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ENVIRONMENTAL NOISE DISCRIPTORS IN EUROPE - comparison of definitions and prediction methods

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To

Ministry of Environment of the Netherlands
Directorate Noise & Traffic

TNO Institute of Applied Physics (TPD) is a contract research organization for industry and government with a multi-disciplinary approach. In-house disciplines are: applied physics, information technology, mechanics, electronics, materials and process technology.

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Contents

1 INTRODUCTION

Between the European countries the legal or usual methods to describe and predict environmental noise differ. This concerns partly essential differences in the quantities and methods used and partly differences which are mainly caused by a more detailed or more simplified approach.
In order to be able to use results from studies in the various countries more easily the EU (DGXI) is considering the harmonization of the descriptors for environmental noise in Europe.

For the Dutch government it is important that the harmonized way of defining and determining these descriptors is in line with the methods used in the Netherlands, which are rather detailed and should not be replaced by too much simplified methods. By contract for the Ministerie of VROM the TPD therefore has studied the quantities and methods in various European countries in order to deduce the minimum requirements for a harmonized system.

The comparison of the different approaches is based on available information at TPD and additional information which could be easily gathered through existing contacts. The comparison will therefore not cover all European countries and might not be completely up-to-date. By covering a reasonable number of countries it is thought however, that there is sufficient background for conclusions and recommendations.

2 APPROACH

2.1 General

The description of the noise load in the environment is generally based on a sound pressure level at the receiver to which corrections and adjustments are added in order to get a relevant rating level. The definition of the sound pressure level may differ however, especially in the time period considered and in the relevant propagation conditions. These differences are sometimes clear from the definitions or follow otherwise from the specified measurement or calculation procedures. In treating this aspect the approach of ISO 1996 will be taken as reference.

The study of the existing procedures is based on the legal or usual procedures in various European countries, concentrating on those countries where prediction schemes are widely used. Besides the Netherlands (NL) it concerns Germany (D), France (F), Austria (A) and the Scandinavian countries(SCAN). In some of these countries the procedures are in revision at the moment, partly due to the new ISO standard on sound propagation. In these cases it will be tried to describe the situation as it will be in force in the next year.

2.2 ISO

In ISO 1996 [1] the basic quantities for the description of environmental noise from all types of noise sources are specified. These are:

$L_{Aeq,T}$	equivalent continuous A-weighted sound pressure level over the reference time interval T;
$L_{Aeq}(LT)$	long term average sound level over the reference time interval T;
$L_{Ar,T}$	rating level over the reference time interval T;
$L_{Ar}(LT)$	long term average rating level over the reference time interval T;
L_{AE}	sound exposure level (A-weighted).

The rating level follows from the equivalent continuous A-weighted sound pressure level over the reference time interval T by adding specific adjustments in order to take subjective effects into account. This concerns particularly the tonal character and the impulsiveness of the sound.

In general the assessment in the various countries is based on a rating level with various adjustments. The basis for this rating level is generally the equivalent continuous A-weighted sound pressure level over a specific time interval. The applied adjustments may be those according to ISO 1996 but can include also additional adjustments for the type of source ('railway bonus'), the type of traffic (flowing traffic, stop lights, etc.) or the period of the 24 h day.
In making the comparison between the various countries the attention will be focused on the sound pressure level used ($L_{Aeq,T}$, $L_{Aeq}(LT)$ over specified time intervals, L_{AE} etc.). The various adjustments to derive a rating level will not be considered in detail.

In ISO 9613-2 [2] a prediction model is given for outdoor sound propagation to determine the equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$ for down wind propagation (DW) and for the long term average propagation (LT). The long term average follows from $L_{Aeq,T}$ (DW) by applying a correction for meteorological conditions C_{meteo}. The model considers point sources characterized by their sound power level and directivity. Extended sources are to be build up from point sources. The main aspects treated for the propagation are the attenuations due to distance, atmosferic absorption, ground effects and screening. Reflections are treated by considering mirror sources or mirror receivers. Additional information is given on attenuation by areas with obstacles like build-up ares, industrial premises and woods. The model describes the calculation in octave bands; as an alternative the calculation for A-weighted levels is also indicated.

remark In ISO 9613 the subscript 'eq' for the levels is deleted. In this report however, we will follow the notations of ISO 1996.

3 SOUND LEVEL

3.1 Road traffic

3.1.1 NL

The rating level ('geluidbelasting B') is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T [3]. These time intervals are day (T=7:00-19:00 h) and night (T=23:00-7:00 h); the intermediate evening period is not considered. For the night the adjustment is +10 dB.

This sound level is deduced from calculations for down wind propagation, $L_{Aeq,T}$(DW), by applying a meteorological correction, C_{meteo}. It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

The traffic intensity to be used is the number of vehicles in each category for each time interval averaged over a year, as it is to be expected in the (near) future.

3.1.2 D

The rating level is deduced from the sound level $L_{Aeq,T}$, the equivalent continuous A-weighted sound pressure level over specified reference time intervals T [10]. These time intervals are day (T=6:00-22:00 h) and night (T=22:00-6:00 h). An adjustment of 0 to +3 dB(A) is applied depending on the distance to traffic lights.

This sound level is deduced from calculations for moderate down wind propagation, $L_{Aeq,T}$(DW). It concerns the level in free field.

The traffic intensity to be used is the number of vehicles in each category for each time interval.

3.1.3 F

The rating level is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T [20]. These time intervals are day (T=6:00-22:00 h) and night (T=22:00-6:00 h). There are no adjustments applied.

This sound level is deduced from calculations or measurements, taking into account the local meteorological conditions. For calculations this is based on results for down wind propagation and for neutral conditions. For measurements

it is based on the prescribed meteorological conditions, varying from neutral to somewhat downwind [21]. The regulations are such that the relevant sound level is never lower than it would be under neutral propagation conditions.
It concerns the level 2 m in front of the considered building, i.e. including the contribution of reflections (+3 dB) against that building.

The traffic intensity to be used is the number of vehicles in each category for each time interval.

3.1.4 A

The rating level is deduced from the sound level $L_{Aeq,T}$, the equivalent continuous A-weighted sound pressure level over specified reference time intervals T. These time intervals are the 8 noisiest hours during the day (T=8 h; 6:00-22:00 h) and the night (T=22:00-6:00 h). There are no adjustments applied.

This sound level is deduced from calculations or measurements for down wind propagation, $L_{Aeq,T}$(DW). It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

The traffic intensity to be used is the number of vehicles in each category for each time interval.

3.1.5 SCAN

The rating level is deduced from the sound level $L_{Aeq,T}$, the equivalent continuous A-weighted sound pressure level over a specified reference time interval T [24]. The time interval is the whole day (T=0:00-24:00 h).

This sound level is deduced from calculations for neutral propagation conditions. In Denmark also measurements can be used, for which down wind propagation is specified. It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

The traffic intensity to be used is the number of vehicles in each category for the 24 hour time interval. In DK this is based on the average intensity for all days of the year.

In Sweden and Norway use is made additionally of the maximum level; it concerns $L_{pA,max}$ with time weighting 'F'.

3.2 Rail traffic

3.2.1 NL

The rating level ('geluidbelasting B') is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T [4]. These time intervals are day (T=7:00-19:00 h), evening (T=19:00-23:00 h) and night (T=23:00-7:00 h). For the evening the adjustment is + 5 dB and for the night +10 dB.

This sound level is deduced from calculations for down wind propagation, $L_{Aeq,T}$(DW), by applying a meteorological correction, C_{meteo}. It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

The traffic intensity is based on the number of trains as a year-average.

3.2.2 D

The rating level is deduced from the sound level $L_{Aeq,T}$, the equivalent continuous A-weighted sound pressure level over specified reference time intervals T [10]. These time intervals are day (T=6:00-22:00 h) and night (T=22:00-6:00 h). An adjustment of -5 dB(A) is applied ('rail way bonus').

This sound level is deduced from calculations for moderate down wind propagation, $L_{Aeq,T}$(DW). It concerns the level in free field.

3.2.3 F

The rating level is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T [20]. These time intervals are day (T=6:00-22:00 h) and night (T=22:00-6:00 h). There are no adjustments applied.

This sound level is deduced from calculations or measurements, taking into account the local meteorological conditions. For calculations this is based on results for down wind propagation and for neutral conditions. For measurements it is based on the prescribed meteorological conditions, varying from neutral to somewhat downwind [21]. The regulations are such that the relevant sound level is never lower than it would be under neutral propagation conditions. It concerns the level 2 m in front of the considered building, i.e. including the contribution of reflections (+3 dB) against that.

3.2.4 A

The rating level is deduced from the sound level $L_{Aeq,T}$, the equivalent continuous A-weighted sound pressure level over specified reference time intervals T. These time intervals are the day (T=6:00-22:00 h) and the night (T=22:00-6:00 h). An adjustment of -5 dB(A) is applied ('rail way bonus').

This sound level is deduced from calculations or measurements for down wind propagation, $L_{Aeq,T}$(DW). It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

3.2.5 SCAN

The rating level is deduced from the sound level $L_{Aeq,T}$(DW), the equivalent continuous A-weighted sound pressure level under down wind conditions over a specified reference time interval T [24]. The time interval is the whole day (T=0:00-24:00 h).

