prolonged periods of time is to be regarded as causing distress”. In addition, “chronic stress hormone disregulations as well as increases of established endogenous risk factors of ischaemic heart diseases have been observed under long-term environmental noise exposure”. In recent years, research has been concentrated on stress hormone excretion as a consequence of high noise levels (e.g. Stansfelt et al [77]).

There is solid evidence for all these effects occurring, for any noise exposure that exceeds a certain”safe” threshold. This evidence was collected among others by the World Health Organisation and in many different national studies, e.g. in Germany, United Kingdom, Sweden, The Netherlands.

From the above overview it is clear that health risks are associated with general annoyance. To some extent, health risks can therefore be assessed by assessing general annoyance. As we have seen in the previous section, general annoyance is well correlated to the long term exposure level L_{den} outside the dwelling, at the façade. Therefore, health effects can be considered to be correlated to this indicator as well. This would imply that the health effects for road and railway noise can be predicted, similar to general annoyance, from the assessed long term exposure, including a NACF of about 5 dB.

But in the view of the general public and politicians this is only partially true. In fact, both the independent variable, i.e. the long term average exposure, and the dependent variable, i.e. the percentage of annoyed or highly annoyed people, are questioned.
With respect to the exposure: railway noise is associated, by the general public, with a periodic structure of relatively short duration noise level peaks and long pauses. Therefore, the justification of the average level as the key parameter is not evident.
And with respect to the effect: the main effects directly associated with railway noise are interference with communication (i.e. disturbance) and sleep disturbance, mainly in terms of awakenings. These effects are sometimes indicated as *specific* annoyance. The reasoning of the criticasters is, that the long term average level would not correlate with these specific disturbance effects in the same way it does with general annoyance. In addition, the noise annoyance correction factor would not apply to effects such as interference with communication and sleep disturbance.
It is not always evident to the general public that health effects due to environmental noise may arise only after a long period of exposure. In addition, typical health effects such as high blood pressure (hypertension) and heart problems could be associated with noise exposure, but also with other causes such as over weight, smoking, air quality etc.

In addition, communication disturbance is an element of general annoyance and can therefore be assumed to be covered by the field surveys of self-reported annoyance. For sleep disturbance, this could be the case for awakenings, as these are self reported, but not necessarily for sleep rhythm disturbances, that may go by unnoticed, but could still have health effects.

In the following paragraph, an overview will be given of the results of research and studies into sleep disturbance caused by traffic noise.

4.3 Sleep disturbance and traffic noise research

A general overview of the elements relevant to sleep disturbance is presented in the following graph, cited from [51].

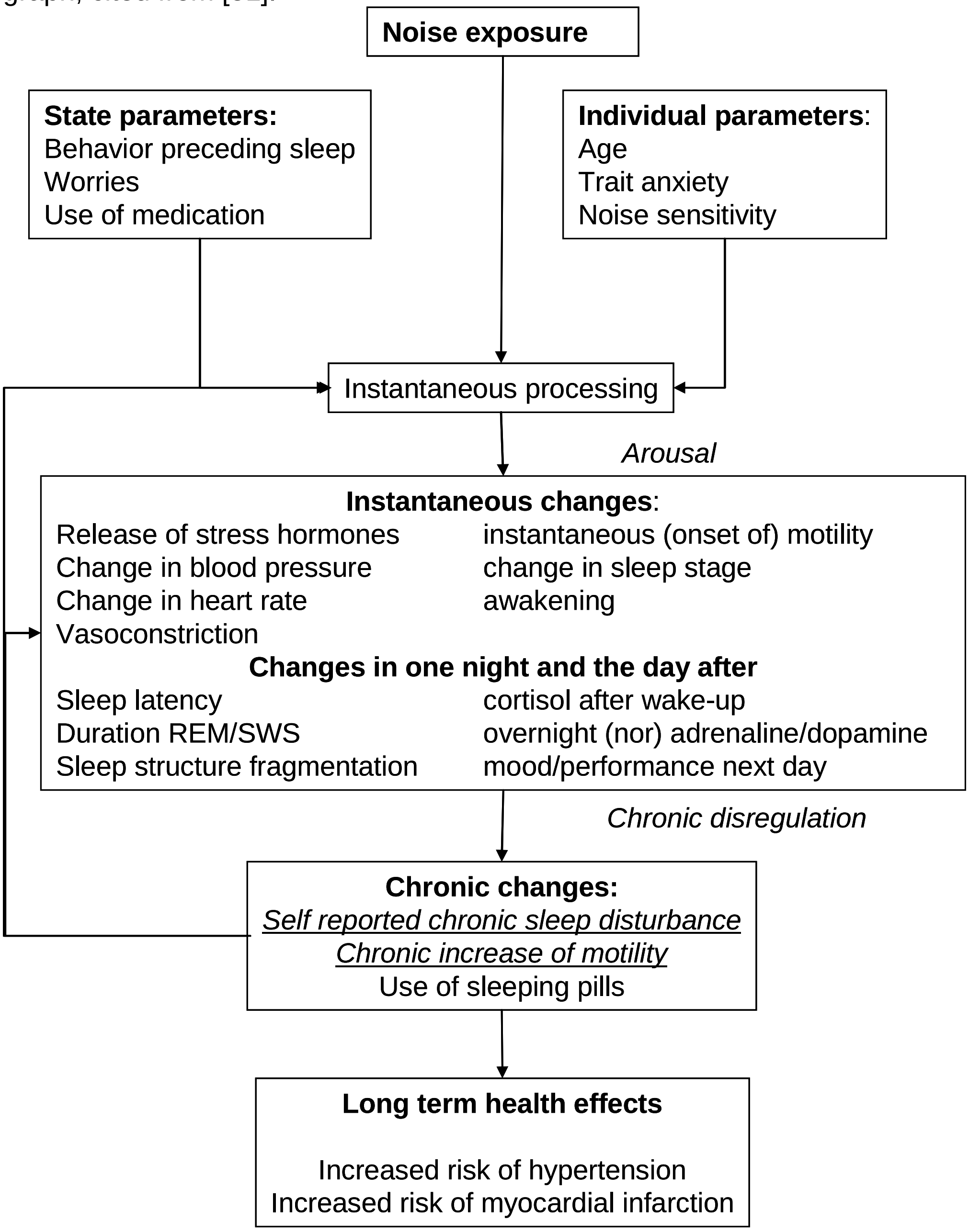


Figure 14: General overview of the effects of noise exposure during the night (from [51])

Although not as extended as noise annoyance research, there have been numerous studies into the effects of environmental noise during the night. Most of these studies concentrated on aircraft noise. There are significant differences between the studies with respect to:

- The basic indicator used (L_{Amax}, L_{night} or SEL are the most commonly used indicators)
- The effect described, the main effects being self reported awakenings, increased motility, sleeping stage disturbance
- The location where the exposure is assessed (inside the bedroom or outside the house in front of the façade)
- The window setting (open windows, windows closed)
- Field or laboratory situations

As an example, the following figure 15 shows the results of several studies, collected by Lawrence Finegold in 2001 [20]. These studies show the relation between the sound exposure level (see list of definitions in annex 3) inside the dwelling and the awakenings in 8 different studies, carried out between 1973 and 1998. The correlation is rather weak (R^2 = 0.22).

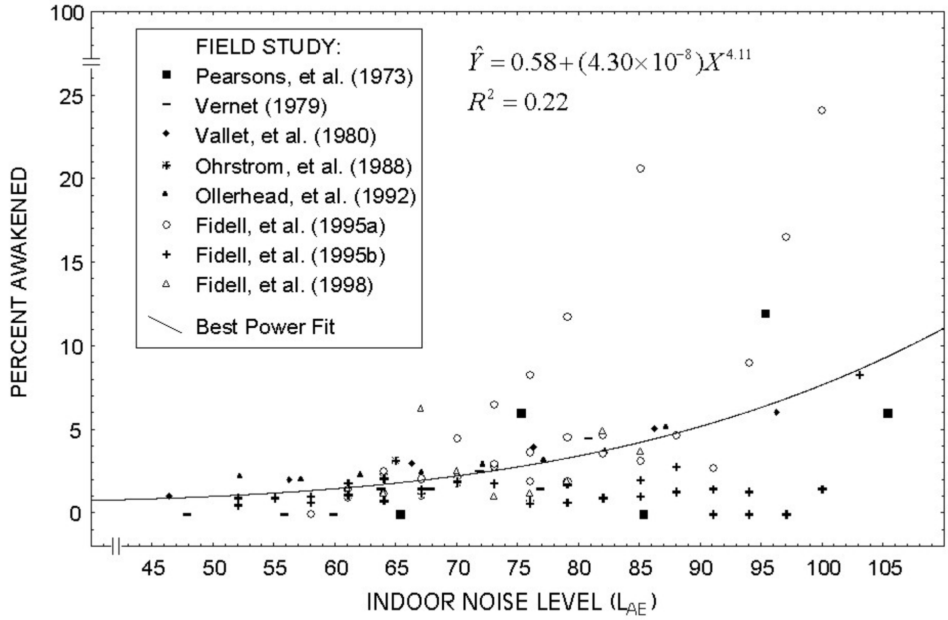


Figure 15: Sleep disturbance as a function of <u>single-event indoor</u> noise exposure levels (Finegold 2001)

In 2000, a large study by Möhler et al. [60] among 1600 individuals exposed to railway noise or road traffic noise showed that reported sleep quality was less affected by railway noise than by road traffic noise. In a sub population of 400 individuals within the same study motility was also measured by means of actimetry and these results showed, as opposed to reported sleep quality, no relation with sound levels and no difference in effects between the two noise sources.

In its Night Noise Guidelines [11], the World Health Organisation makes an attempt to summarize the evidence of various effects and their dependency of long term average noise levels <u>outside</u> the dwelling. The results are shown for road traffic noise and aircraft noise (they are not available for rail noise).

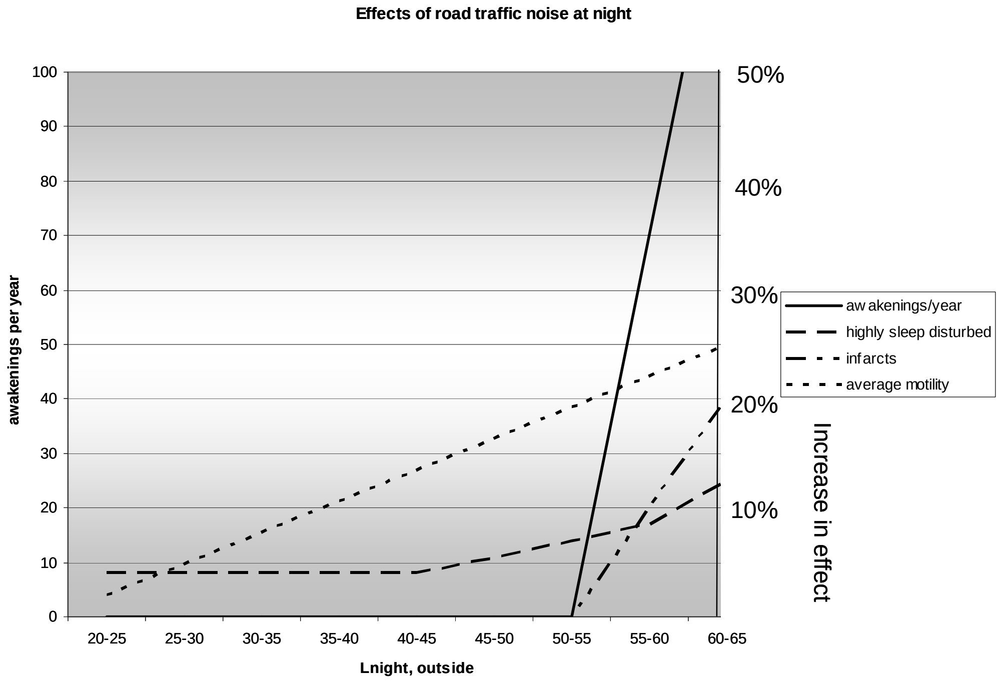


Figure 16: Dependency of L_{night} outside for road traffic noise, for various sleep disturbance effects (from WHO, [11])

