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RAILWAY NOISE PREDICTION MODELS: A COMPARISON

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This paper represents a comparison between some European prediction models for rail traffic noise. These models are from Austria, Denmark, France, Germany, The Netherlands, Norway, Sweden, Switzerland and the U.K. In the propagation part the ISO 9613-2 is also considered. The comparison of the noise emission gives results for disc- and block-braked passenger trains and for freight trains. For purposes of comparison the propagation model is divided according to the usual attenuation elements including geometrical spreading, atmospheric attenuation, ground attenuation, screening attenuation and reflections. These attenuation effects are compared separately.

1. INTRODUCTION

Most railway noise prediction models in Europe have been developed by either the national railway company, a local research institute, or the national Ministry of Environment or Traffic. All these institutions had their own points of view about acoustical matters, which did not necessarily match those of the neighbouring countries. In addition, most countries have their own regulations, acts and laws, which influence the prediction standard. The time at which the prediction models was defined has determined the form of the model. This automatically implies that when a model was designed when computers were widely used, more complex formulae could be used.

When the model was developed, most countries took a set of their own measurement data as a starting point. These data were used to develop the formulae. The extension to include less or more variables will result in different calculated values; the use of national data sets is therefore of great interest. Variations in the noise emission of comparable trains on a comparable rail construction gives information about the accuracy of the measurements and the accuracy of noise prediction.

The comparison is made between models from

- Austria—Önorm S5011/ÖAL28 [1, 2];
- Denmark—Beregning af støj fra jernbaner [3];
- France—Guide du bruit [4];

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- France—Mitra-Fer [5];
- Germany—Schall 03 [6];
- The Netherlands—SRMII [7];
- Norway—NMT Norwegian trains [8];
- Sweden—NMT Swedish trains [9];
- Switzerland—Semibel [10];
- UK—Ashdown [11];
- UK—Department of Transport [12].

In the propagation part, ISO 9613-2 "Attenuation of sound during propagation outdoors—Part 2: General method of calculation" [13] is also considered.

This investigation has been carried out and reported [14] by *dgmr* consulting engineers in The Hague on the request of the European Rail Research Institute, Working Committee 6.

2. GENERAL SET-UP OF A PREDICTION MODEL

The relation between sound pressure level and the sound power level is equal to

$$L_p = L_w + \sum \Delta_{propagation\ factors} \quad \text{in dB or dB(A)},$$

where L_p is the calculated noise level, L_w is the sound power level of the source and $\sum \Delta_{propagation\ factors}$ is the summation of the total of all the attenuation and corrections due to propagation.

This means that a prediction model can be split into two main parts. The first part is the source description. This part gives a description of all the important factors concerning the position of the source or sources, as well as the calculation of the noise emission depending on, for example, the type of train and its speed and the construction of the track. A description of all the propagation models is given in the second part. As a general principle all noise will propagate uniformly but there is a wide variety of assumptions for railway noise.

The most general set-up of a propagation model with the $\sum \Delta_{propagation\ factors}$ is, in principle, composed with the following parts:

Δ_{geo}	the attenuation as a result of the geometrical spreading
Δ_{air}	the attenuation as a result of air absorption
Δ_{ground}	the attenuation due to the ground absorption
$\Delta_{barrier}$	the free-field-diffraction attenuation of a barrier
$\Delta_{reflections}$	the contribution of the sound level due to reflections
Δ_{meteo}	the correction due to the meteorological effects

There is another difference in the method of calculating the sound pressure level at the receiver. Some calculation models calculate the total level in dB(A) directly, while others calculate the source level and the propagation per octave frequency band.

The track can be modelled in the propagation models in two different ways. The first is to use the track as a line source and evaluate the propagation effects starting from the perpendicular distance between the line source and the receiver. Since the

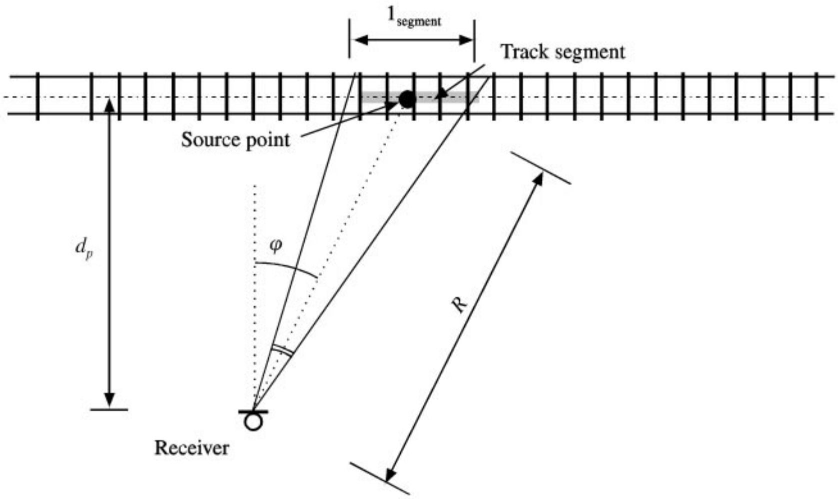

Figure 1. Division of the track into segments.

propagation from the line source to the receiver has to be the same over the whole area, this method is not common in most cases. The second method is to split up the line source into segments. These track segments are represented acoustically by point sources, for each of which the propagation to the receiver is evaluated separately. All contributions from the track segments are aggregated to give the total sound pressure level of one track. For each track segment, an angle of sight Φ can be defined. An example is given by Figure 1, where $l_{segment}$ is the length of the track segment, R is the distance from the point source to the receiver and φ is the angle between R and d_p.