This sound level is deduced from calculations for down wind propagation conditions.It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

Additionally use is made of the maximum level for the noisiest type of train; it concerns $L_{pA,max}$ with time weighting 'F' in Sweden and time weighting 'S' in Denmark and Norway.

3.3 Industrial activities

3.3.1 NL

The rating level ('geluidbelasting B') is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T [5]. These time intervals are day (T=7:00-19:00 h), evening (T=19:00-23:00 h) and night (T=23:00-7:00 h). For the evening the adjustment is + 5 dB and for the night +10 dB. For some regulations adjustments for tonal character and impulsiveness of the sound are also applied.

This sound level is deduced from calculations or measurements for down wind propagation, $L_{Aeq,T}$(DW), by applying a meteorological correction, C_{meteo}. It concerns the level in free field.

The sound level is determined for the industry working under maximum load.

3.3.2 D

The rating level is in general deduced from an estimation of the sound level $L_{Aeq,T,}$ the equivalent continuous A-weighted sound pressure level over specified reference time intervals T [11] during the predominant meteorological conditions. These time intervals are 16 hours during the day (T=6:00-22:00 h) and the noisiest hour during the night (T=1h; 22:00-6:00 h). For the periods from 6:00-7:00 and 19:00-22:00 6 dB(A) is added to the sound level.

The sound level is measured under the prevailing meteorological conditions or calculated primarily for moderate downwind conditions. The estimation follows from the variation in the sound levels with time weighting 'F' (L_{AF}) taking into account the duration of the operation. Adjustments are applied for tonal character and impulsiveness of the sound. In case of impulsive noises, alternatively the sound level with time weighing 'I' is used or the linear average of L_{AF} within a 5 seconds period with only adjustments for tonal character if appropriate. The prescribed measurement position is such that the contribution of facade reflections is negligible.

3.3.3 F

The rating level is deduced from the sound level $L_{Aeq,T}$ at the property limits of the industry. The time intervals considered are normally day (T=7:00-20:00 h) and night (T=22:00-6:00 h) and the intermediate periods, with some adjustements for free days. The rating level is compared with a level of 45 dB(A) with adjustments for the period of the day (0 to -10 dB) and the type of environment (0 to +25 dB). Additional requirements are applied for industrial noise from within occupied buildings.

The sound level is determined during prevailing meteorological consditions.

For other types of neighbouring noise the rating level is deduced from the (equivalent) sound level of the ambient noise during operation, which should not exceed the ambient noise alone by more than 5 dB(A) for the daytime and 3 dB(A) for the nighttime, taking into account the total operation period t, roughly equal to 3 lg t relative to an 8 hour period [23]. The time intervals considered are day (T=7:00-22:00 h) and night (T=22:00-7:00 h).

3.3.4 A

The rating level is deduced from the sound level $L_{Aeq,T}$(LT), the long term equivalent continuous A-weighted sound pressure level over specified reference time intervals T. These time intervals are the 8 noisiest hours during the day (T=8h; 6:00-22:00 h) and the noisiest half hour during the night (T=1/2h; 22:00-6:00 h). Adjustments are applied for tonal character and impulsiveness of the sound.

This sound level is deduced from calculations or measurements for down wind propagation, $L_{Aeq,T}$(DW), by applying a meteorological correction, C_{meteo}. It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

3.3.5 SCAN

The rating level is deduced from the sound level $L_{Aeq,T}$(DW), the equivalent continuous A-weighted sound pressure level under down wind conditions over specified reference time intervals T [24]. The time interval are day (T= 7:00-18:00 h), evening (T=18:00-22:00 h) and night (T=22:00-7:00 h).
Remark: In Norway the day starts at 6:00 h.
Adjustments are applied for tonal character and impulsiveness of the sound.

This sound level is deduced from calculations or measurements for down wind propagation conditions. It concerns the level in free field, i.e. without the contribution of reflections against the considered building.

Additionally use is made of the maximum level; it concerns $L_{pA,max}$ with time weighting 'F' in Denmark and Sweden and time weighting 'S' in Norway.

3.4 Air traffic

3.4.1 NL

The rating level (KE) is deduced from the maximum A-weighted sound level of an operation $L_{A,max}$ and the number of operations with adjustments up to 10 dB for the time of the operation. In the summation over operations the levels are included with 4 dB per energy-doubling and the number with 6 dB per doubling.

The maximum sound level is calculated for moderate downwind propagation conditions for the free field.

The operation intensity considered is the total over a year.

3.4.2 D

The rating level ('Stör-index') is deduced from the maximum A-weighted sound level of an operation $L_{A,max}$, the duration of an operation (-10 dB-points) and the number of operations with adjustments up to 9 dB for the time of the operation. In the summation over operations the levels are included with 3 dB per energy-doubling and the operation time and number with 4 dB per doubling.

The maximum sound level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is an average 24 hour period.

3.4.3 F

The rating level is deduced from the Perceived Noise Level L_{PN} of an operation, which takes into account maximum level and duration, with adjustments of 10 dB for nighttime operations. In the summation over operations the levels and numbers are included with 3 dB per (energy-) doubling.

The maximum sound level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is an average 24 hour period.

3.4.4 A

The rating level is deduced from the maximum A-weighted sound level of an operation $L_{A,max}$, the fly-over time and the number of operations, separate for day time (6:00-22:00 h) and for day and nighttime (22:00-6:00 h) with an adjustments of 10 dB for nighttime operations. In the summation over operations the levels and numbers are included with 3 dB per (energy-) doubling.

The maximum sound level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is an average for the most busy 6 month over a 24 hour period or the working period of the airport.

3.4.5 DK

The rating level (L_{DEN}) is the A-weighted (equivalent continuous) Day-Evening-Night level for a 24h time interval. It is deduced from the sound exposure level L_{AE} for each operation, including taxiing, with adjustments of 5 dB for the evening (T=19:00-22:00 h) and 10 dB for the night (T=22:00-7:00 h) and 5 dB for specific annoying types of traffic. Additionally use is made of the maximum level for the night time and during taxiing; it concerns $L_{pA,max}$ with time weighting 'S'.

The sound exposure level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is the average intensity of the three busiest months in a year.

3.4.6 N

The rating level (EFN) is the A-weighted equivalent continuous sound level for a 24h time interval with adjustments up to 10 dB for the time of the operation. Additionally use is made of the maximum level; it concerns $L_{pA,max}$ with time weighting 'S'.

The sound exposure level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is the average intensity of the four most busy weeks during summer, unless four weeks in winter time are twice as busy.

3.4.7 S

The rating level (FBN) is the A-weighted equivalent continuous sound level for a 24h time interval with adjustments of 5 dB for evening operations and 10 dB for night operations. Additionally use is made of the maximum level; it concerns $L_{pA,max}$ with time weighting 'F'.

The sound exposure level is calculated for neutral propagation conditions for the free field.

The operation intensity considered is the average intensity over a year.

3.5 Summary sound level

A summary of the main quantities used is given below.

SOUND LEVEL	road traffic	rail traffic
ISO	$L_{Aeq,T}$ (DW) or $L_{Aeq,T}$ (LT) = $L_{Aeq,T}$ (DW) + C_{meteo} ; receiver position and reference time interval T to be specified.	
NL	$L_{Aeq,T}$ (LT); T= 7-19, 23-7 h	$L_{Aeq,T}$ (LT); T= 7-19, 19-23, 23-7 h
D	$L_{Aeq,T}$ (DW); T= 6-22, 22-6 h	$L_{Aeq,T}$ (DW) ; T= 6-22, 22-6 h
F	$L_{Aeq,T}$ $(LT)^{\&}$; T= 6-22, 22-6 h	$L_{Aeq,T}$ $(LT)^{\&}$; T= 6-22, 22-6 h
A	$L_{Aeq,T}$ (DW); T= 8h(6-22), 22-6 h	$L_{Aeq,T}$ (DW) ; T= 6-22, 22-6 h
SCAN	$L_{Aeq,T}$ (N); T= 24 h $L_{pA,max}$ 'F' or 'S'	$L_{Aeq,T}$ (DW) ; T= 24 h $L_{pA,max}$ 'F' or 'S'
	industrial activities	**air traffic**
ISO	$L_{Aeq,T}$ (DW) or $L_{Aeq,T}$ (LT) = $L_{Aeq,T}$ (DW) + C_{meteo} ; receiver position and reference time interval T to be specified.	
NL	$L_{Aeq,T}$ (LT); T= 7-19, 19-23, 23-7 h	$10\lg \Sigma n^2 10^{1,33 LAmax^*/10}$; T= year
D	$L_{Aeq,T}$ (P); T= 7-18, 18-22, 22-7 h	$10\lg \Sigma n 10^{1,33 LAX^*/10}$; T = 24 h
F	$L_{Aeq,T}$ $(P)^{\&}$; T= 7-20, 6-7/20-22, 22-6 h	$10\lg \Sigma n 10^{LPNmax^*/10}$; T = 24 h
A	$L_{Aeq,T}$ (DW); T= 8h(6-22), ½h(22-6)	$10\lg \Sigma n 10^{LAX^*/10}$; T= 6-22 h; 24 h
SCAN	$L_{Aeq,T}$ (DW); T= 7-18, 18-22, 22-7 $L_{pA,max}$ 'F' or 'S'	$10\lg \Sigma n 10^{LAX^*/10}$; T= 24 h $L_{pA,max}$ 'F' or 'S'

T = reference time interval (7-19: total interval; 8h(6-22): 8 h within interval;
DW = down wind, N = neutral, LT = long term average, P = prevailing conditions;
& = including building reflection at receiver position of 3 dB;
* = adjustment for evening and night operations, either through adjustments to the level or through an increased number of operations n.