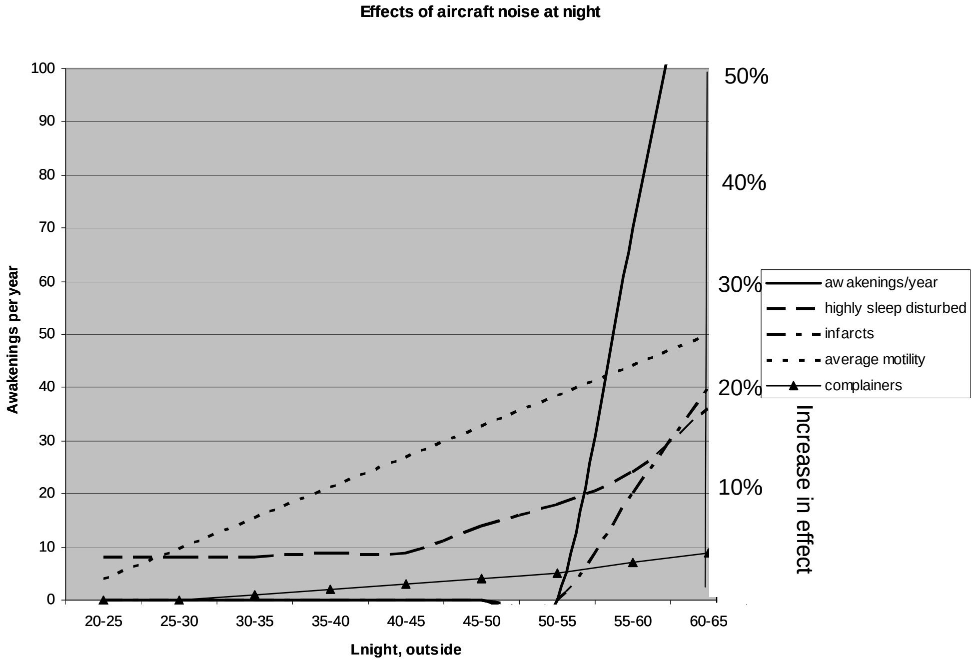


Figure 17: Dependency of L_{night} outside for aircraft noise, for various sleep disturbance effects (from WHO, [11])

From the two graphs, it can be concluded that, at the same L_{night} outside, there is no difference in effects from exposure to either road traffic noise or aircraft noise, as far as awakenings, motility and infarcts are concerned. However, for self reported sleep disturbance, the effects for aircraft noise are higher than for road traffic noise. On the basis of the character of the noise (continuous for road traffic and intermittent for aircraft noise) one could assume that the same tendency could occur for railway noise compared to road traffic noise.

In 2007, TNO in The Netherlands published a report on Sleep and Traffic Noise [65], with at least the partial objective to look into the differences between road and rail noise for sleep disturbances. The study included almost 1600 nights, with 6 consecutive nights for most of the individuals investigated.

With respect to motility, the report concludes that both the motility within one sleeping period and the average motility over a range of sleeping periods at similar exposure levels are substantially lower for railway noise than for road traffic noise. The study expresses as an assumption that the difference is thanks to the much lower background noise level between two consecutive passages.
For other effects, including self reported awakenings and heart beat frequency, there was no significant correlation between the exposure and the effect. On the basis of these results, the report concludes that

“it is highly unlikely that the effects due to railway noise during the night are more serious than those of road noise with the same exposure level. On the contrary, effects may be less serious for railway noise.”

In [1], 12 different studies comprising 15 datasets and 12000 individuals were combined in an attempt to relate self reported sleep disturbance to L_{night} outside the house for road, aircraft and rail. The following graph is copied from the report.

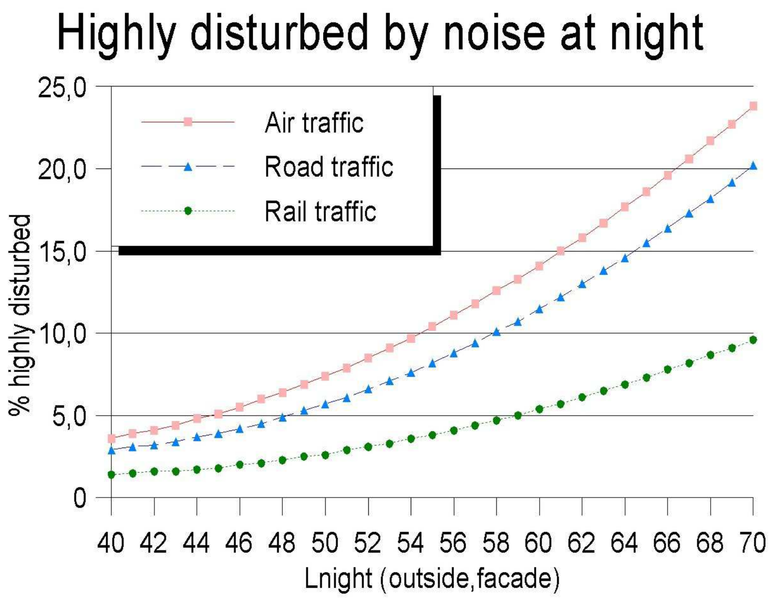


Figure 18: Dose response relationships for L_{night} outside and percentage highly sleep disturbed, for aircraft, road and rail noise, from [1]

Figure 18 shows a distinct difference between the relationships for the three different sources. In comparison to road traffic noise, aircraft noise shows a correction factor of approximately – 2 to – 4 dB, whereas railway noise shows a correction factor of around + 10 dB. The curve is derived from a set of algorithms that have been proposed by a working group of internationally renowned experts.

Similar to what was done in figure 6 and 7, the Sleep Disturbance Correction Factor (SDCF) and High Sleep Disturbance Correction Factor (HSDCF) have been derived from the algorithms presented in [1]. The results are shown in the following graphs.

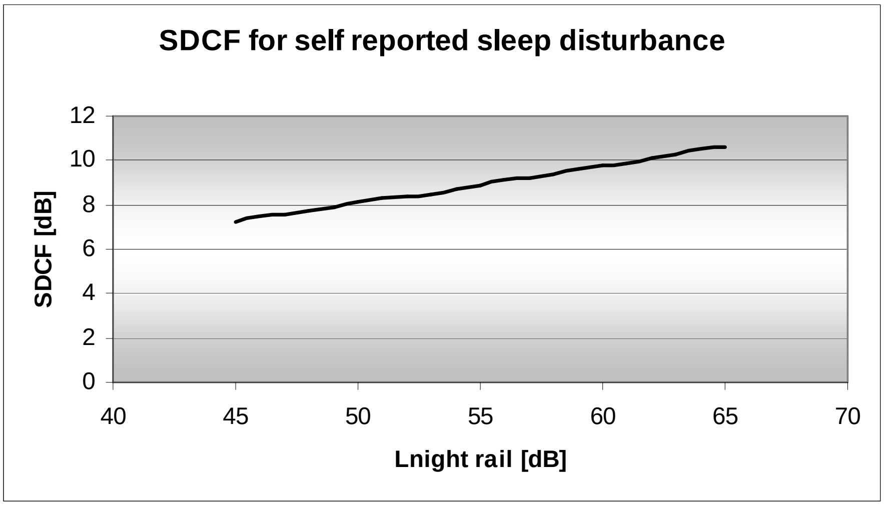


Figure 19: Sleep Disturbance Correction Factor between road and rail traffic noise, for L_{night} outside the dwelling façade

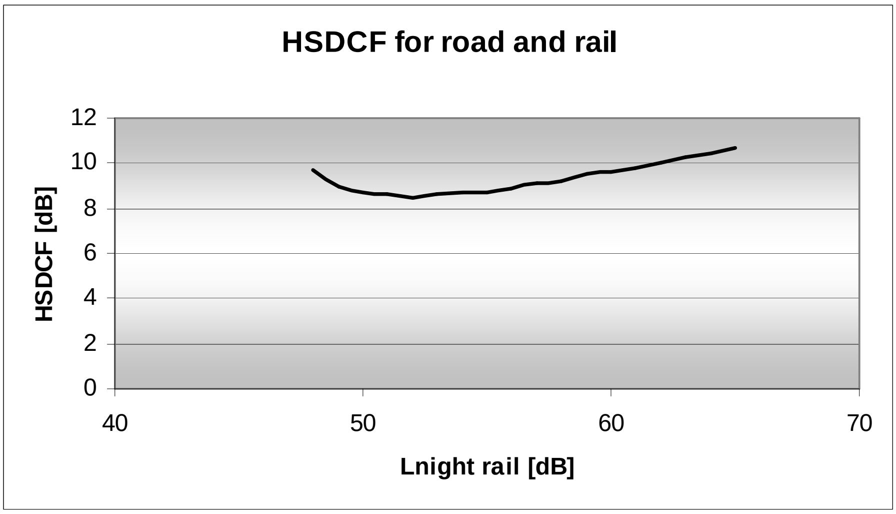


Figure 20: High sleep disturbance correction factor between road and rail traffic noise, for L_{night} outside at the dwelling façade

The analysis of figures 19 and 20 demonstrates that a positive correction factor was found for the relation between L_{night} and self-reported sleep disturbance. The correction is in the order of 10 dB. This number is in the same order of magnitude as the correction factor of 11.1 dB between road and rail for self reported awakenings and L_{night} as reported by Griefahn in 2000 [26].

The key issue that might question this conclusion is whether or not the L_{night} is the appropriate indicator for sleep disturbance. Many people claim that indicators like L_{Amax} or SEL would be more suitable. This issue is treated in the next section.

4.3.1 Indicators for sleep disturbance

The issue of the best indicator for sleep disturbance is addressed in the leading WHO document Night Noise Guidelines [1], where it is said:

"From a scientific point of view the best criterion for choosing a noise indicator is its ability to predict an effect. Therefore, for different health end points, different indicators could be chosen. Long-term effects such as cardiovascular disorders are more correlated with indicators summarizing the acoustic situation over a long time period, such as yearly average …. outside at the façade, while instantaneous effects such as sleep disturbance are better correlated with the maximum level per event …"

In its report of 1994 [3], the National Health Council of The Netherlands reported the evidence for a large range of effects from exposure to noise. It was concluded, that for awakenings and sleep phase disturbance, there was, at the time of the report, not sufficient data to relate it directly to the noise exposure. However, the evidence of these effects occurring was strong for situations with a SEL per single event exceeding a certain lower limit. For awakenings, if a SEL inside the bedroom of 60 dB(A) were exceeded, awakenings were likely to occur. For disturbance of sleep stages, this threshold level was found to be SEL = 35 dB(A).

These lower threshold levels can be compared with the threshold levels for any effect at all, as given by the World Health Organisation in its report Night Noise Guidelines [1]. The threshold levels are expressed in L_{Amax} and are presented in the following table.

Table 5: WHO Evidence levels for various effects of sleep disturbance

Effect	Indicator	Evidence level
EEG awakening	$L_{Amax, inside}$	35 dB
Onset of motility	$L_{Amax, inside}$	32 dB
Changes in duration of sleep stages	$L_{Amax, inside}$	35 dB
Waking up during the night	$L_{Amax, inside}$	42 dB
Increased motility while sleeping	$L_{Amax, outside}$	42 dB
Self reported sleep disturbance	$L_{Amax, outside}$	42 dB

Various researchers have pursued the path of using SEL or L_{Amax} as the preferred indicator for sleep disturbance effects. The Dutch Health Council collected many of the acquired results and published their analysis in the 1994 [3] report. The two following graphs present the percentage of awakenings and percentage of people with disturbed sleeping stages as a function of SEL inside the bedroom. The data refers to laboratory studies by Griefahn [22] and Lukas [45], field studies (epidemiological studies) by Ollerhead [62] and both laboratory and field studies by Pearsons [65].