3. COMPARISON OF THE SOURCE DESCRIPTION

3.1. Introduction

The sound power levels in the models are mostly given as an emission value on which corrections can be made to determine the sound power level. Once the emission level has been determined for each category, corrections can be made. The following formulae are then presented for the source level used in the calculation procedures:

$$L_{W,\,train\,unit} = E_{train\,unit} + C_{speed} \quad \text{in dB or dB(A)}$$

$$L_{W,\,train\,unit+corr} = L_{W,\,train\,unit} + C_{track} + C_{bridge} + C_{misc} \quad \text{in dB or dB(A)}$$

$$L'_{W,\,train\,units} = L_{W,\,train\,unit+corr} + 10\,\lg\left[\frac{Q}{v}\right] \quad \text{in dB/m or dB(A)/m}$$

$$L'_{W\varphi} = L'_{W,\,train\,units} + C_{DI} \quad \text{in dB/m or dB(A)/m}$$

where $L'_{w,\,\varphi}$ the directivity relevant sound power level in dB/m or dB(A)/m, E the sound emission of one train unit in dB or in dB(A), Q the number of train units passing per hour and v is the running speed of the train in km/h.

The emission value is used to describe the sound power level for a category and is dependent of the speed of the train. A correction must be made for the number of trains, for the speed of the train, the type of track and, if applicable, for a bridge. The miscellaneous correction is for added corrections, such as brake, superstructure, crossing and radius. These are all corrections that are dependent on the source itself. The angle correction is not only dependent on the source, but also on the distance and the other geometrical properties of the terrain between source and receiver. The directivity correction is also dependant on the height and the distance of the receiver and the source.

An overview of the determination of the source and the corrections used in the different models is given in Table 1.

3.2. SOURCE POSITION

The position of the source is basically determined by the height of the source above the railhead. All models, except for the two U.K. models, place the source at the centre of the track. The U.K. Department of Transport model places the source on the near side rail and the Ashdown model places the source on the centre of two tracks. The source position of the different models is shown in Figure 2.

These source positions can be divided in four groups. The first group assumes that the source is at the rail-wheel contact and is thus placed at the height of the railhead. The second group assumes that the source is at a height of the axle, and therefore placed at 0·5 m above the railhead. The third group assumes that the source is placed at a height of 0·8 m above the railhead and the fourth group assumes that the source is at a considerable distance above the railhead, for example 2 m. To use a frequency-dependent source height will complicate the calculations, especially when working with different source heights due to different trains.

3.3. SOUND RADIATION CHARACTERISTICS

Most models use an attenuation to describe the sound radiation characteristics. The formulae used by the models are shown in Figures 3 and 4. The Dutch model has this attenuation incorporated in the geometrical spreading, but the radiation characteristics can be filtered out easily. The U.K. DpT model has two directivity indexes, the first is for locomotives under full power, and the second is for all other trains, but is also a function of the angle of sight. An angle of sight of 90° gives a value that fits with the other indexes. When the angle of sight is 5°, the dipole effect is more dominant, but the attenuation is larger due to the smaller angle. Except for the French Mithra model, all other models have only a total directivity index in dB(A). Mithra has a directivity index which is different for every octave band frequency. The French Guide de Bruit model is the only one which has only a vertical directivity index, but not the horizontal one.

TABLE 1

An overview of the determination of the source and the corrections

	Frequency/ dB(A)	Type of source	Reference track sleepers	C_{speed}	C_{track}	C_{bridge}	$C_{DI, hor}$	$C_{DI, ver}$	Segment condition
Austria	Both	Point	Wooden/concrete	Yes	No	Yes	Yes	Yes	$l_{segment} < d/3$
Denmark	dB(A)	Line	Wooden/concrete	Yes	Yes	No	No	No	N/A (line)
France—GdB	dB(A)	In between	Not described	Yes	No	Yes	No	Yes	N/A (line)
Germany	dB(A)	Point	Wooden	Yes	No	Yes	Yes	Yes	$d/100 \leqslant l_{segment} \geqslant d/2$
Netherlands	Both	Point	Concrete	Yes	Yes	Yes	Yes	Yes	1°–5°
Nordic	Both	Point	Wooden/concrete	Yes	Yes	Yes	No	No	$l_{segment} < d/2$
Switzerland	dB(A)	Point	Wooden/concrete	Yes	Yes	Yes	Yes	Yes	9°
UK—DpT	dB(A)	Line	Wooden/concrete	Yes	Yes	Yes	Yes	Yes	N/A (line)