The rating level for noise from road traffic, rail traffic and industrial activities is in most countries deduced from the long term equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$(LT). In some countries this is the case already now, in others the regulations are being changed in this direction. In general this concerns the free field level, without the contribution of reflections against the facade if that is the relevant immission point. Only in France it is explicitly stated that the rating level is inclusive of 3 dB facade reflection. In the Netherlands the height of the immission point for planning purposes is specified at 5 m, in Germany at 3,5 m and in the Scandinavian countries at 1,5 m. For noise from industrial activities generally adjustments for tonal character or impulsiveness are included in the rating level, though not always in the same way.

The considered reference time intervals differ between types of sources and between countries as do the adjustements to the level (or the difference in requirement) for the different time intervals.

The relevant emission situation is not always indicated clearly. For road and rail traffic the traffic intensity in the Netherlands and Denmark is based on a year-average as it is to be expected in the near future, while other countries are less explicit about it. For industries often no indications are given, while in the Netherlands and the Scandinavian countries the maximum load as typical of normal operations is specified.

For air traffic noise the rating levels show more variations. Differences occur in the type of sound level to characterize an operation, the weighting of the time of operation, the considered reference time interval and the weighting of levels and numbers in the summation of operations over the time interval. The relevant intensity varies from the average over a year (NL, S) to the average over the busiest three month (DK).

4 SOURCE EMISSION LEVEL

4.1 Road traffic

4.1.1 Definitions

The emission of road traffic noise is given in the various countries for various categories of vehicles as function of the number of vehicles per hour, the speed, the type of road surface and the elevation of the road (descend, ascend). Normally the emission is specified as an A-weighted level, sometimes also in octave bands. We will restrict ourselves to A-weighted levels.

The quantity to express the emission is rather different in the various countries: maximum level per vehicle at a specified distance, equivalent continuous level of traffic flow at a specified distance, sound power level for vehicles or for traffic flows or related quantities. These differences in the definition of the emission level is reflected in differences in attenuation terms for the propagation. To be able to compare the different approaches the emission level will be presented as the sound power level per meter for flow traffic with 1 vehicle per hour in the free field, denoted as L'_W. To deduce this from the data in the various models use will be made of the equivalent continuous sound level for a (incoherent) line source for a reference situation according to ISO 9613. The reference situation is an infinitely long line source ($\Phi = \pi$) with a reflecting ground (A_{ground} = -3 dB):

$$L_{A,eq} = L'_W + 10\lg\frac{\Phi}{4\pi d} - A_{atm} - A_{ground}$$

$$L_{A,eq} = L'_W - 10\lg d - 3\ (-A_{atm}) \qquad (1)$$

The term for the atmospheric absorption (A_{atm}) is negligible for reference situations at short distance and will only be taken into account if the distance in the reference situation is rather large.
By comparing the sound levels according to eq. (1) with the sound level at the reference distance according to the various models, the sound power level L'_W is obtained for all these models.

4.1.2 NL

The emission in [3] is expressed in the emission term E in dB(A) for four categories of vehicles. With 1 vehicle per hour this term follows for passenger cars (p) and heavy trucks (t) from:

$$\begin{aligned} E_p &= 51{,}2 + 0{,}21v - 10\lg v \\ E_t &= 76{,}2 + 0{,}03v - 10\lg v \end{aligned} \qquad (2)$$

where v is the speed in km/h. This is based on measurements in a speed range from 35 km/h to 130 km/h.
From the resulting sound level at short distance according to [3] and eq. (1) follows:

$$\begin{aligned} L_{A,eq} &= E - 10\lg d = L_W' - 10\lg d - 3 \\ L_W' &= E + 3 \end{aligned} \qquad (3)$$

For other road surfaces than 'normal; concrete or asphalt a correction is applied to the emission. For surfaces with a rougher texture the correction maximum 3 dB and for 'bricks' maximal 4,5 dB for passenger cars only, decreasing to 0 resp. 1 dB with an increasing percentage of trucks.
For slopes of 2-7% a correction is applied from 0 to 2,7 dB. The largest of these two corrections is to be used

4.1.3 D

The emission in [9] is expressed in the equivalent continuous A-weighted sound pressure level for a line source at a distance of 25 m, L_{Am}. With 1 vehicle per hour this term follows for passenger cars (p) and heavy trucks (t) from:

$$\begin{aligned} L_{Am,p} &= 32{,}4 && v < 70 \text{ km/h} \\ &= -23{,}0 + 30\lg v && v \geq 70 \text{ km/h} \\ L_{Am,t} &= +11{,}5 + 20\lg v && v \geq 55 \text{ km/h} \end{aligned} \qquad (4)$$

In the more recent document RLS 90 [14] the emission for passenger cars at low speed is lower (up till 4 dB(A)), while the emission for trucks is 2 to 6 dB(A) lower.

From the resulting sound level at 25 m distance according to [9, 14] and eq. (1) follows:

$$L_{Aeq} = L_{Am} - 14\lg\frac{d}{25} = L_W^{/} - 10\lg d - 3 - 0{,}4 \qquad (5)$$

$$L_W^{/} = L_{Am} + 17{,}4$$

The speed is taken as 55 km/h for speeds below 60 km/h.

For passenger cars a correction is applied for road surfaces other than 'fine asphalt or concrete'. These corrections range from 1 dB tot 6 dB for very rough surfaces, depending on vehicle type and speeed. For slopes up to 7% there is no correction; no data is given for steeper slopes.

4.1.4 F

The emission in [22] is expressed in the emission level E for two categories under different driving conditions (freely flowing, up/down hill, acceleration, decelerating). With 1 vehicle per hour this term for freely flowing traffic follows for passenger cars (p) and heavy trucks (t) from:

$$E_p = 29{,}4 + 21{,}5\lg\frac{v}{44}\ ; \qquad v \geq 44 \text{ km/h}$$

$$E_t = 43{,}5 - 8{,}8\lg\frac{v}{50}\ ;\ 20 \leq v \leq 50 \text{ km/h} \qquad (6)$$

$$= 43{,}5 + 14{,}8\lg\frac{v}{70}\ ; \qquad v \geq 70 \text{km/h}$$

At other driving conditions the emission for passenger cars varies for low speeds between 2 dB(A) lower and 5 dB(A) higher and for trucks between 5 dB(A) lower and 1 dB(A) higher.

From the resulting sound level at short distance according to [22] and eq. (1) follows:

$$L_{Aeq} = E + 20 - 10\lg 2d = L_W^{/} - 10\lg d - 3 \qquad (7)$$

$$L_W^{/} = E + 20$$

4.1.5 A

The emission in [19] is expressed in the equivalent continuous A-weighted sound pressure level for a line source at a distance of 1 m, $L_{eq,1\,m}$ for five categories of vehicles and three categories of road surfaces.With 1 vehicle per hour this term for freely flowing traffic on normal asphalt follows for passenger cars (p) and heavy trucks (t) from:

$$\begin{aligned} L_{eq,1m,p} &= 47 + 26{,}2\lg\frac{v}{50} \\ L_{eq,1m,t} &= 59 + 21{,}5\lg\frac{v}{50} \\ v &\geq 50\ \text{km/h} \end{aligned} \tag{8}$$

For other road surfaces both the constant as the velocity power is different.

From the resulting sound level at short distance according to [19] and eq. (1) follows:

$$\begin{aligned} L_{Aeq} &= L_{eq,1m} - 10\lg d + 3 = L_W' - 10\lg d - 3 \\ L_W' &= L_{eq,1m} + 6 \end{aligned} \tag{9}$$

For slopes above 8% a correction is applied of up till 3 dB for passenger cars. For trucks a correction is applied for slopes above 4% up till 8 dB (up-hill) and 4 dB (down-hill).

4.1.6 SCAN

The emission in [25] is expressed in the equivalent continuous A-weighted sound pressure level for a line source at a distance of 10 m, $L_{eq,10\,m}$ for passenger cars and heavy trucks. With 1 vehicle per hour this term follows for passenger cars (p) and heavy trucks (t) from:

$$\begin{aligned} L_{eq,10m,p} &= 38 + 30\lg\frac{v}{50} \\ L_{eq,10m,t} &= 48 + 20\lg\frac{v}{50}\ ;\ v \leq 90\ \text{km/h} \\ v &\geq 50\ \text{km/h} \end{aligned} \tag{10}$$

From the resulting sound level at 10 m distance according to [25] and eq. (1) follows:

$$L_{Aeq} = L_{eq,10m} - 10\lg\frac{d}{10} = L_W^{\prime} - 10\lg d - 3$$
$$L_W^{\prime} = L_{eq,10m} + 13 \qquad (11)$$

4.1.7 Comparison for road traffic

In figure 1 and 2 the emission levels as used in the different countries are compared as a function of speed. It can be concluded that the differences are quite large. The differences seem larger than could be explained by differences in composition of the vehicle park. Remarkable are the differences with regard to the velocity dependence for heavy trucks. The lower levels at higher speed for the Dutch model are the result of the slightly positive linear dependence of the maximum pass-by level on speed, which is counter-balanced by the negative dependence on the logarithm of the speed for the equivalent level.