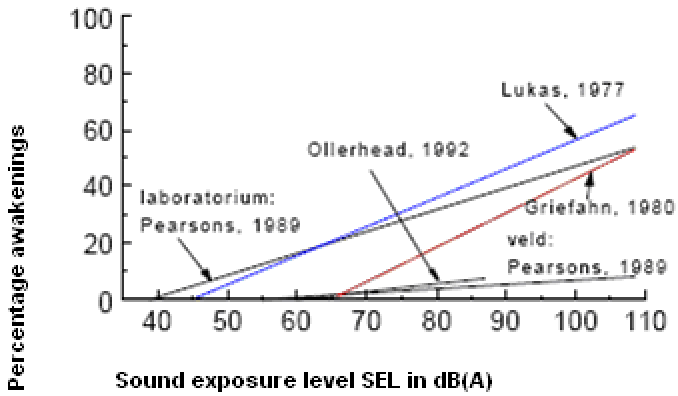


Figure 21: Relation between SEL inside bedroom and awakenings

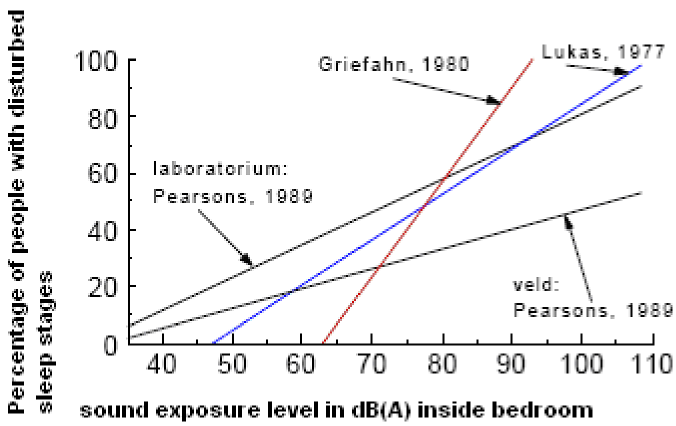


Figure 22: Relation between SEL inside bedroom and percentage of people with disturbed sleep stage pattern

The graphs do not show the uncertainty ranges. All curves suggest strong relations between SEL and the sleep disturbance effect under concern. The relationship with sleep stage disturbance is stronger than with self reported awakenings.

The graphs do not express any difference between road and rail noise per se, but this could be derived from the ratio between L_{night} and SEL (see following chapter).

In recent years, more specific results have been reported by Griefahn [24]. These refer to a laboratory experiment, where the length of different sleep stages (REM sleep and deep sleep) was monitored for 3 different noise sources (aircraft, road and rail) and for a generally quiet situation. It was found, that rail noise had the largest reducing effect on the length of these stages, whereas aircraft noise had the smallest reducing effect.

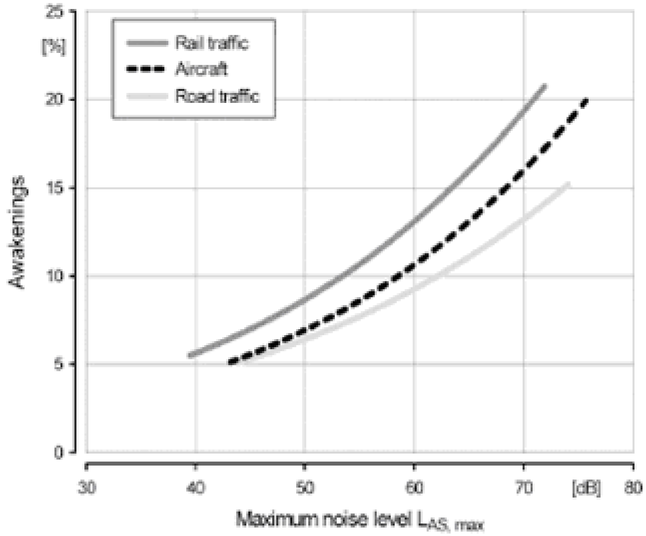


Figure 23: Dose response relationship for awakenings relative to the L_{Amax} [24]

4.3.2 Conclusions on sleep disturbance

Effects of traffic noise on sleep quality have been investigated in numerous studies. The results of these studies are sometimes contradictory. Possible reasons are:

- the effects are manifold and differently related to exposure,
- the methods to assess the effects differ; for instance for awakenings, some researchers count the percentage of people who report (any) awakenings, other researchers count the number of awakenings per unit of time.
- the exposure is expressed in different ways, both with respect to location, indicator and integration time.

Some researchers claim that a better correlation is achieved when changing from a long term average exposure indicator like L_{night} to an incident indicator like SEL or L_{Amax}. Even with these differences in mind, it is virtually impossible to draw consistent conclusions with respect to a source dependent correction factor.
For self reported sleep disturbance, there are indications of a positive correction factor, in the same order or larger than the NACF for L_{den}. For effects like awakenings, sleep stage disturbances and motility, the data shows large spreads, but with respect to awakenings at least one researcher claims larger effects for railway noise than for road traffic noise, for the situation where the exposure is expressed as L_{Amax}.

4.4 Relation between different exposure indicators

In the previous chapters several indicators for noise exposure have been introduced. The basic distinction is between energy equivalent indicators, such as L_{den}, L_{night} or even SEL or any other L_{eq} level on the one side, and other indicators like L_{Amax} on the other side. In general, the energy equivalent quantities describe the long term average noise exposure, averaging out fluctuations in traffic density as well as fluctuations in weather conditions.

Obviously, such indicators are best suited to predict chronic effects such as health effects and general annoyance.

Other than these energy equivalent indicators are instantaneous indicators, such as L_{Amax}. Such indicators are best suitable to describe the exposure due to any single event, such as the pass by of a train or a motorcar. It is important to note that these quantities completely ignore the frequency of occurrence of the events. This makes them unfit to predict effects that become evident after some stretch of time, even as short as one night. In other words: the may be capable to predict the likelihood of a single awakening response, but they will be able to predict the health effects of awakenings as long as the number of awakenings is not known. The Sound Exposure Level SEL is an energy equivalent level, but it is suitable for single events, as it comprises all the energy within a single event and "compresses" that energy into a time interval of 1 second. To a certain extent it has the same limitations as the L_{Amax}: it describes a single event and therefore it can not describe the long term health effects as long as it is not know how often these single events occur.

The question is, if and how these different indicators relate. Some researchers have made efforts to give indications for their interrelations. In his 2007 paper [23], Gjestland compares aircraft noise to road traffic noise, using some very simple equations to relate L_{max} to L_{eq}. He also derives indoor levels from outdoor levels, assuming that the sound insulation of the façade is similar for both noise sources (which is not generally true). He finds a distinct NACF for L_{eq} outdoor against annoyance, whereas there is hardly any difference for L_{max} indoor against annoyance (see figures 24 and 25).

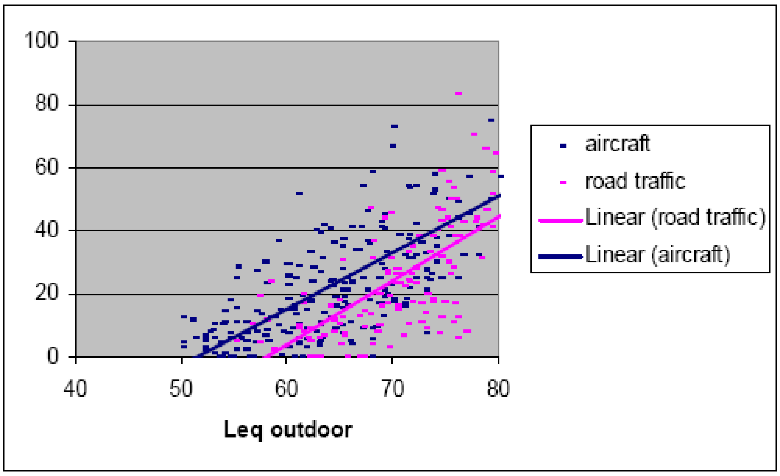


Figure 24: Annoyance versus outdoor Leq [23]

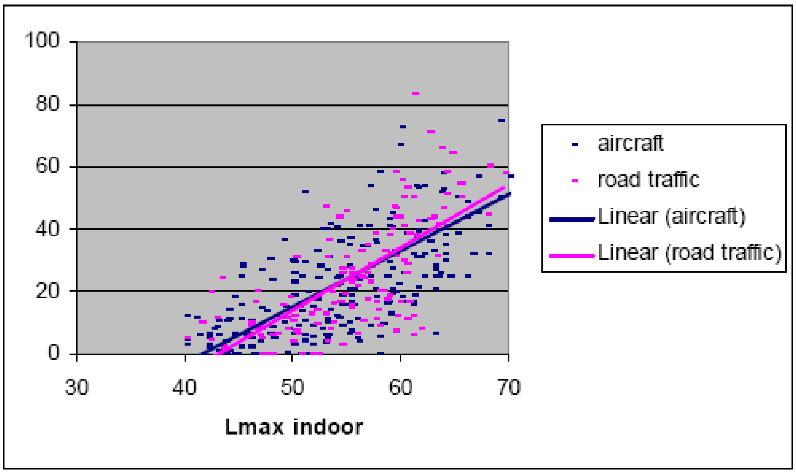


Figure 25: Annoyance versus indoor Lmax [23]

The question is whether this conclusion could similarly apply to road and rail.

The problem here is that the relation between “max” and “eq” indicators depends strongly on the distance from source to receiver. According to a well known approximation, the energy level caused by a line source such as a road or railway decreases by 3 dB for every doubling of distance. The L_{Amax} however decreases by 6 dB for every doubling. This simple analysis demonstrates that there is no straightforward relation between the two, if the distance between source and receiver is ignored.

A similar conclusion applies to SEL values. The further one is away from the source, the longer the pass by time and therefore the larger the difference between SEL and L_{eq}. This is illustrated in the following table, relating to a pass-by of 1 high speed train per hour, during day-time only. In this example, the high speed train is 250 m long, has a speed of 300 km/hour and complies with a TSI-Noise level of 87 dB(A) at 25 meters distance from the track.

Table 6: Relation between various energy equivalent indicators and one instantaneous indicator for different distances from the track.

Distance from track	Pass-by time	$L_{eq, pass by}$	L_{den}	SEL	L_{Amax} (estimated)
25 m	3,9 sec	87 dB(A)	54 dB(A)	93 dB(A)	89 dB(A)
100 m	6,6 sec	80 dB(A)	50 dB(A)	88 dB(A)	83 dB(A)
200 m	10,2	76 dB(A)	48 dB(A)	86 dB(A)	77 dB(A)
500 m	21 sec	70 dB(A)	45 dB(A)	83 dB(A)	71 dB(A)

Most of the researchers who have indicated exposure levels either as L_{eq} or SEL or L_{Amax} have not specified the source receiver distance and therefore it is not feasible to calculate the corresponding exposure in a preferred indicator.

To a certain extent, the same applies to the speed of the traffic. When a vehicle goes faster, it will have a shorter pass by time and therefore the difference between L_{Amax} and L_{eq} will be smaller.

In the following example, a specific case is presented which illustrates the difficulty of comparing L_{eq} and L_{max} values for road and rail.
We assume a dwelling which is 100 m away from the infrastructure. The L_{eq} exposure level is 65 dB(A), both for road and rail. This level refers to a road with fairly dense traffic and also a railway with fairly dense rail traffic. We assume a semi-continuous flow of road vehicles and a flow of 12 trains per hour with an average speed of 120 kph. Assuming an average train length of 200 m, the pass-by time for one train, at an observer position 100 m from the track, amounts to approximately 15 seconds. With 12 trains per hour, there would be 180 seconds of noise and 3420 seconds of pauses. The difference between L_{max} and L_{eq} would then amount to approximately 12 dB. For road, the difference could be around 5 dB to the maximum. The maximum levels at the façade therefore differ by 7 dB (at equal L_{eq}). When we assume a 3 dB better sound insulation for railway noise than for road noise, the resulting indoor maximum levels differ by 4 dB.

Road: L_{eq} = 65 dB $L_{Amax, outdoor}$ = 70 dB $L_{Amax, indoor}$ = 50 dB

Rail L_{eq} = 65 dB $L_{Amax, outdoor}$ = 77 dB $L_{Amax, indoor}$ = 54 dB

In this example we have ignored the distribution of noise over the time of day. Both for dense road (motorway) and rail traffic, the night time has grown to be dominant period of time, where freight traffic is the dominant transport. Therefore, this does not explain any recent developments in NACF.

Many researchers suspect that the intermittent character of railway noise, as opposed to road noise with its continuous character, may be a reason for different annoyance. Such a difference could be described by the difference in long term average level (L_{den} or L_{night}) and peak level L_{Amax} during passage of a single vehicle. Obviously, this difference would be larger for intermittent noise than for continuous noise. In fact, these differences could best be described with statistical levels such as L_1, L_{10}, L_{50} and L_{90}. Unfortunately, we have not found any researcher who has used these statistical levels to describe the exposure.

A further difference is between exposure indicators outside at the façade and inside in the room where the test person stays, i.e. either the bedroom (for sleep disturbance) or the living room (for communication disturbance). Usually, in legal procedures and in the END noise maps, the façade level refers to the incident noise outside at the façade, i.e. it does not include the reflection against the façade under concern. It is not always clear whether the researchers have indeed complied with this concept.

Relevant to the level difference between outside at the façade and inside in the room is a range of different parameters:

- The window setting, i.e. closed or open,
- The window sound insulation (single pane or double pane),
- The type and status of permanent ventilation provisions,
- The reverberation time of the room,
- The frequency spectrum of the sound under concern.

In very broad terms, one may expect that railway noise has a typical frequency spectrum that allows a slightly (2 to 3 dB) higher noise insulation of the closed window than road traffic noise.

As a very rough indication, the WHO suggests an average difference outside-inside of 21 dB. In reality, differences may be between 10 dB (for windows slightly open) and 30 dB (for high insulation windows firmly closed). This means that the 21 dB is a fair average, but it can not be used as a general correction.

Concluding, the difference in the exposure indicators often used can be quite substantial, is not always specified in the reference documents and can not be predicted or estimated with any satisfactory level of accuracy. Therefore, any conclusion that suggests that results using one indicator would have to be revised on the basis of results using a different indicator is highly speculative.

5. Discussion on NACF

5.1 Arguments

This chapter presents an overview of the arguments, used currently and frequently to support or argue the existence and justification of a noise annoyance correction factor. The arguments are listed and a likely score is presented, where + means: supports the existence and – means: denies the existence of a NACF.

Frequency content
The frequency content of railway noise shows higher contributions in the 1000 and 2000 Hz than road traffic noise. For high speed road traffic noise, where the traction noise is masked by tyre road noise, the difference is small or negligible. The larger the high frequency content, the better is the efficiency of noise mitigation measures such as noise barriers or noise insulating windows.

This argument supports the existence of a NACF +

Intermittent character
Railway noise has an intermittent character, providing long quiet periods (typically 20 minutes between two trains) when no train is present. Road traffic noise, at least for motorways, is more continuous and provides hardly any relaxation (typically a few seconds between two passages). The difference is not relevant for small city roads, where the road traffic noise shows long pauses as well. Neither is it valid for observers at large distance from a very dense rail link, where the noise is almost continuous.

This argument supports the existence of a NACF +

Intermittent character (2)
Railway noise has an intermittent character, providing long quiet periods (typically 20 minutes between two trains) when no train is present. This means that every train passing represents a sudden increase of noise level, which is likely to cause disturbance of communication (speech, listening to radio, etc) or sleep. Therefore, this argument denies the existence of a NACF, and supports even the existence of a negative NACF.

This argument denies the existence of a NACF -

Information content
Railway noise is predictable because it repeats itself with every train and every train more or less sounds the same. In road traffic noise, certain incidents may contribute to higher annoyance, for instance cars with bad exhaust silencers or loud motorcycles. It is well known that noise is generally more annoying when it contains more information.

This argument supports the existence of a NACF +

Predictability
Railway noise occurs according to a time schedule which is generally known to the residents. This makes it much more predictable than road traffic noise. Predictability provides a feeling of control, which may reduce annoyance. In addition, it is easier to get used to this type of noise.

This argument supports the existence of a NACF +

Positive attitude
Many people have a positive attitude towards the railway, which is generally considered an environmentally friendly mode of transport. This however does not apply to residents in sensitive areas where the awareness has considerably increased (like in the Rhine valley).

This argument does not necessarily support the existence of a NACF +/-

Peak and maximum levels
The peak levels for railway noise are much higher above the equivalent level than for road noise with the same L*den*. Peak levels are likely to disturb communication and possibly to provoke awakenings.

This argument does not support the existence of a NACF -

Day, evening and night distribution
At the same identical long term noise level, different transport lines may behave quite differently. A high speed rail link would have hardly any traffic at night, a freight line would have considerable traffic at night, a mixed line would have passenger trains during the day and evening, and mainly freight trains at night. A city road would have little traffic at night, whereas motorways have lorries in the early morning (part of the night time period).

This argument does not necessarily support the existence of a NACF +/-

Free view
Residents living close to a railway line have a free view of the landscape for most of the time. The view is disturbed only when a train is passing. For residents close to a motorway, the view is inhibited most of the time by the uninterrupted flow of vehicles (particularly lorries).

This argument supports the existence of a NACF +

Duration of pass-by
For rail noise, with long vehicles and low speeds, the duration of a single pass by is much longer than for road vehicles. This leads to longer and more annoying interruption of activities like sleep or communication.

This argument does not support the existence of a NACF -

Number of events
In railway traffic, the number of events is much smaller than for road traffic noise. Typically, a busy rail road could have 200 pass bys per day, whereas a busy road could have 20.000 pass bys per day.

This argument supports the existence of a NACF +

Distance between observer and infrastructure
For railway lines, only very few people live very close to the line, as opposed to traffic roads: most people live close to a traffic road, and most often to several traffic roads at the time. European statistics show that most people near a railway live at about 90 meters distance from it. Most people near a road live at approximately 20 meters distance from it.

This argument supports the existence of a NACF +

Quiet façade
The positive effect of a quiet façade, even in situations with high noise exposure at the most exposed façade, has been demonstrated repeatedly. For railways, it is the standard situation to have the railway noise coming from one side and a quiet façade at the other side of the house. For road traffic, this is not at all obvious, as most people have roads at both sides of the house.

This argument supports the existence of a NACF +

Time constant
The time constant of the instantaneous noise level rising when a train passes by is shorter than for road vehicles. This is due to the horizontal directivity of rolling noise of a train, which has a dipole character. In road traffic vehicles, this does not occur. The level rising therefore is steeper than for cars. This applies in particular to high speed trains, which have substantially higher speed than cars. However, it was found in specific studies, that the steep level rise was

not relevant for perceived annoyance. In addition, at large distances from the track, the level rise is not dramatically steeper than for roads.

This argument does not necessarily support the existence of a NACF +/-

5.2 Future trends

It is often heard, that the current NACF reflects the situation at the time that the supporting research was carried out. The current or future situation may differ from that situation, and thus the current NACF may no longer be applicable. As we have seen in section 4.1.6, the NACF has remained virtually unchanged between 1975 and 2000, even though the circumstances with respect to traffic and living environment had substantially changed over that period. Nevertheless, it is conceivable that certain recent and future trends have influenced the NACF. Such trends may be either *exposure related* (different character of the noise) or *subject related* (different attitude and sensitivity towards noise).

Relevant future trends may lead to higher intensity on the track (triggered by more advanced signaling systems), more night time traffic (shift from daytime to night time) and more high speed traffic. As we have stated in chapter 4, these arguments hold for road traffic as well, but maybe not to the same extent.

High intensity on the track might lead to a change in pause structure; the pauses between two train passages would be shorter, so the time that noise is present would be longer. To a certain extent, this effect is accounted for in any energy equivalent exposure indicator. After all, when the noisy periods get longer, the L_{den} would assume a higher value. The corresponding annoyance can be predicted using the usual dose response relationships. On the other hand, one could expect that the shorter pauses affect the typical rail noise character. The noise would become more continuous and comparable to road noise, and this would affect the NACF as well. Several studies, referred to in [23], have demonstrated that the NACF can be maintained for rail traffic intensities currently found on European tracks. The highest intensities with the shortest distances are found on light rail and street car lines. A study by Griefahn et al [68] compared trams to buses and found that the NACF was confirmed even in that situation. On the basis of these results we conclude that the increased intensity is not a valid argument to question the NACF.

The increased night time traffic, particularly on freight lines, has similar arguments. Night time noise is penalized by 10 dB in the L_{den} definition. As a consequence, an increase in night time traffic leads to a drastic increase in L_{den} and thus to an equally drastic increase in predicted annoyance. As we have seen in the previous chapter, the effects on sleep disturbance may be more outspoken.

With respect to the difference between day/evening/night, the following examples serve as illustration.

Motorway with dense traffic:
$L_{night} = L_{den} – 8$ dB $L_{evening} = L_{den} – 5$ dB $L_{day} = L_{den} – 2$ dB

City street:
$L_{night} = L_{den} – 9$ dB $L_{evening} = L_{den} – 5$ dB $L_{day} = L_{den} – 1$ dB

Railway with dense passenger traffic:
$L_{night} = L_{den} – 9$ dB $L_{evening} = L_{den} – 3$ dB $L_{day} = L_{den} – 1$ dB

Railway with dense freight traffic:
$L_{night} = L_{den} – 6$ dB $L_{evening} = L_{den} – 7$ dB $L_{day} = L_{den} – 6$ dB

The figures in this example are confirmed by the following quote:

“In urban settings, night-time average noise levels (22-6 h) for road traffic tend to be approx. 7-10 dB(A) lower than daytime average noise levels, relatively independent (no freeways) of the traffic volume of the street [12].”

The situation with dense freight traffic lines is clearly different from the other situations. At equal L_{den}, the night time level is typically 3 dB higher for the freight situation. By nature, that means that the day- and evening level must be lower than for the other situations. The table shows differences of 2 to 4 dB. In terms of annoyance factors this could imply a slightly higher sleep disturbance but a more modest disturbance of communication and concentration. In terms of general annoyance the likely effect is that a cancellation occurs and the general annoyance effect is the same.

5.3 Recent studies with contradictory results

5.3.1 Introduction

During more recent years a number of studies, both in the field and in experimental laboratory settings, show somewhat contradictory results and the railway bonus does not always seem to be justified. not for speech interference.
Over time, a few studies have been presented that show results contradictory to the findings in the previous chapters. These studies demonstrate a negative NACF or they can not confirm the existence of a NACF at all. In the following sections, three studies are presented that have stood out with respect to their conclusions concerning the NACF. The results of these studies are discussed shortly.

5.3.2 The Japanese studies

Recent surveys on annoyance reactions to transportation noise have been conducted in Japan. These surveys seem to confirm that the annoyance response is source dependent, as stated by Miedema and Vos [50] in 1998. However, the responses are different from those adopted by the EU.
Yano et al. [86] (2007) have studied the response to road traffic, rail and aircraft noise in Japan. Their results seem to confirm the Miedema and Vos (1998) relationship for road traffic noise, but they report a much higher annoyance due to aircraft noise. Their results also show that noises from railroads are more annoying than noise from road traffic.

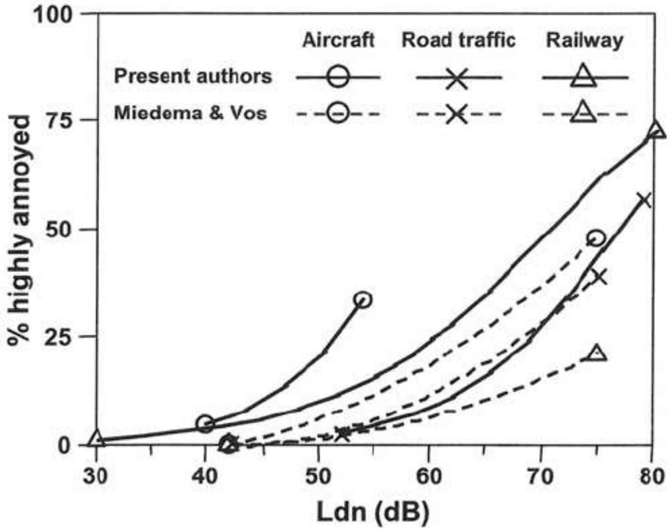


Figure 26: Results from noise annoyance field studies in Japan [53]

Similar results have been reported by Ota et al. [63] in 2007. They have found that the response to conventional railroad noise and road traffic noise is quite similar, whereas noise from high speed trains, the Shinkansen, causes reactions similar to aircraft noise. This study shows no indication of a NACF.