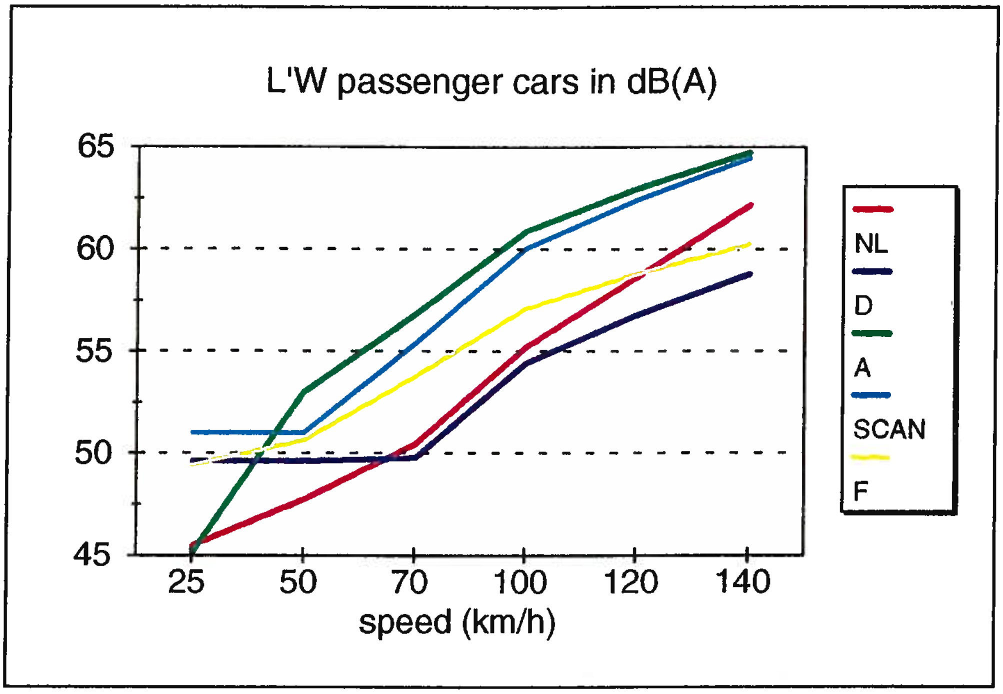

Figure 1: Comparison of emission by passenger cars.

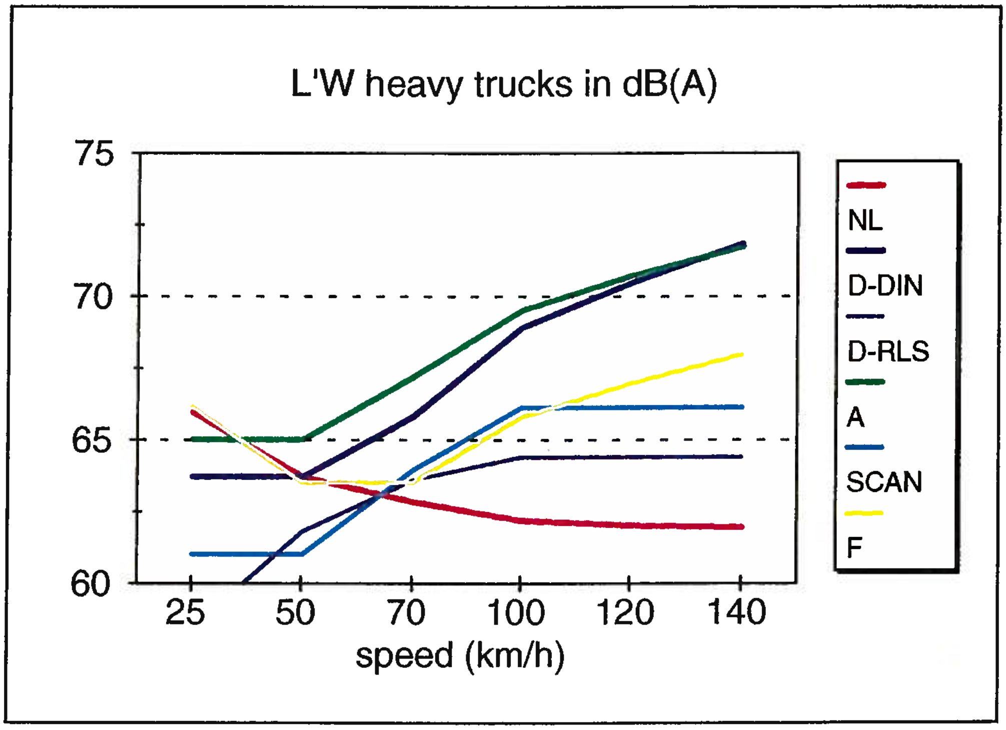

Figure 2: Comparison of emission by heavy trucks.

4.2 Rail traffic

4.2.1 Definitions

The emission of rail noise is given in the various countries for various categories of trains as function of the speed and corrections for the condition of the track. Normally the emission is specified as an A-weighted level, sometimes also in octave bands. We will restrict ourselves to A-weighted levels.
As with road traffic the quantity used to express the emission varies (sound power level or related quantity, equivalent sound pressure level). For comparing the emission the same approach can be used for rail traffic noise as for road traffic noise. That is by transposing the data to the sound power per unit length of line source. For rail traffic we will not present a summary of the emission as given in the various models, since these are related to specific descriptions of the national train categories. We restrict ourselves to the translation relations.
A complicating factor is that also the unit to which the emission refers varies: number of trains, length of trains or number of train units. It is chosen to refer the sound power to 1 train passage per hour, assuming were needed a fixed value for train length. Consequently the comparison is of course not as accurate as for road traffic noise. Furthermore, the trains and tracks are normally more a national product than is the case with cars and roads.

4.2.2 NL

The emission in [4] is expressed in the emission term E in dB(A) of a train unit for several train categories. With 1 train per hour, assuming a passenger train consists of four units and a goods train of 24 units, with a flat track of continuously welded rail in ballast then follows:

$$L_W' = E + 4{,}8 + 10 \lg (4 \text{ or } 24) \qquad (12)$$

For other track conditions the emission increases up till 7 dB(A).

4.2.3 D

The emission in [9,15] is expressed in the equivalent continuous A-weighted sound pressure level for a line source at a distance of 25 m, L_{Am}, for three categories of trains [9] or for a train with 100 m length depending on the type of brakes [15], in dependence of the number of trains per hour. These values refer to the normal speeds for the category without further indication of the track conditions. With 1 train per hour then follows:

$$L_W' = L_{Am} + 17{,}4 \qquad (13)$$

4.2.4 A

The emission in [18] is expressed in the equivalent continuous A-weighted sound power level per meter train, L'_{WA}, for several categories of trains as function of the train speed. These values refer to the normal track conditions. With 1 train per hour, assuming a passenger train length of 100 m and a goods train length of 600 m, then follows:

$$L'_W = L'_{WA} + 10\lg\frac{\text{length}}{1000} - 10\lg v \qquad (14)$$

where v is the speed in km/h.

4.2.5 SCAN

The emission in [26] is expressed in the 24 hour equivalent continuous A-weighted sound pressure level L for a reference situation at 100 m distance with a total length of passing trains of 1000 m at a speed of 80 km/h. The reference situation is a long straight track with continuously welded rail. With 1 train per hour, assuming a train length of 100 m, then follows:

$$L'_W = L + 27 + 23{,}5\lg\frac{v}{80} \qquad (15)$$

For one type of train in Norway the emission is 3 dB(A) lower. For other track conditions the emission can be 3 to 6 dB(A) higher.

4.2.6 Comparison for rail traffic

In figure 3 and 4 the emission levels as used in the different countries are compared as a function of speed. It can be concluded that the speed dependence is quite comparable; the spread in level is however quite large. Certainly a part of this spread will be due to real differences between types of trains and/or track conditions. The differences are however also influenced by the necessary assumptions about average train length.