The results of these studies were taken as a starting point by a Korean group of researchers [16], who came up with at least a partial explanation for the differences found. In Japan, like in Korea, the residential areas are situated much closer to the railway line than in Europe. At moderate traffic intensities, this means that the peak levels are much higher than in Europe at equal equivalent exposure (ref. table 1 in section 4.4). Clearly the Japanese results, with short distance to high speed track, are less relevant to the European situation.

5.3.3 The Tyrolean study

Lercher et al [41] carried out repeated surveys in two different valleys in Austria in 2006. The valleys constitute the main freight corridors across the Alps in Austria, both for road and rail transport.

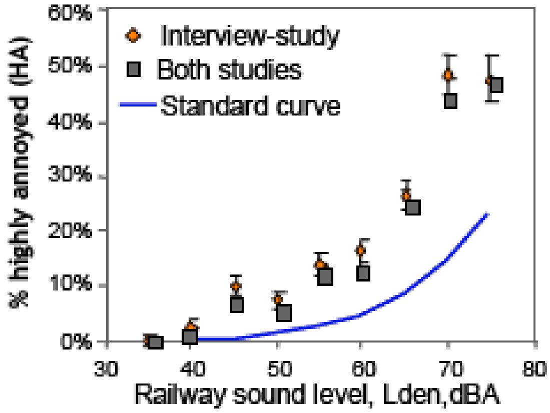


Figure 27: Results from the Tyrol surveys [41], compared to standard dose response curves for railway noise.

The results show substantial deviations from the standard curves, the deviations being higher at higher noise levels. Remarkably, similar deviations (with a higher spread) were found for motorway noise.

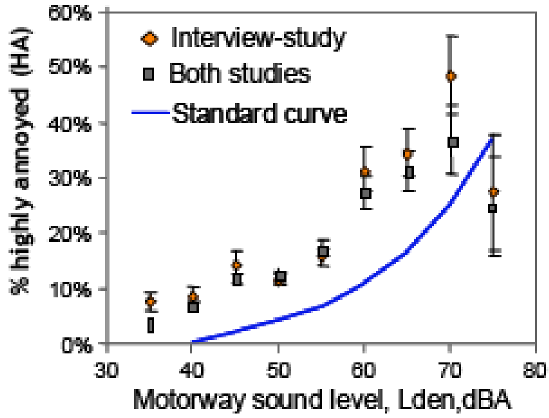


Figure 28: Results from the Tyrol surveys for motorway noise.

The anomalies found in this study therefore seem to be based on the situation under concern, with a dramatic increase of traffic over the years and ever growing concern within the population. Given the large spread for motorway results, the study does not give sufficient evidence that a NACF would not be justified in this case.
In the Inn-valley, the following results were obtained:

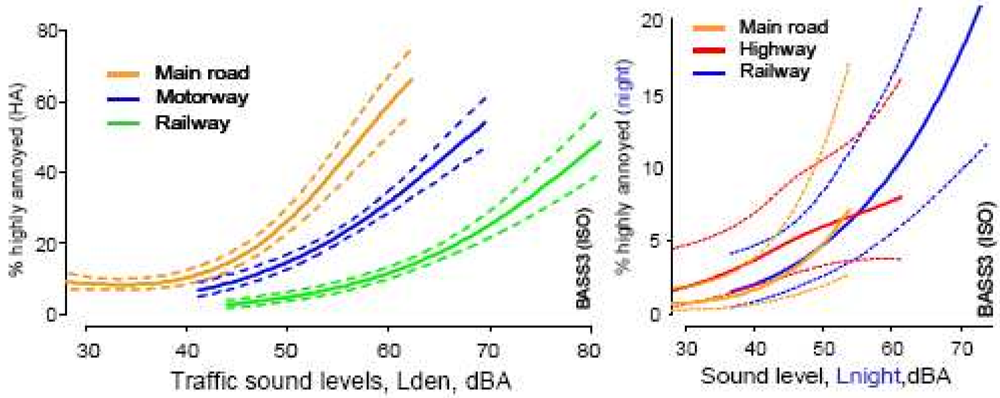


Figure 29: Results from the Inntal, with L_{den} (left) and L_{night} (right) as exposure indicators

These results show a very distinct NACF of up to + 10 dB if L_{den} is used as an indicator, but a very small NACF if L_{night} is used as an indicator. Possible explanations could be the window setting (open windows near railways, windows closed near the motorway) and also the fact that there is a night ban for heavy trucks on the motorway for all trucks that are not particularly quiet.

5.3.4 The Öhrström and Griefahn studies

Both in Sweden (Evy Öhrström of Stockholm University) and in Germany (Barbara Griefahn at Ifado) numerous studies wre carried out on the effects of noise on human beings. Mostly, these are laboratory studies, comprising a limited number of test persons under very well defined conditions.
According to a recent review (Öhrström & Skånberg 2006) it seems likely that a NACF is justified for general annoyance and possibly for sleep disturbances. Results from a 2008 study by Öhrström et al. [62] disclosed somewhat more awakenings due to railway noise than road traffic noise with the same sound levels, corresponding to a situation with the window slightly open. No other significant differences, i.e. no evidence of a SDCF, in reported sleep disturbances were found.

The study by Griefahn and Marks was mentioned already in section 4.2.1. It concludes that railway noise has a negative correction factor for disturbances of the healthy sleeping pattern. Sleeping patterns, although relevant for health, constitute only one element of the total range of noise effects that may affect general health. We conclude that these studies, although relevant, are too specific to allow drawing general conclusions with respect to the relation between long term average exposure and annoyance.

5.4 Current and ongoing research work

5.4.1 Tassi et al

In 2010, Patricia Tassi et al reported a study on long term effects of nocturnal noise on seep and health [80]. Their work refers mainly to the issue of adaptation. They investigated the influence of age and habituation to a situation with relatively high noise exposure due to railway noise. The study results suggest that people who have been living along a railway line for many years show less fragmentation of sleep stages and less cardiovascular responses when exposed to nocturnal railway noise than people who are confronted with it for the first time in their life. The study does not express itself about the application or justification of a NACF.

5.4.2 DLR

In the framework of the German-French collaboration Deufrako, the German Aerospace Institute is currently carrying out a study on the effects of nocturnal rail noise on sleep [60]. An extensive field study was carried out in the Rhine valley, an area where very serious response from local residents emerged when the intensity of the rail freight traffic increased drastically.

In the study, physiological effects are measured and individual reports collected for residents living close to the railway. Their exposure is assessed both outside in front of the façade and inside the bedroom.
The study includes 33 healthy individuals who were each monitored during 9 consecutive nights. Although from the study it is clear that freight train noise can disturb a healthy sleep, the published data does not allow a firm conclusion with respect to the justification of a NACF or even a SDCF.

5.4.3 Freiburg University

In recent years, researchers related to the Freiburg University have been involved in a number of studies, all dedicated to the question whether railway noise affects health or not. The report [46] is an impressive overview of research over the last 4 decades. It was published in April 2010. This study particularly addresses the NACF, and the statement is that the current NACF is based on outdated information and is therefore no longer valid.
The approach was a comprehensive elaboration of available references from open sources and specifically targeted authors. The report thoroughly analyses a very large dataset. With respect to the NACF however, the arguments, cited freely below, do not directly refer to NACF:

- The NCAF is based on datasets that were collected before 2000, and therefore the existence of a NACF should be re-investigated (recommendation in the report),
- In view of the health effects of environmental noise, the legal limits in Germany should be reduced (this comment in the report is not directly related to the NACF),
- The NACF refers to self-reported annoyance, not to physiological effects (this issue was discussed in the current report: when health effects are directly related to self-reported annoyance, then the health effects could be described with sufficient accuracy by looking at the long term average exposure).
- The long term average level is not sufficient to describe the effects on man; one would need to take the maximum level into account.

5.4.4 Griefahn 2010

In recent work [27], Griefahn refers to railway noise as a cause of awakening responses. She relates the risk of awakening and many other physiological effects to the maximum noise level. A direct conclusion with respect to the NACF can not be drawn.

6. Synthesis and conclusions

6.1 Conclusions

In the previous chapters a robust evidence has been presented, that railway noise, at an equal exposure expressed in long term average Lden, leads to a smaller percentage of annoyed or highly annoyed people. This underlines the justification of a noise annoyance correction factor. The studies indicate correction factors ranging from zero or a few dB at very low exposure levels (around 40 dB), up to more than 10 dB at high exposure levels (around 70 dB). A political choice of 5 dB for a general NACF seems a good and conservative compromise.

The evidence becomes weaker when either a different exposure indicator is chosen or when a different effect is described. In recent years, much attention was given to sleep disturbance effects, such as disturbance of sleep stages, motility and awakenings. All these effects are elements of general annoyance and there is no evidence that their long term effect on health differs significantly from the effect of annoyance on health.

Changes in physical and geometrical conditions of the traffic, such as distance between receiver and traffic, traffic flow intensity, traffic composition and traffic speed, have been investigated in different studies but the general conclusion for the relation between exposure and annoyance is generally confirmed. Only in exceptional situations (e.g. very close distance to a high speed track in Japan) deviating relationships are found.

In spite of all this scientific evidence, the concept of NACF is consistently criticized by the general public and often by decision makers. The criticism is, at least to a certain extent, based on two misunderstandings:

- The railway bonus is merely there to grant a better position to a transportation mode that is generally considered to be more sustainable.
- The effects of noise on man are best described by the amount of complaints that they provoke (mainly by step changes and incidents) instead of by the health effects that may occur in the long run.

6.2 Recommendations for strategy

It is recommended to rephrase the concept of railway bonus into noise annoyance correction factor. For Germany and Switzerland, it is recommended to include the NACF in the legal limits instead of keeping it as an element in the prediction method.
Efforts should be undertaken to include some sort of NACF in the process of strategic noise mapping that is required under the EU Directive 2002/49/EC.

6.3 Recommendations for further work

Methods to assess the effects of environmental noise on sleep quality should be harmonized to obtain a general consensus, e.g. with respect to:

- The definition of the effects to be assessed (sleep stages, motility, awakenings),
- The methods to assess these and to analyse the results,
- The time and place where the exposure is assessed (outside or inside, windows open or closed, etc)
- The indicator to be used to describe the exposure (preferably L_{den} or L_{night}).

In future field studies, the emphasis should be on the health effects of long term sleep disturbance for different modes of transport noise, as well as for mixed flows, both in rural and urban areas.

APPENDIX

APPENDIX 1 Literature

Literature list in alphabetical order of the first author or institute

[1] *EU*, Position paper on dose- effect relationships for night time noise, working group on health and socio-economic effects, November 2004

[2] *EU,* Position paper on dose response relationships between transportation noise and annoyance, working group on the assessment of the exposure to noise, February 2002, ISBN 92-894-3894-0

[3] *Gezondheidsraad*, Noise and Health (in Dutch), Recommendation of the Dutch Health Council, report number 94/15, ISBN: 90-5549-046-6

[4] *Gezondheidsraad,* judging environmental noise (in Dutch), proposal for a uniform system of noise indicators to judge annoyance and sleep disturbance due to noise, ISBN: 90-5549-190-X, report 1997/23, Rijswijk 1997

[5] ISO 1996, Acoustics -- Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures, Part 2: Determination of environmental noise levels

[6] *ISO/TS* 15666:2003 Acoustics -- Assessment of noise annoyance by means of social and socio-acoustic surveys

[7] Interdisziplinäre Feldstudie II über die Besonderheiten des Schienenverkehrslärms gegenüber dem Straßenverkehrslärm, Forschungs-Nummer 70081/80 des Bundesministers für Verkehr, München/Bonn, Planungsbüro *Obermeyer*, 1983

[8] Annoyance caused by Maglev-trains, minutes of the International Workshop with various experts, organized by *TNO-Human Factors*, Soesterberg, February 2003

[9] Arbeitsgemeinschaft Verkehrswirking, Lärmbonus bei der Bahn, Ist die Besserstellung der Bahn im Vergleich zu anderen Verkehrsträgern noch gerechtfertigt?, *Umwelt Bundes Amt* Bericht UBA-FB 001338, Dessau-Rosslau, april 2010, ISSN 1862-4804

[10] *VDI* 3722, Blatt 1, Wirkungen von Verkehrsgeräusch, 1988

[11] *WHO*, Night Noise Guidelines for Europe, ISBN 978 92 890 4173 7, 2009

[12] Babisch, W., Transportation noise and cardiovascular health, German Federal Environment al Agency, January 2006

[13] Basner, M., Müller, U., Griefahn, B.: Practical Guidance for Risk Assessment of Traffic Noise Effects on Sleep, Applied Acoustics 71, p. 518-522, (2010).

[14] Basner, M., Müller, U., Elmenhorst, E.-M.: Single and combined effect of air, road, and rail traffic noise on sleep and recuperation, SLEEP, in press

[15] Basner, M., Elmenhorst, E.M., Maass, U., Müller, U., Wuehl, J., Vejvoda, M., single and combined effects of air, road and rail traffic noise on sleep, Proc. 9th ICBEN, Connecticut 2008

[16] Changwoo Lim, Jaehwan Kim, Jiyoung Hong, Soogab Lee, The relationship between railway noise and community annoyance in Korea, JASA 120 (4), 2006

[17] Fastl, H. et al, 2003 Railway Bonus for sound without meaning?

[18] Fidell, S., The Schultz curve 25 years later: A research perspective, JASA 114 (6), 2003

[19] Fields, J.M. and Walker, J.G., Comparing the relationships between noise level and annoyance in different surveys: a railway vs. aircraft and road traffic comparison, J. Sound Vib., 81, 1982

[20] Finegold, L., Harris, C. S., and von Gierke, H. E. ‘‘Community annoyance and sleep disturbance: Updated criteria for assessing the impacts of

general transportation noise on people,'' Noise Control Eng. J. 42,199425–30.
[21] Franssen, A.E.M. and Kwekkeboom, J.M.I., Effects of noise from road traffic on sleep, a systematic review of studies in the urban environment, RIVM report 725120010/2003,
[22] Griefahn B, Jansen G, Klosterkötter W. Zur Problematik lärmbedingter Schlafstörungen: eine Auswertung von Schlaf-Literatur. Umweltbundesamt 1976; 4: 1-251.
[23] Gjestland, T., Research on community response to noise – in the last five years, Proc. 9tth ICBEN, Foxwood 2008
[24] Griefahn, B., Lärmbedingte Schlafstörungen, Verkehrslärmarten, Frequenzspektren, temporäre Verkehrsruhe, IfADo Bericht im Forschungsverbund Leiser Verkehr, Dortmund 2007
[25] Griefahn, B. Sleep disturbances related to environmental noise. Noise Health 2002;4:57-60
[26] Griefahn, B., Möhler, U., Schümer, R., Vergleichende Untersuchung über die Lärmwirkung bei Straßen- und Schienenverkehr, Studiengemeinschaft Schienenverkehr, München, 2000? (Aufweckstudie, nicht veröffentlicht)
[27] Griefahn, B., Schienenverkehrslärm, Paper to the VDEI Nachhaltigkeitsforum, 2010
[28] Griefahn, B., Marks, A., Robens, S., Noise emitted from road, rail and air traffic and their effects on sleep, J. Sound Vib 295 (2006)
[29] Hauck, G., Lästigkeitsunderschied zwischen den Geräuschen des Straßenverkehrs und des Schienenverkehrs, Z. Lärmbekämpfung 38 (1991), 162-166
[30] Heimerl, G. and Holzmann, E., Ermittlung der Belästigung durch Verkehrslärm in Abhängigkeit von Verkehrsmittel und Verkehrsdichte in einem Ballungsgebiet, Forschungsarbeit des Verkehrswissenschaftlichen Institut der Universität Stuttgart, Bericht 13, 1978, also published in Kämpf dem Lärm, 26
[31] Hoeger, R., Schreckenberg, D., Felscher-Suhr, U., & Griefahn, B.(2002). Night-time noise annoyance: State of the art. Noise and Health, 4(15), 19–25
[32] Ising, H. and Kruppa, P., Health effects caused by noise : Evidence in the literature from the past 25 years, Noise Health 2004;6:5-13
[33] Jäger, K., Neue Erkenntnisse bei der Bewertung von Schienenlärm. ETR 52 (2003), Heft 7/8, S. 469 - 475.
[34] Joncour, S., Cailhau, D., Gautier, P.-E., Champelovier, P., Lambert, J., Annoyance due to combined noise sources, Proc. Inter.Noise 2000, Nice
[35] Jong, R.G. de, Eisses, A.R, reviewed by Lambert, J. and Vos, P.H. de, A prediction of annoyance due to high speed train noise in The Netherlands, TNO report 96.071, October 1996
[36] Kaku J. and Yamada I. The possibility of a bonus for evaluating railway noise in Japan, J. Sound Vib. 193. 1996
[37] Kasch, Reinhold and Vogts, Gesine, Schienenbonus: Es bleiben Fragen - Führen nur die geänderten Rahmenbedingungen zu steigenden Fahrgastzahlen?, in Der Nahverkehr, Nr. 3/2002, S. 39 ff
[38] Klosterkötter, W., Gono, I, Bericht über Untersuchungen von Schienenverkehrs-, Flug- und Straßenverkehrslärm in Hinblick auf Differenzen ihrer A- und C-Schallpegel, Essen, 1978
[39] Knall, V. and Schümer, R., the differing annoyance levels of rail and road traffic noise, J. Sound Vib., 87 (1983)
[40] Lambert, J., Le bruit des transports en Europe : exposition de la population, risques pour la santé et coûts pour la collectivité, Proc. Le Bruit en Europe,

Paris, December 2000
[41] Lercher, P. Auswirkungen des Straβenverkehrs auf Lebens-qualität und Gesundheit. Transitstudie-Sozialmedizinischer Teilbericht. Bericht aus dem Tiroler Landtag. Durchgeführt im Auftrag des Amtes der Tiroler Landesregierung-Landesbau-direktion, Innsbruck, 1992
[42] Lee, C.S.Y., and Fleming, G.G., General Health Effects of Transportation Noise, report of the US Department of Transportation and the Federal Railroad Administration, Report number DTS-34-RR297-LR2, FRA/RDV-03/01, June 2002,
[43] Liepert; Manfred, Möhler; Ulrich, Schreckenberg; Dirk, Schümer; Rudolf, Fastl, Hugo, Lästigkeit von Schienen- und Straßenverkehrslärm bei hohen Vorbeifahrhäufigkeiten Ergebnisse einer Feld- und Laborstudie. DAGA ´05, München, S. 369-370, 2005.
[44] Liepert, M., Möhler, U., Schreckenberg, D., Schümer, R., Lästigkeitsunterschied von Straßen- und Schienenverkehrslärm im Innenraum, Studiengemeinschaft Schienenverkehr, München, 2000
[45] Lukas, J.S., Noise and sleep: a literature review and a proposed criterion for assessing effect. JASA 1975; 58(6): 1232-42.
[46] Mersch-Sundermann, V., et al, Macht Schienenlärm krank?, Studie des Universitätsklinikums Freiburg zur Evaluierung der gesundheitlichen Wirkungen bei Exposition gegenüber Schienenlärm unter besonderer Berücksichtigung der DB-Trasse Basel-Offenburg (und der Haltbarkeit des Schienenbonus), Regionalverband Südlicher Oberrhein, Freiburg, April 2010
[47] Miedema, H.M.E., et al, EU. Position paper on dose response relationships between transportation noise and annoyance, working group Dose/Effect, 2002, ISBN: 92-894-3894-0,
[48] Miedema, H.M.E, Relationships between exposure to multiple noise sources and noise annoyance, JASA 116, 2004
[49] Miedema, H.M.E., Annoyance caused by two noise sources, J. Sound Vib.,98, 1985
[50] Miedema, H.M.E. and Vos, H., Exposure-response relationships for transportation noise, JASA 104, 1998
[51] Miedema, H.M.E., Passchier-Vermeer, W. and Vos, J., Elements for a position paper on night-time transportation noise and sleep disturbance, TNO report number 02 5N 160 61241, January 2003, ISBN 90-6743-981-9
[52] Miedema, H.M.E., and Oudshoorn, C.G.M., Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals, Environ. Health Perspect., 109, 2001
[53] Mitchell, C.G.B., Railway noise and the insulation of dwellings, Department of Transport report, ISBN 0-11-551012-5, London, 1991
[54] Möhler, U., Vergleich der Pausenstruktur von Schienenverkehrslärm und Straßenverkehrslärm, Zeitschrift für Lärmbekämpfung 35, 1988
[55] Möhler, U., "Community response to railway noise: a review of social surveys", *J. Sound Vib.,* 120. 321-332 (1988)
[56] Möhler, U. u.a., Stichpunkte zum Stand der Technik in der Lärmwirkungsforschung zum Thema „Schienenbonus", Stand August 2008, Anfrage des Bundesministeriums für Verkehr, Bau und Stadtentwicklung zur Notwendigkeit des Schienenbonus vom 08.07.2008, NOT PUBLISHED
[57] Möhler ,U., Liepert, M., Schreckenberg, D., Zur Anwendung des Schienenbonus bei der Beurteilung von Verkhersgeräuschen, Z.Lärmbekämpfung, Band 5, 2010
[58] Möhler, U., Schümer-Kors, A., Literaturstudie über die Wirkung von Schienenverkehrslärm allein und in Vergleich zu anderen

Verkehrslärmquellen, report of Planungsbüro Obermeyer, ORE report DT 170 (C163), Utrecht 1985

[59] Möhler, U., Schümer, R.. Knall, V., Schümer-Kors, A., Vergleich der Lästigkeit von Schienen- und Straßenlärm, Z. Lärmbekämpfung 33 (1986), 132-142

[60] Möhler, U., Liepert, M., Schümer, R.(Hrsg), Griefahn, B., Differences between Railway and Road Traffic Noise, J Sound Vib 2000; 231(3):853-864.

[61] Müller, U., Elmenhorst, E.-M., Rolny, V., Maaß, H., Pennig, S., Basner, M., Effects of Nocturnal Rail Noise on Sleep – Results of a Field Study in the Cologne/Bonn area,

[62] Öhrström, Evy, Barregård, Lars, Anderson, Eva, Skanberg, Ann-Britt, Svensson, Helena, Ängerhelm, Pär, Annoyance due to single and combined sound exposure from railway and road traffic, Noise Notes 2008

[63] Ollerhead, J.B., Jones, C.J., Cadoux, R.E., et al. Report of a field study of aircraft noise and sleep disturbance. London: Civil Aviation Authority, 1992.

[64] Ota A, Yokoshima S, Tamura A (2007). Comparison of dose-response relationships among different traffic noises. In: Inter-Noise 2007, Istanbul, Turkey.

[65] Passchier-Vermeer, W., Vos, H., Janssen, S.A. and Miedema, H.M.E., Sleep and Traffic Noise, TNO report TNO-rapport 2007-D-R0012/A, Delft 2007

[66] Pearsons, K..S, Barber, D.S., Tabacknick, B.G., Analyses of the predictability of noise-induced sleep disturbance. Canoga Park: BBN Systems and Technologies Corporation, 1989; (Report AD-A220 156).

[67] Rombach, Matthias, Schienenverkehrslärm als Rechtsproblem, Verlag Dr. Kovac,Hamburg, 2009,

[68] Sandrock, S., Griefahn, B., Kaczmarek, T., Hafke, H., Preis, A., and Gjestland, T., Experimental studies on annoyance caused by noises from trams and buses, J. Sound Vib 313, June 2008

[69] Schomer, P., Biases Introduced by the Fitting of Functions to Attitudinal Survey Data, Proc. ASA/Noise Con, Minneapolis, 2005

[70] Schreckenberg, Dirk, Schümer-Kohrs, Anke, Schümer, Rudolf, Griefahn, Barbara, Möhler, Ulrich, An Interdisciplinary Study on Railway and Road Traffic Noise: Annoyance Differences ,Proc. Forum Acusticum, Berlin 1999

[71] Schreckenberg, D., Möhler, U. and Liepert, M., Gilt der Schienenbonus auch während der Abendzeit?, Vergleich der Lästigkeit von Schienen- und Strassenverkehrslärm zu unterschiedlichen Tageszeiten, Z. Lärmbekämpfung Band 5, 2010

[72] Schümer; Rudolf, Schreckenberg; Dirk, Felscher-Suhr , Ute, Wirkungen von Schienen- und Straßenverkehrslärm. Bochum: Zeus GmbH, 2003

[73] Schümer; Rudolf, Schümer-Kohrs, A., Lästigkeit von Schienenverkehrslärm im Vergleich zu anderen Lärmquellen - Überblick über Forschungsergebnisse, in Zeitschrift für Lärmbekämpfung 38, Nr. 6; S. 1-9, 1991.