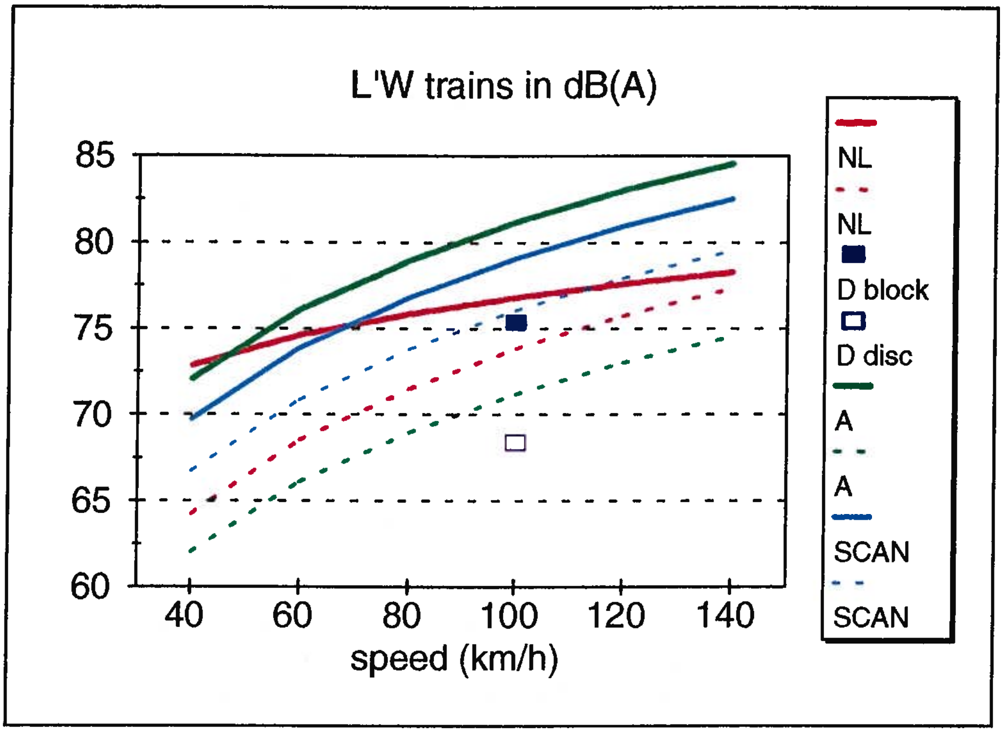

Figure 3: Comparison of emission by passenger trains (lower and higher values of different categories per country).

Figure 4: Comparison of emission by goods trains.

4.3 Industrial activities

Due to the large variety of sources and industrial situations their are no fixed values for the sound emission by industrial activities. The emission is normally expressed as the sound power level of the sources taking into account directivity of sources if relevant. The measurement methods to determine the sound power level vary, depending on the type of source. For small sources reference is made to international measurement standards (ISO), for other sources a variety of methods is available and sometimes prescribed in regulations and guidelines.

4.4 Air traffic

The emission of aircrafts is normally given in national databases, giving the sound level as function of aircraft type and power setting, either at a specified distance or as function of the (horizontal) distance. In the latter case these emission data include the propagation effects due to distance and air absorption. These databases are often based on a mixture of results from type approval measurements and in-situ measurements. According to [32] the differences between the Dutch and German database varies between about 0 and 2 dB(A).
Several aspects influence the actual noise emission of aircraft during operation:
- the variation in individual engine operating conditions;
- the variation due to actual operating weight;
- influence of meteorological conditions on the engine operating conditions;
- directivity of the sound emission (including shielding by the aircraft fuselage);
- ground roll (landing and take-off), use of thrust reversal.

The different prediction models tend to take only part of these aspects into account.

4.5 Summary emision level

A summary of the principle emission quantities used is given below.

SOURCE EMISSION	road traffic	rail traffic
ISO	point sources with L_W + D	
NL	line source L'_W ; D=0	line source L'_W ; $D_{horizon.} = \cos^2 \varphi$
D	line source $L_{eq,25\ m}$; D=0	line source $L_{eq,25\ m}$; D= 0
F	line source L'_W ; D=0	-
A	line source $L_{eq,\ 1\ m}$; D=0	line source $L'_{W,train}$; $D_{horizon.} = \cos^2 \varphi$
SCAN	line source $L_{eq,10\ m}$; D=0	line source $L_{eq,ref.situ}$; D= 0

	industry	air traffic
ISO	point sources with L_W + D	
NL	point source L_W +D	$L_{A,max}$ at specified distance / power setting
D	point source L_W +D	$L_{A,max}$ at specified distance / power setting
F	-	$L_{PN,max}$ at specified distance / power setting
A	point source L_W +D	$L_{A,max}$ at specified distance / power setting
SCAN	point source L_W + D	L_{AE} and $L_{A,max}$ at specified distance / power setting

In the various countries the emission level for all traffic sources is expressed in different, though more or less related, quantities. Quite often the emission quantity contains a part of the sound propagation. This makes a direct comparison not straightforward.

For road traffic noise the emission levels seem to vary much more than is to be expected. For rail traffic noise this might also be the case, though the comparison is less decisive. For aircraft noise a first indication is that the emission levels do not vary much, though there are small differences for exactly the same aircraft type.

5 SOUND PROPAGATION

5.1 Road and rail traffic, industry

5.1.1 NL

The propagation model is a general propagation model in octave bands for point sources, with some fixed parameters for the different applications. The most general form is applied to industrial activities. The propagation is predicted for point sources, characterized by their sound power level in the relevant direction, under down wind meteorological conditions. The attenuation due to distance, air absorption, ground condition, screens (including the interaction with the ground effect), vegetation and industrial areas is taken into account .

For road traffic short sections of the road are represented by a point source; the length and orientation of the road section is taken into account through the attenuation by distance. The source height (0,75 m) and the width of the ground region near the source (70 m) are fixed. Only screens at one side of the road can be calculated.
From the octave band model a model in dB(A) is deduced for simple situations, taking into account distance, air absorption and attenuation due to the ground. For the effect of screens only indications are given.

For rail traffic short sections of the track are represented by point sources; the length and orientation of the track section is taken into account through the attenuation by geometrical spreading as is the directivity of the source in the horizontal plane ($\cos^2 \varphi$). Two source heights (0,0 and 0,5 m above rail) and the width of the source area (15 m) are fixed. The effect of screens can only be calculated for screens with an absorbing side to the track.
From the band model a model in dB(A) is deduced for simple situations, taking into account distance, air absorption and attenuation due to the ground. For the effect of screens only indications are given.

5.1.2 D

The propagation model [9] considers road and rail traffic as line sources [14,15] and industrial noise as point sources. It deals primarily with attenuation in dB(A) due to distance, air absorption, ground effect and screening in relation to a reference situation (sound emission). The propagation terms for these effects are based on measurements. Additional information is given for dealing with attenuation due to vegetation and build-up areas. In [12] models are given for the attenuation due to screens taken into account the interaction with attenuation due to the ground effect. In [13] a model is presented for the noise from industrial activities which is more in line with the ISO-model.

5.1.3 F

For road traffic noise a model for down-wind propagation is being developed along the lines of ISO 9613 with a different approach for screening. A model for propagation under neutral conditions exists which is based on a theoretical treatment for point sources of the effects due to air absorption, ground effect and screening.

5.1.4 A

For road traffic, rail traffic and industrial activities a propagation model is applied in octave bands which follows closely the Dutch models. Models in dB(A) is deduced from the octave band model.

5.1.5 SCAN

For road traffic the propagation model [25] in dB(A) is deduced from a theoretical model for the propagation effects of ground and screens for point sources under neutral propagation conditions and specifies these effects in relation to a reference situation (sound emission).

For rail traffic the propagation model [26] in dB(A) is an empirical/ theoretical model for the propagation effects of ground and screens under down wind propagation conditions in relation to a reference situation (sound emission). It takes into account the interaction between screens and ground.Indications of the sound pressure spectrum can be deduced from the level in dB(A).

For industrial activities the propagation model [27] is a model in octave bands which follows closely the Dutch model.

Work is in progress to renew the three models and bring them more in line with each other.

5.1.6 Comparison for road and rail traffic, industry

Fi ures 5, 6, 7 and 8 compares the excess attenuation according to some of the dB(A)-models for road traffic, rail traffic and industrial noise for the situation without screens. The excess attenuation is the attenuation relative to the attenuation due to distance over a perfectly reflecting ground for a long line source (10 lg 2d). The differences between the models for absorbing ground are up to about 5 dB(A).

Figures 9 and 10 compares the attenuation due to a screen for road traffic according to some of the models. The Scandinavian and German models are dB(A)-models for the considered source. For the others the calculation is done in octaves and the result expressed in dB(A) according to a typical road or rail traffic spectrum shape. In these figures the interaction between ground effect and screening is not considered.The differences between the models for screening are up to about 5 dB(A).

The differences between the attenuation models is only partly due to different assumption about the meteorological conditions.