[74] Schümer-Kors, A, Schümer, R., Knall, V., and Kasubek, W., Vergleich der Lästigkeit von Schienen- und Straßenverkehrslärm in städtischen und ländlichen Regionen, Z. Lärmbekämpfung 28, 1981

[75] Schultz, Theodore J. Synthesis of Social Surveys on Noise Annoyance," Journal of the Acoustical Society of America, Vol. 64, No. 2, pp. 377-405, August 1978.

[76] Schulz, Mareike und Meinhold, Chajim, Quantifizierung des Schienenbonus - Messung des Kundennutzens mittels Choice-Based-Conjoint-Analyse, in Der Nahverkehr, Nr. 6/2003, S. 26ff

[77] Stansfeld, S.A. and Matheson, M.P., Noise Pollution: non-auditory effects on health, British Medical Bulletin 2003; 68: 243–257
[78] Steenbekkers, A.H.M. and Jong, R.G.de, Noise annoyance by freight trains, JASA 105, 1999
[79] Versfeld, N.J. and Vos, J. , Annoyance caused by sounds of wheeled and tracked vehicles, JASA 101, 1997
[80] Tassi, P., Rohmer, O., Schimchowitsch, S., Eschenlauer, A., Bonnefond, A., Margiocchi, F., Poisson, F. and Muzet, A., Living alongside railway tracks: long-term effects of nocturnal noise on sleep and cardiovascular reactivity as a function of age, Environment International 26 (2010), 683-689
[81] Vallet, M., Gagneux, J.-M., Blanchet, V., Favre, B. and Labiale, B., Long term sleep disturbance due to traffic noise, Journal of Sound and Vibration, 90 (2), 1983
[82] Vos, J., Annoyance caused by the sounds of a magnetic levitation train, JASA 115, April 2004
[83] Walker, J.G., Railway noise exposure: A possible method of establishing criteria for acceptability, J.Sound Vib. 120 (2), 1988
[84] Waterman, E. and Vos, P.H. de, Sleep disturbance by rail traffic (in Dutch), NSTO report 98/9610095/0004, September 1998
[85] Windelberg, D., Aufweck-Pegel und Lärmpausen bei Schienen- und Fluglärm. Immissionsschutz 9 (2004) S. 114-124, 2004
[86] Windelberg, D., Mathematische Verfahren zur Bewertung und zum Vergleich von Befragungen zur Verkehrslärm-Lästigkeit. DAGA ´10, Berlin, 2010.
[87] Yano T, Sato T, Morihara T (2007). Dose-response relationships for road traffic, railway and aircraft noises in Kyushu and Hokkaido, Japan. In: InterNoise 2007, Istanbul, Turkey
[88] Zeichart, K., Kilcher, H., Hermann, W., Hils, T., Gawlik, M., Untersuchungen zur Lästigkeit von Hochgeschwindigkeitszügen am Beispiel der Neu- und Ausbaustrecke Hannover-Göttingen, Studiengemeinschaft Schienenverkehr, München 1999
[89] Ziechart, K., Sinz, A., Schweiger, M., Kilcher, H., Hermann, W., Untersuchung zur Lästigkeit von Reise- und Güterzügen, Abschlussbericht, SGS 2001

Literature list in chronological order of the date of publication

[1] Lukas, J.S., Noise and sleep: a literature review and a proposed criterion for assessing effect. JASA 1975; 58(6): 1232-42

[2] Griefahn B, Jansen G, Klosterkötter W. Zur Problematik lärmbedingter Schlafstörungen: eine Auswertung von Schlaf-Literatur. Umweltbundesamt 1976; 4: 1-251

[3] Schultz, Theodore J. Synthesis of Social Surveys on Noise Annoyance," Journal of the Acoustical Society of America, Vol. 64, No. 2, pp. 377-405, August 1978.

[4] Klosterkötter, W., Gono, I, Bericht über Untersuchungen von Schienenverkehrs-, Flug- und Straßenverkehrslärm in Hinblick auf Differenzen ihrer A- und C-Schallpegel, Essen, 1978

[5] Heimerl, G. and Holzmann, E., Ermittlung der Belästigung durch Verkehrslärm in Abhängigkeit von Verkehrsmittel und Verkehrsdichte in einem Ballungsgebiet, Forschungsarbeit des Verkehrswissenschaftlichen Institut der Universität Stuttgart, Bericht 13, 1978, also published in Kämpf dem Lärm, 26

[6] Schümer-Kors, A, Schümer, R., Knall, V., and Kasubek, W., Vergleich der Lästigkeit von Schienen- und Straßenverkehrslärm in städtischen und ländlichen Regionen, Z. Lärmbekämpfung 28, 1981

[7] Fields, J.M. and Walker, J.G., Comparing the relationships between noise level and annoyance in different surveys: a railway vs. aircraft and road traffic comparison, J. Sound Vib., 81, 1982

[8] Interdisziplinäre Feldstudie II über die Besonderheiten des Schienenverkehrslärms gegenüber dem Straßenverkehrslärm, Forschungs-Nummer 70081/80 des Bundesministers für Verkehr, München/Bonn, Planungsbüro *Obermeyer*, 1983

[9] Knall, V. and Schümer, R., the differing annoyance levels of rail and road traffic noise, J. Sound Vib., 87 (1983)

[10] Möhler, U., Schümer-Kors, A., Literaturstudie über die Wirkung von Schienenverkehrslärm allein und in Vergleich zu anderen Verkehrslärmquellen, report of Planungsbüro Obermeyer, ORE report DT 170 (C163), Utrecht 1985

[11] Miedema, H.M.E., Annoyance caused by two noise sources, J. Sound Vib.,98, 1985

[12] Möhler, U., Schümer, R.. Knall, V., Schümer-Kors, A., Vergleich der Lästigkeit von Schienen- und Straßenlärm, Z. Lärmbekämpfung 33 (1986), 132-142

[13] Möhler, U., Vergleich der Pausenstruktur von Schienenverkehrslärm und Straßenverkehrslärm, Zeitschrift für Lärmbekämpfung 35, 1988

[14] *VDI* 3722, Blatt 1, Wirkungen von Verkehrsgeräusch, 1988

[15] Möhler, U., "Community response to railway noise: a review of social surveys", *J. Sound Vib.,* 120. 321-332 (1988)

[16] Pearsons, K..S, Barber, D.S., Tabacknick, B.G., Analyses of the predictability of noise-induced sleep disturbance. Canoga Park: BBN Systems and Technologies Corporation, 1989; (Report AD-A220 156).

[17] Schümer; Rudolf, Schümer-Kohrs, A., Lästigkeit von Schienenverkehrslärm im Vergleich zu anderen Lärmquellen - Überblick über Forschungsergebnisse, in Zeitschrift für Lärmbekämpfung 38, Nr. 6; S. 1-9, 1991

[18] Hauck, G., Lästigkeitsunderschied zwischen den Geräuschen des Straßenverkehrs und des Schienenverkehrs, Z. Lärmbekämpfung 38

(1991), 162-166
[19] Mitchell, C.G.B., Railway noise and the insulation of dwellings, Department of Transport report, ISBN 0-11-551012-5, London, 1991
[20] Ollerhead, J.B., Jones, C.J., Cadoux, R.E., et al. Report of a field study of aircraft noise and sleep disturbance. London: Civil Aviation Authority, 1992.
[21] Lercher, P. Auswirkungen des Straβenverkehrs auf Lebens-qualität und Gesundheit. Transitstudie-Sozialmedizinischer Teilbericht. Bericht aus dem Tiroler Landtag. Durchgeführt im Auftrag des Amtes der Tiroler Landesregierung-Landesbau-direktion, Innsbruck, 1992
[22] *Gezondheidsraad*, Noise and Health (in Dutch), Recommendation of the Dutch Health Council, report number 94/15, ISBN: 90-5549-046-6
[23] Finegold, L., Harris, C. S., and von Gierke, H. E. ‘‘Community annoyance and sleep disturbance: Updated criteria for assessing the impacts of general transportation noise on people,’’ Noise Control Eng. J. 42,1994, 25–30.
[24] ISO 1996 part 2, Acoustics -- Description, measurement and assessment of environmental noise -- Part 2: Determination of environmental noise levels
[25] Kaku J. and Yamada I. The possibility of a bonus for evaluating railway noise in Japan, J. Sound Vib. 193. 1996
[26] Jong, R.G. de, Eisses, A.R, reviewed by Lambert, J. and Vos, P.H. de, A prediction of annoyance due to high speed train noise in The Netherlands, TNO report 96.071, October 1996
[27] Versfeld, N.J. and Vos, J. , Annoyance caused by sounds of wheeled and tracked vehicles, JASA 101, 1997
[28] *Gezondheidsraad,* judging environmental noise (in Dutch), proposal for a uniform system of noise indicators to judge annoyance and sleep disturbance due to noise, ISBN: 90-5549-190-X, report 1997/23, Rijswijk 1997
[29] Waterman, E. and Vos, P.H. de, Sleep disturbance by rail traffic (in Dutch), NSTO report 98/9610095/0004, September 1998
[30] Miedema, H.M.E. and Vos, H., Exposure-response relationships for transportation noise, JASA 104, 1998
[31] Steenbekkers, A.H.M. and Jong, R.G.de, Noise annoyance by freight trains, JASA 105, 1999
[32] Zeichart, K., Kilcher, H., Hermann, W., Hils, T., Gawlik, M., Untersuchungen zur Lästigkeit von Hochgeschwindigkeitszügen am Beispiel der Neu- und Ausbaustrecke Hannover-Göttingen, Studiengemeinschaft Schienenverkehr, München 1999
[33] Schreckenberg, Dirk, Schümer-Kohrs, Anke, Schümer, Rudolf, Griefahn, Barbara, Möhler, Ulrich, An Interdisciplinary Study on Railway and Road Traffic Noise: Annoyance Differences ,Proc. Forum Acusticum, Berlin 1999
[34] Griefahn, B., Möhler, U., Schümer, R., Vergleichende Untersuchung über die Lärmwirkung bei Straßen- und Schienenverkehr, Studiengemeinschaft Schienenverkehr, München, 2000? (Aufweckstudie, nicht veröffentlicht)
[35] Möhler, U., Liepert, M., Schümer, R.(Hrsg), Griefahn, B., Differences between Railway and Road Traffic Noise, J Sound Vib 2000; 231(3):853-864.
[36] Liepert, M., Möhler, U., Schreckenberg, D., Schümer, R., Lästigkeitsunterschied von Straßen- und Schienenverkehrslärm im Innenraum, Studiengemeinschaft Schienenverkehr, München, 2000
[37] Joncour, S., Cailhau, D., Gautier, P.-E., Champelovier, P., Lambert, J., Annoyance due to combined noise sources, Proc. Inter.Noise 2000, Nice
[38] Lambert, J., Le bruit des transports en Europe : exposition de la population, risques pour la santé et coûts pour la collectivité, Proc. Le Bruit en Europe,