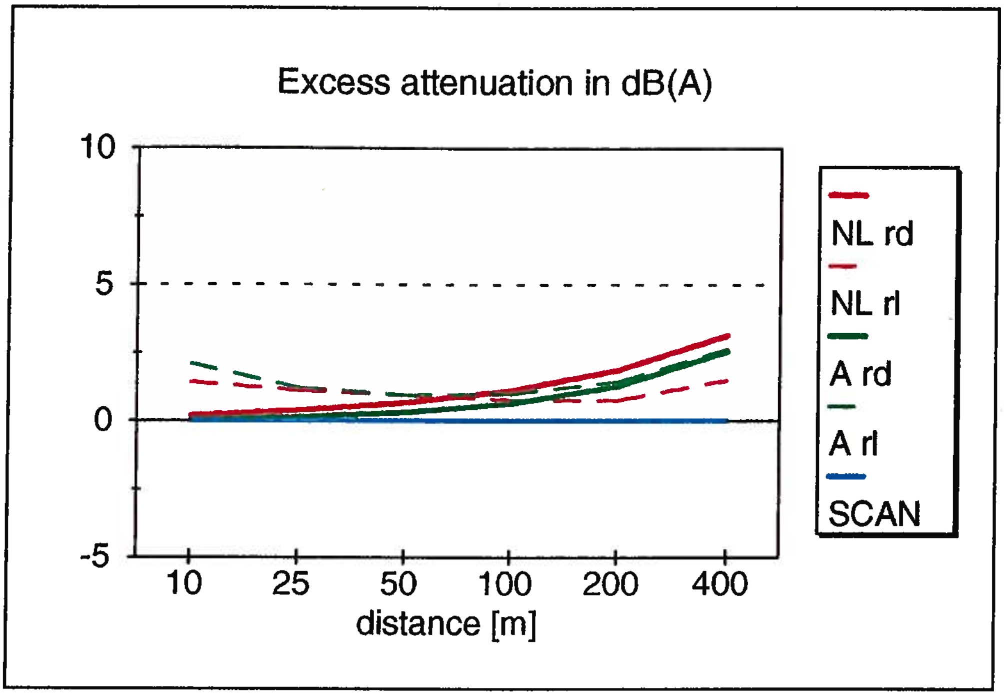

Figure 5: Comparison of excess attenuation for **road traffic** by ground and air for a **hard ground** surface and downwind propagation.

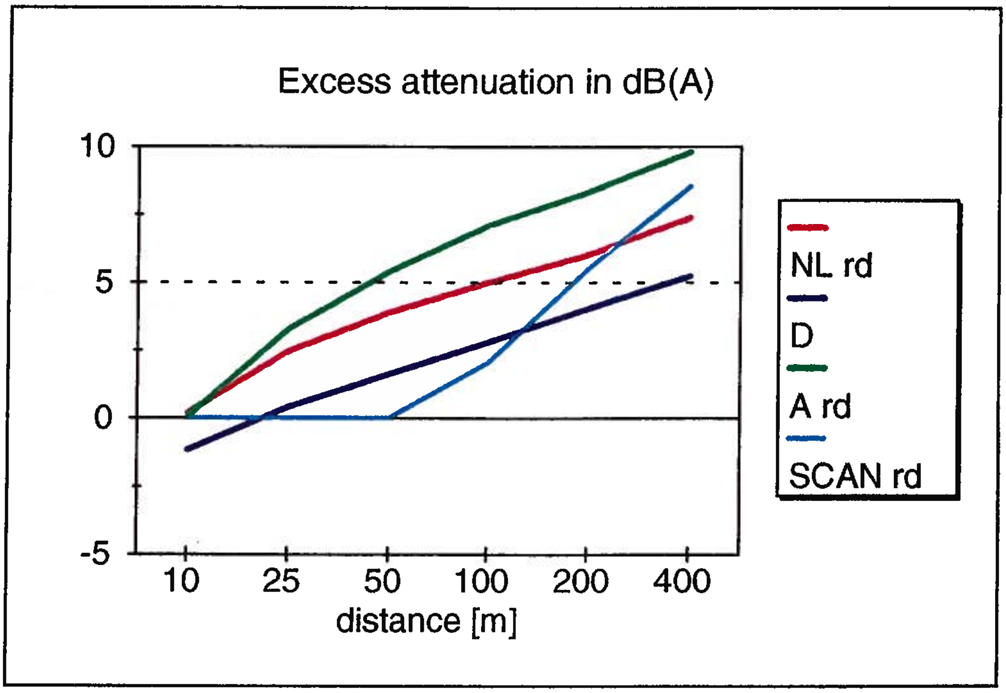

Figure 6: Comparison of excess attenuation for **road traffic** by ground and air for an **absorbing ground** surface and down wind propagation.

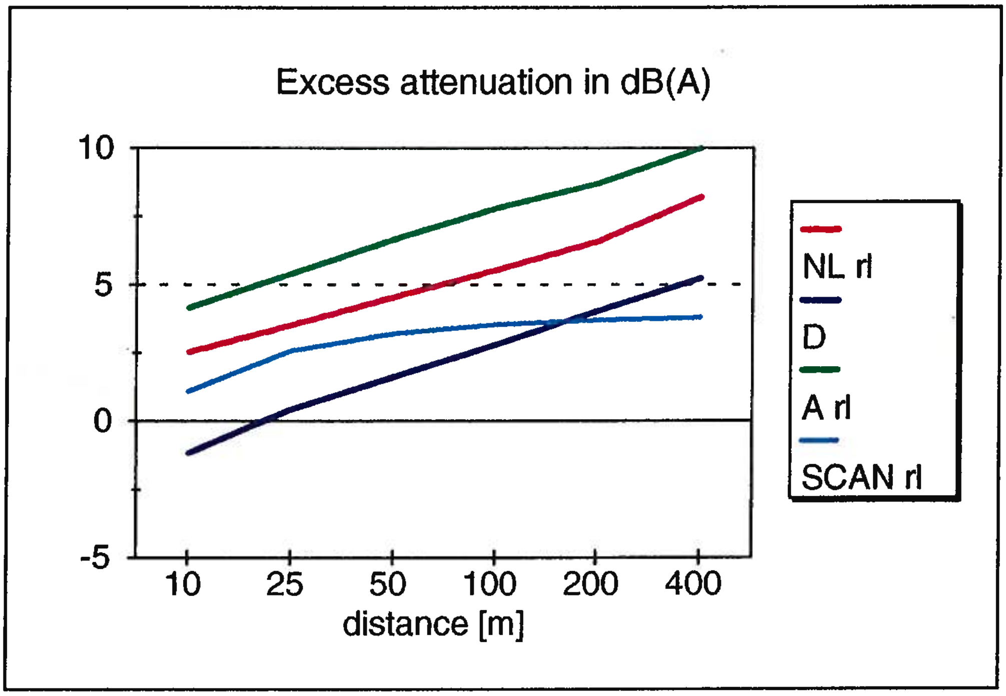

Figure 7: Comparison of excess attenuation for **rail traffic** by ground and air for an **absorbing ground** surface and down wind propagation.

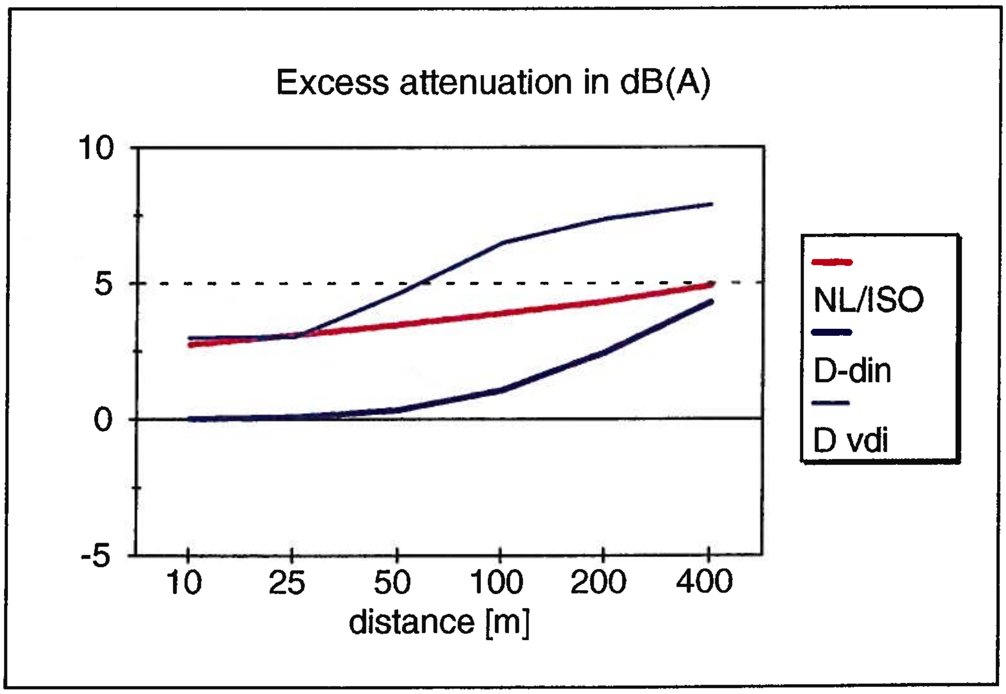

Figure 8: Comparison of excess attenuation for **industrial noise** by ground and air for an **absorbing ground** surface and down wind propagation.