Paris, December 2000
[39] Ziechart, K., Sinz, A., Schweiger, M., Kilcher, H., Hermann, W., Untersuchung zur Lästigkeit von Reise- und Güterzügen, Abschlussbericht, SGS 2001
[40] Miedema, H.E., and Oudshoorn, C.G.M., Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals, Environ. Health Perspect., 109, 2001
[41] Griefahn B. Sleep disturbances related to environmental noise. Noise Health 2002;4:57-60
[42] Miedema, H., et al, EU. Position paper on dose response relationships between transportation noise and annoyance, working group Dose/Effect, 2002, ISBN: 92-894-3894-0,
[43] Hoeger, R., Schreckenberg, D., Felscher-Suhr, U., & Griefahn, B.(2002). Night-time noise annoyance: State of the art. Noise and Health, 4(15), 19–25
[44] Lee, C.S.Y., and Fleming, G.G., General Health Effects of Transportation Noise, report of the US Department of Transportation and the Federal Railroad Administration, Report number DTS-34-RR297-LR2, FRA/RDV-03/01, June 2002
[45] Kasch, Reinhold und Vogts, Gesine, Schienenbonus: Es bleiben Fragen - Führen nur die geänderten Rahmenbedingungen zu steigenden Fahrgastzahlen?, in Der Nahverkehr, Nr. 3/2002, S. 39 ff
[46] *EU,* Position paper on dose response relationships between transportation noise and annoyance, working group on the assessment of the exposure to noise, February 2002, ISBN 92-894-3894-0
[47] Fidell, S., The Schultz curve 25 years later: A research perspective, JASA 114 (6), 2003
[48] Stansfeld, S.A. and Matheson, M.P., Noise Pollution: non-auditory effects on health, British Medical Bulletin 2003; 68: 243–257
[49] Fastl, H. et al, 2003 Railway Bonus for sound without meaning?
[50] Annoyance caused by Maglev-trains, minutes of the International Workshop with various experts, organized by *TNO-Human Factors*, Soesterberg, February 2003
[51] Schulz, Mareike und Meinhold, Chajim, Quantifizierung des Schienenbonus - Messung des Kundennutzens mittels Choice-Based-Conjoint-Analyse, in Der Nahverkehr, Nr. 6/2003, S. 26ff
[52] *ISO/TS* 15666:2003 Acoustics -- Assessment of noise annoyance by means of social and socio-acoustic surveys
[53] Jäger, K., Neue Erkenntnisse bei der Bewertung von Schienenlärm. ETR 52 (2003), Heft 7/8, S. 469 - 475.
[54] Miedema, H.M.E., Passchier-Vermeer, W. and Vos, J., Elements for a position paper on night-time transportation noise and sleep disturbance, TNO report number 02 5N 160 61241, January 2003, ISBN 90-6743-981-9
[55] Schümer; Rudolf, Schreckenberg; Dirk, Felscher-Suhr , Ute, Wirkungen von Schienen- und Straßenverkehrslärm. Bochum: Zeus GmbH, 2003
[56] Franssen, A.E.M. and Kwekkeboom, J.M.I., Effects of noise from road traffic on sleep, a systematic review of studies in the urban environment, RIVM report 725120010/2003,
[57] *EU*, Position paper on dose- effect relationships for night time noise, working group on health and socio-economic effects, November 2004
[58] Ising, H. and Kruppa, P., Health effects caused by noise : Evidence in the literature from the past 25 years, Noise Health 2004;6:5-13
[59] Vos, J., Annoyance caused by the sounds of a magnetic levitation train, JASA 115, April 2004

[60] Miedema, H.M.E, Relationships between exposure to multiple noise sources and noise annoyance, JASA 116, 2004

[61] Windelberg, D., Aufweck-Pegel und Lärmpausen bei Schienen- und Fluglärm. Immissionsschutz 9 (2004) S. 114-124, 2004

[62] Liepert; Manfred, Möhler; Ulrich, Schreckenberg; Dirk, Schümer; Rudolf, Fastl, Hugo, Lästigkeit von Schienen- und Straßenverkehrslärm bei hohen Vorbeifahrhäufigkeiten Ergebnisse einer Feld- und Laborstudie. DAGA ´05, München, S. 369-370, 2005

[63] Changwoo Lim, Jaehwan Kim, Jiyoung Hong, Soogab Lee, The relationship between railway noise and community annoyance in Korea, JASA 120 (4), 2006

[64] Babisch, W., Transportation noise and cardiovascular health, German Federal Environment al Agency, January 2006

[65] Griefahn, B., Marks, A., Robens, S., Noise emitted from road, rail and air traffic and their effects on sleep, J. Sound Vib 295 (2006)

[66] Griefahn, B., Lärmbedingte Schlafstörungen, Verkehrslärmarten, Frequenzspektren, temporäre Verkehrsruhe, IfADo Bericht im Forschungsverbund Leiser Verkehr, Dortmund 2007

[67] Yano T, Sato T, Morihara T (2007). Dose-response relationships for road traffic, railway and aircraft noises in Kyushu and Hokkaido, Japan. In: InterNoise 2007, Istanbul, Turkey

[68] Ota A, Yokoshima S, Tamura A (2007). Comparison of dose-response relationships among different traffic noises. In: Inter-Noise 2007, Istanbul, Turkey.

[69] W. Passchier-Vermeer, H. Vos, S.A. Janssen and H.M.E. Miedema, Sleep and Traffic Noise, TNO report TNO-rapport 2007-D-R0012/A, Delft 2007

[70] Sandrock, S., Griefahn, B., Kaczmarek, T., Hafke, H., Preis, A., and Gjestland, T., Experimental studies on annoyance caused by noises from trams and buses, J. Sound Vib 313, June 2008

[71] Gjestland, T., Research on community response to noise – in the last five years, Proc. 9tth ICBEN, Foxwood 2008

[72] Stephan Sandrock, Barbara Griefahn, Tomasz Kaczmarek, Honorata Hafke, Anna Preis and Truls Gjestland, Experimental studies on annoyance caused by noises from trams and buses, J. Sound Vib 313, June 2008

[73] Möhler, U. u.a., Stichpunkte zum Stand der Technik in der Lärmwirkungsforschung zum Thema „Schienenbonus“, Stand August 2008, Anfrage des Bundesministeriums für Verkehr, Bau und Stadtentwicklung zur Notwendigkeit des Schienenbonus vom 08.07.2008, NOT PUBLISHED

[74] Basner, M., Elmenhorst, E.M., Maass, U., Müller, U., Wuehl, J., Vejvoda, M., single and combined effects of air, road and rail traffic noise on sleep, Proc. 9th ICBEN, Connecticut 2008

[75] Evy Öhrström, Lars Barregård, Eva Anderson, Annbritt Skanberg, Helena Svensson, Pär Ängerhelm, Annoyance due to single and combined sound exposure from railway and road traffic, Noise Notes 2008

[76] *WHO*, Night Noise Guidelines for Europe, ISBN 978 92 890 4173 7, 2009

[77] Rombach, Matthias, Schienenverkehrslärm als Rechtsproblem, Verlag Dr. Kovac,Hamburg, 2009,

[78] Windelberg, D., Mathematische Verfahren zur Bewertung und zum Vergleich von Befragungen zur Verkehrslärm-Lästigkeit. DAGA ´10, Berlin, 2010.

[79] Tassi, P., Rohmer, O., Schimchowitsch, S., Eschenlauer, A., Bonnefond, A., Margiocchi, F., Poisson, F. and Muzet, A., Living alongside railway tracks: long-term effects of nocturnal noise on sleep and cardiovascular reactivity as a function of age, Environment International 26 (2010), 683-689

[80] Schreckenberg, D., Möhler, U. and Liepert, M., Gilt der Schienenbonus auch während der Abendzeit?, Vergleich der Lästigkeit von Schienen- und Strassenverkehrslärm zu unterschiedlichen Tageszeiten, Z. Lärmbekämpfung Band 5, 2010

[81] Müller, U., Elmenhorst, E.-M., Rolny, V., Maaß, H., Pennig, S., Basner, M., Effects of Nocturnal Rail Noise on Sleep – Results of a Field Study in the Cologne/Bonn area,

[82] Möhler ,U., Liepert, M., Schreckenberg, D., Zur Anwendung des Schienenbonus bei der Beurteilung von Verkhersgeräuschen, Z.Lärmbekämpfung, Band 5, 2010

[83] Griefahn, B., Schienenverkehrslärm, Paper to the VDEI Nachhaltigkeitsforum, 2010

[84] Arbeitsgemeinschaft Verkehrswirking, Lärmbonus bei der Bahn, Ist die Besserstellung der Bahn im Vergleich zu anderen Verkehrsträgern noch gerechtfertigt?, *Umwelt Bundes Amt* Bericht UBA-FB 001338, Dessau-Rosslau, april 2010, ISSN 1862-4804

[85] Basner, M., Müller, U., Griefahn, B.: Practical Guidance for Risk Assessment of Traffic Noise Effects on Sleep, Applied Acoustics 71, p. 518-522, (2010).

[86] Mersch-Sundermann, V., et al, Macht Schienenlärm krank?, Studie des Universitätsklinikums Freiburg zur Evaluierung der gesundheitlichen Wirkungen bei Exposition gegenüber Schienenlärm unter besonderer Berücksichtigung der DB-Trasse Basel-Offenburg (und der Haltbarkeit des Schienenbonus), Regionalverband Südlicher Oberrhein, Freiburg, April 2010

[87] Basner, M., Müller, U., Elmenhorst, E.-M.: Single and combined effect of air, road, and rail traffic noise on sleep and recuperation, SLEEP, in press

APPENDIX 2 Wording and translations

English	German	French	Explanation/definition
Annoyance	Belästigung.	Gêne	the feeling of being disturbed without being able to influence it
General annoyance	Nicht spezifische Belästiging	Gêne non spécifique	Mostly self reported annoyance, without specific effects
Specific annoyance	Spezifische Belästiging	Gêne spécifique	Element of general annoyance with specific effect, such as disturbance of concentration, communication, etc.
Awakening	Aufwachen	Se reveiller	Specific disturbance of healthy sleep that leads to a conscious reaction of being awake
Cardiovascular	Cardiovasculär	Cardiovasculair	Referring to the heart and the arteries
Complaints	Beschwerden	Plaintes	expression of feelings of annoyance, often being triggered by substantial changes in an existing situation, .e.g. start of exploitation of a newly built line.
Disturbance	Störung	nuisance	Forced interruption of a specific activity, including sleep
Noise exposure	Lärmbelastung	Exposition de bruit	Incident noise level at a receiver point referring to a particular individual or group of individuals
Health effects	Gesundheitsschaden	effets sur la santé	Total negative impact on health (definition of health see below)
Health	Gesundheit	Santé	According to WHO, Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.
Ischaemic			Referring to problems with the transport of blood through the arteries
Motility	Beweglichkeit	Motilité	Refers to unconscious movements of the body during sleep
NACF	Belästigungsbedingte Pegelkorrektur	Correction de niveau de bruit en dependence	Noise annoyance correction factor

		de la gêne	
REM-sleep	REM Schlaf	Sommeil REM	Referring to a particular stage of the healthy sleep that is connected to rapid eye movements
SDCF	Durch Schlafstörungen bedingte Pegelkorrektur	Correction de niveau de bruit en dépendance de la nuisance de sommeil	Sleep disturbance correction factor
Sleep disturbance	Schlafstörung	Perturbance du sommeil	Any disturbance of healthy sleep, such as awakening, increased motility, disturbance of normal sleep stages or increase hormone secretion

It has been suggested by some authors, that the French word “gêne” refers to a more serious reaction than annoyance, for instance “irritation”.

APPENDIX 3 Definitions

L_{Amax}	A-weighted maximum noise level, usually assessed with time constant “fast” of the sound level meter
L_{den}	Long term average, A-weighted sound level during the day, evening and night, where the evening period is penalised by + 5 dB and the night period is penalised by + 10 dB
L_{day}	Long term average, A-weighted sound level during a 12 hours period of the day (usually 7.00 – 19.00 hours)
$L_{evening}$	Long term average, A-weighted sound level during a 4 hours period of the evening (usually 19.00 – 23.00 hours)
L_{night}	Long term average, A-weighted sound level during an 8 hours period of the night (usually 23.00 – 7.00 hours)
SEL	Sound Exposure Level, energy equivalent sound level of an event with specific time lenght, corrected down to a standard time length of 1 second with equal energy
L_{10}	Continuous A-weighted sound level that is exceeded during 10% of the time of a particular observation or assessment. More general: L_n: exceeded during n% of the time.