Remark: *The German model (DIN) does not differentiate between hard and absorbing ground and road or rail traffic.*

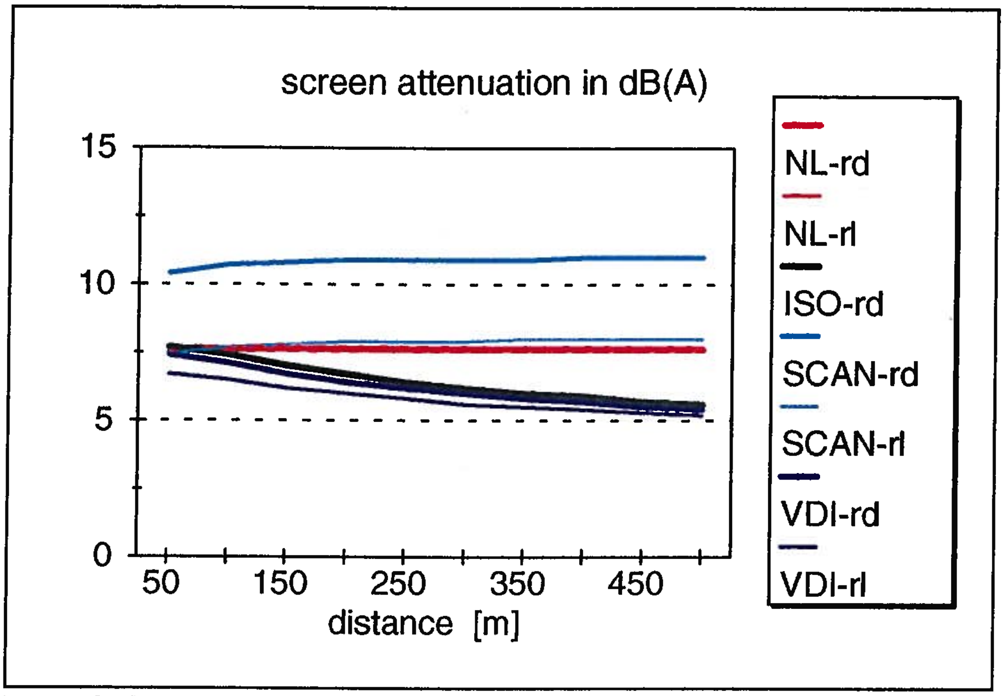

Figure 9: Comparison of attenuation due to a screen of 2 m at 10 m distance from the line source; **receiver height 2 m.**

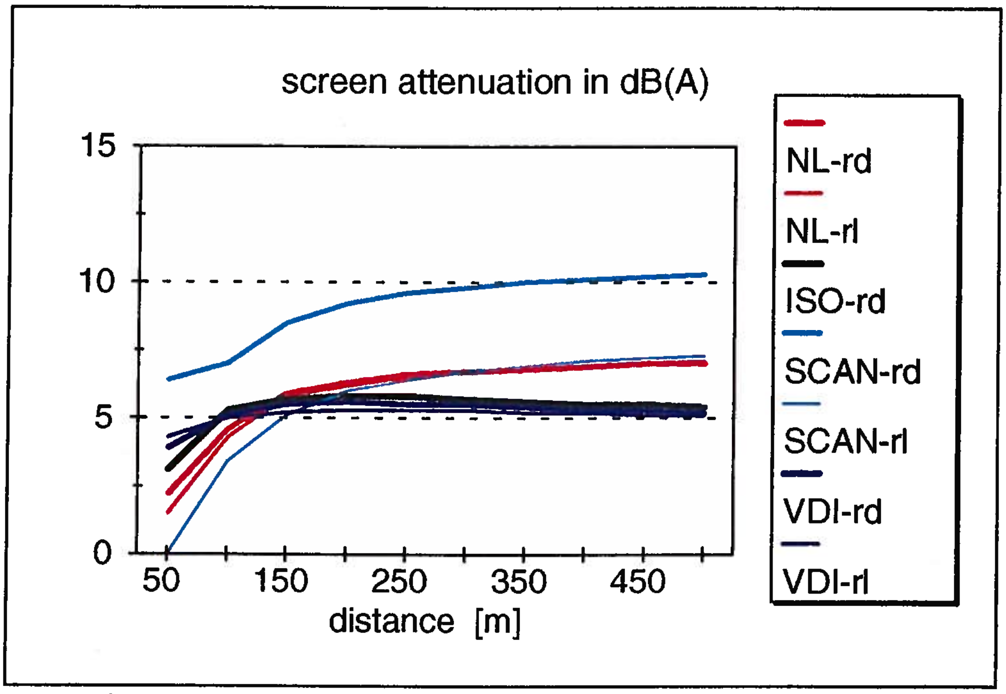

Figure 10: Comparison of attenuation due to a screen of 2 m at 10 m distance from the line source; **receiver height 10 m.**

5.2 Air traffic

The various prediction models all construct nominal flight paths to determine the distance at a given time after take-off or before landing from which the sound level reduction is deduced, taken into account distance, air absorption and ground effects. With the given emission at that time the sound pressure level as function of time is determined from which follows either the maximum level during that flight or the equivalent level. Various aspects which influence the sound propagation are:

- variation around the nominal flight path, both horizontal as vertical, influencing the actual distance;
- meteorological conditions, like wind speed and direction;
- ground effects and effects of topology.

In the various models all or some of these effects are taken into account, the details of the approach varying. The effect of shielding by the aircraft fuselage is sometimes taken into account as an emission directivity (see 4.4) and sometimes as a propagation effect.

As an example figure 11 gives the lateral attenuation over ground for moderate downwind for elevation angles of 0° and 10°, according to the Dutch, German and Nordic prediction model. For higher elevations than around 20° the attenuation reduces to zero. The differences become quite large at distance, which could be partly due to the different basic data used for these parts of the models [8,16, 29].

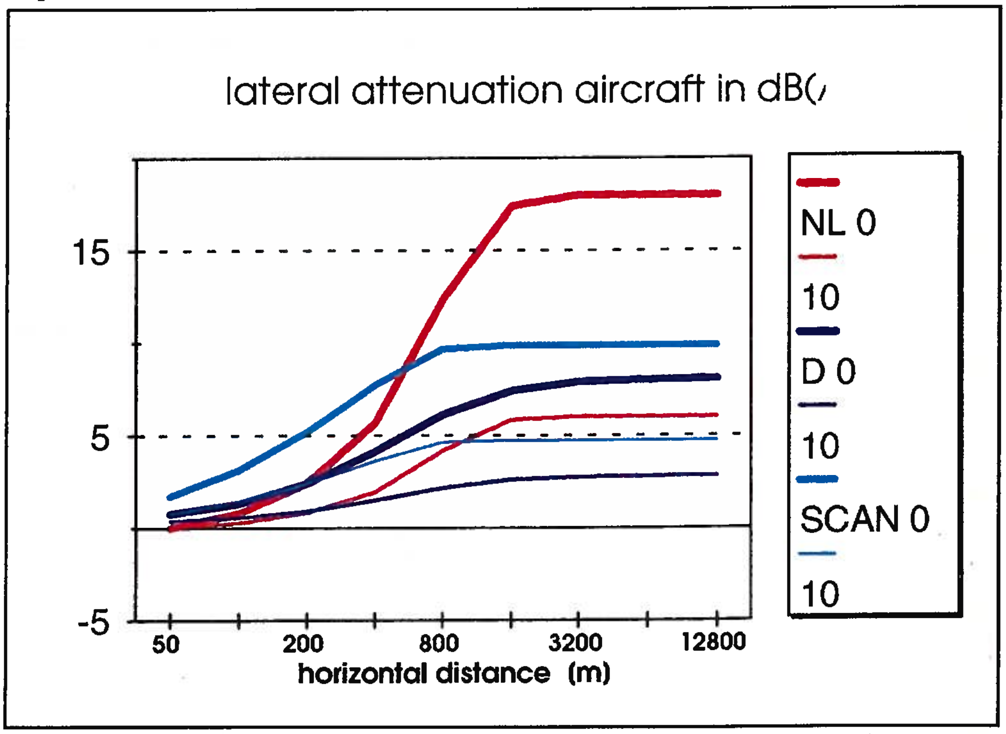

Figure 11: Comparison of lateral attenuation (ground effect) for aircraft noise with distance at two elevation angles (0° and 10°) for three models (NL, D, SCAN).

5.3 Summary sound propagation

A summary of the way in which the different aspects are treated by the various models is given below.

PROPAGATION		distance	air	ground
ISO	octave (dBA) all sources	$10\lg\ 4\pi\ r^2$	αr	NL/DK-model dBA-model
NL	octave (A) RD, RL IN	line: $10\lg\ 4\pi d/\theta$ point: $10\lg\ 4\pi\ r^2$	αr "	NL-model "
	AIR - dBA	point: function of r, elevation, directivity		
D	dBA RD, RL IN	line: $+14\lg r - 10\lg \theta$ point: $10\lg\ 2\pi r^2 + 3{,}5\lg(1+10^{-4}r^2)$		
	octave IN	point: $10\lg\ 4\pi\ r^2$	αr	empirical or NL/DK-model
F	octave (A) RD, RL	point: $10\lg\ 4\pi\ r^2$	αr	NL/DK-model + theoretical (neutral)
A	octave (A) RD, RL IN	line: $10\lg\ 4\pi d/\theta$ point: $10\lg\ 4\pi\ r^2$	αr "	NL/DK-model "
SCAN	RD - dBA RL - dBA IN - octave	line: $10\lg\ 4\pi d/\theta$ line: $10\lg\ 4\pi d/\theta$ point: $10\lg\ 4\pi\ r^2$	 αr	theoretical (neutral) deduced from IN NL/DK-model
	AIR - dBA	point: function of r, elevation, directivity		

PROPAGATION		screen	various	reflection
ISO	octave (dBA) all sources	D-model dBA-model	forrest, build-up areas βr downwind	mirror Source mirror Receiv
NL	octave (A) RD, RL, IN	'Maekawa'+downwind	βr downwind	mirror S
D	dBA RD, RL, IN	empirical, downwind	βr, limited	mirror S/R
	octave IN	empirical, downwind	βr downwind	mirror S/R
F	octave (A) RD, RL	adjusted ISO-model	?	mirror S/R
A	octave (A) RD, RL, IN	'Maekawa'+downwind	βr downwind	mirror S/R
SCAN	RD - dBA RL - dBA IN - octave	theoretical (neutral) deduced from IN 'Maekawa'+downwind	- - βr downwind	- - mirror S

A = dB(A)-model deduced from octave band model; dBA = model in dB(A)
RD= road traffic, RL= rail traffic, IN = industry, AIR= air traffic
r = direct distance source-receiver.
d = perpendicular distance receiver- line source section.
θ = opening angle line source section.
α = attenuationcoefficient air, dB/m or dB(A)/m; not necessarily identical for all models.
β = attenuation coefficient scattering area (forrest, buildings, industrial site), dB/m or dB(A)/m; not necessarily identical for all models.

6 CONCLUSIONS

Immission

The basis for the rating level for environmental noise in most countries is the long term equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$(LT) in the free field. In some countries this is the case already now, in others the regulations are being changed in this direction. Only for air traffic noise also other rating levels are in use, with a different weighting of the number of operations. However, the considered reference time intervals differ between types of sources and between countries as do the adjustments to the level (or the difference in requirement) for the different time intervals.

The relevant source conditions (intensity, working conditions, period of averaging) for measurement or calculation of the immission, differ between countries and source types and seem to be not always clearly specified.

For noise from industrial activities generally adjustments for tonal character or impulsiveness are included in the rating level, though not always in the same way. In some countries adjustments are also applied for some forms of traffic noise.

Emission

In the various countries the emission level for all traffic sources is expressed in different, though more or less related, quantities. Quite often the emission quantity contains a part of the sound propagation. This makes a direct comparison difficult.

For road traffic noise the emission levels show differences of 5 to 10 dB(A), which seems to be much more than could be expected on the basis of differences in vehicle park. For rail traffic noise the differences are of the same order, though the comparison is less decisive. For aircraft noise a first indication is that the basic emission levels do not vary much, but the effects of actual operation conditions and directivity are taken into account in more or less detail.

Propagation

The propagation models for all noise sources vary in the aspects taken into account and the details of the formulations. This is partly due to the age differences of these models.

As an indication, the propagation over absorbing ground results in differences in attenuation of up to about 5 dB(A) and the effect of screens also results in differences up to about 5 dB(A). These differences are only partly due to different assumptions about the meteorological conditions.

The observed differences in emission and propagation models cancel each other only partly, resulting in differences in the predicted immission up to 10 dB(A).

7 PROPOSAL FOR A HARMONIZED APPROACH

For the rating level, the level to which requirements apply, it would be beneficial if a clear and consequent distinction is made between the basic sound level and the various possible adjustment terms, like 'railway bonus', tonal character, nighttime penalty and such. Since almost all countries consider the free field situation, the reflection by the facade could best be considered as an adjustement term also. In that way a comparison between rating levels with different national or local adjustments, will be much easier.

The best choice for the basic sound level for all types of environmental sources would be the already largely accepted long term averaged equivalent continuous A-weighted sound pressure level, L_{Aeq} (LT), over the relevant reference time interval T. This level can be determined directly, but more conviniently follows from the downwind level, L_{Aeq} (DW), and an adjustment for the long term meteorolocial conditions (C_{meteo}). The applied relevant time intervals do vary at the time as do the appropriate operating conditions of the sources. As far as these reflects real national or local differences this is of course realistic, though a slight handicap for comparing rating levels. For comparisons these differences can be corrected for, without too large an error.
So the rating level for a time interval T could be:

$$L_{r,T} = L_{A,eq,T}(DW) - C_{meteo} + K_{tone} + K_{pulse} + K_{source\ charact} + K_{facade} + \ldots + K_{various} \qquad (16)$$

where the interval T and all the adjustement terms (C, K) should be as much harmonized as is realistic.

For the prediction of the equivalent sound level it would be beneficial if a clear distinction is made between source emission and sound propagation. In that way it is much easier to use results from various studies to improve and extend prediction models and to gather source emission data.
The propagation model should at least take into account the following aspects:
- geometrical divergence
- air absorption
- ground effect for various ground types and topology
- screening
- attenuation by build-up areas, woods etc
- meteorological influences

dealing also with the interaction, where relevant, between these aspects. It should at least deal with these effects for down wind propagation.
This approach is in line with ISO 9613 which forms a good basis for the development of a harmonized model for all environmental sources.

So the model could look like:

$$L_{A,eq,T}(DW) = L_W + D - A$$
$$A = A_{div} + A_{atm} + A_{ground} + A_{screen} + A_{misc} \qquad (17)$$

In order to minimize discrepancies it is advisable to deduce any dB(A)-model directly from a model in frequency bands.

The description and definition of the models should be such that future improvements of elements is kept possible. This is especially relevant for the interaction between the mentioned aspects and the influence of meteorological conditions. Much more is already known about these aspects than is included in the excisting models like ISO 9613.

An effort should be made to construct the same emission model for the same type of sources, like road traffic, aircraft and, partly, trains. This should include at least the emission quantity, the basic set-up for emission measurements, the methodology to deduce the emission quantity from measurements and the relevant independent parameters describing the source.

Delft, 1996-07-10

TNO Institute of Applied Physiscs

prof. ir. E. Gerretsen

LITERATURE

ISO

[1] ISO 1996, Acoustics - Description and measurement of environmental noise, 1987.

[2] ISO/DIS 9613-2, Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation, 1994.

NL

[3] Reken- en Meetvoorschrift Verkeerslawaai, Staatsuitgeverij, 1981

[4] Reken- en Meetvoorschrift Railverkeerslawaai, MVROM, 1987

[5] Handleiding meten en rekenen industrielawaai, ICG-rapport IL-HR-13-01, 1981.

[6] Voorschrift voor de berekening van de geluidbelasting door grote vliegtuigen, Besluit LI/5198, Stcrt 1987, 165 en ICG-rapport LL-HR-20-01, 1980.

[7] Besluit geluidbelasting kleine luchtvaart, Stb. 1991, 22.

[8] Rozema, D.J. and A. Moerkerken, Methode voor de berekening van de laterale geluidverzwakking als onderdeel van de berekening van vliegtuiggeluid (modified model based on SAE AIR 923:1966), NLR TR 79072 L, 1979.

D

[9] DIN 18005, Schallschutz im Städtebau - Berechnungs- und Bewertungsgrundlagen, 1987

[10] Verkehrslärmschutzverordnung - 16.BimSchV

[11] VDI 2058, Beurteilung von Arbeitslärm in der Nachbarschaft

[12] VDI 2720, Schallschutz durch Abschirmung im Freien, entwurf 1987

[13] VDI 2714, Schallausbreitung im Freien, 1980

[14] RLS 90, Richtlinien für den Lärmschutz an Strassen, 1990.

[15] SCHALL 03, Richtlinie der Deutschen Bundesbahn zur Berechnung der Schallimmission von Schienenwegen, 1990.

[16] Anleitung zur Berechnung von Lärmschutzbereichen an Zivilen und militärischen Flugplätzen nach dem Gesetz zum Schutz gegen Fluglärm, BGBl I S.282, 1971.

A

[17] ÖAL-Richtlinie 28,Schallabstrahlung und Schallausbreitung ,1987.

[18] ÖNORM 5011, Berechnung der Schallimmission durch Schienenverkehr, Zugverkehr, Verschub- und Umschlagbetrieb, 1995.

[19] Lang, J., A new model to calculate road traffic noise in Austria, draft publication.

F

[20] Arrête relatif au bruit des infrastructures routieres, 1995.

[21] NF- S31-085, Caractérisation et mesurage des bruits de l'environuement, 1985

[22] Guide du Bruit des transports terrestres

[23] Décret relatif á la lutte contre les bruits de voisinage et modifiant le code de la santé publique, 1995.

SCAN

[24] Informal note on quantities used to decribe some types of environmental noise in Scandinavia, DELTA Acoustics & Vibration AV 669/96.

[25] Beräkningsmodell för vägtrafikbuller, report Naturvardsverket,1989

[26] Noise from railway traffic, KILDE-report 1984

[27] Environmental noise from industrial plants, Lydteknisk Laboratorium report 32, 1982

[28] Nord 1994:38, Air traffic noise calculation - Nordic guidelines, 1993.

[29] SAE AIR 1751, Prediction method for lateral attenuation of airplane noise during take-off and landing, 1981.

general

[30] Large, J.B. and M.E. House, The status of airport noise prediction, with special reference to the United Kingdom and Europe', Noise Control Engineering, 1981.

[31] Jonkhart, S., The existing methodologies for the calculation of aircraft noise load in the EEC member states, Internoise '93, Leuven, 143.

[32] Isermann, U., An investigation on the difference between noise measurements and calculations performed at Amsterdam Schiphol airport for 1992, report ...., 1995.