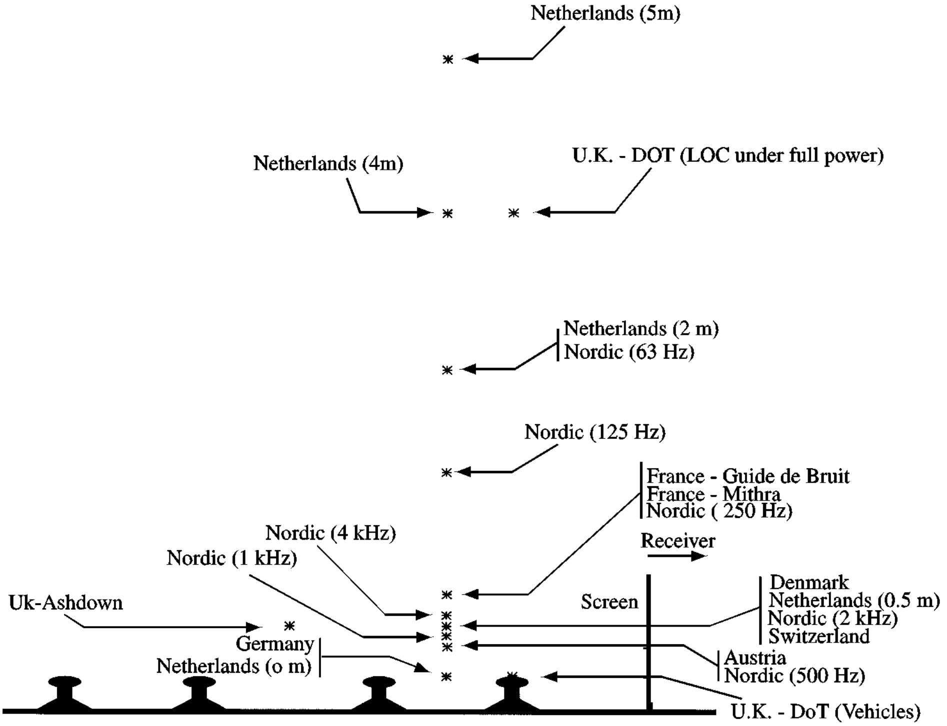

Figure 2. Comparison of the source position.

3.4. COMPARISON OF THE NOISE LEVELS AT 25 M

To compare the different models, a classification was made. Three classes are distinguished: disc-braked passenger train, tread-braked passenger train and freight train. For comparison of the source levels it is assumed that the passenger trains has a speed of 100 km/h and the freight trains have a speed of 80 km/h. The flow is 3600 vehicles/h, i.e., 1/s which is similar to the sound exposure level of one vehicle. No vehicles apply brakes. Normal conditions for track and superstructure, and no rail discontinuities are assumed. The length of one unit is 30 m for passenger trains and 15 m for freight trains. The mean values for the sound pressure level at 25 m of the centre of the track are shown in Figure 5.

The French Guide du Bruit and the Danish model do not include a disc-braked passenger train. The mean of the disc-braked passenger train lies around the 80 dB(A).

The mean of the block-braked passenger train lies around the 88 dB(A). The levels for tread-braked passenger trains are more evenly distributed than the levels for disc braked passenger trains; all levels lie within a range of 6 dB(A).

The sound pressure levels for freight trains lies around the 83–84 dB(A). The levels of freight trains lie within an acceptable range of 3·5 dB(A), which reflects the exchange of freight wagons between operators, and implies a similar mix of the vehicle fleet for most countries.

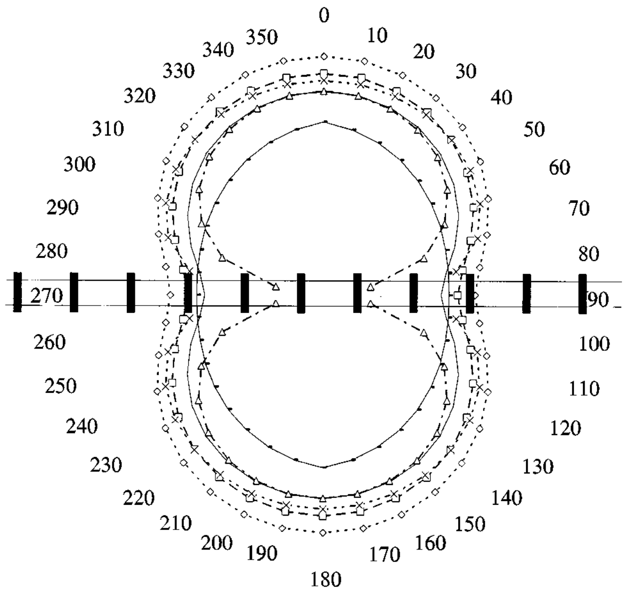

Figure 3. The horizontal directivity index: ——, Austria; – · –, Germany; · · · · ·, Switzerland; – · · – · · –, Netherlands; – ·×–, France-Mithra; —, UK-DOT.

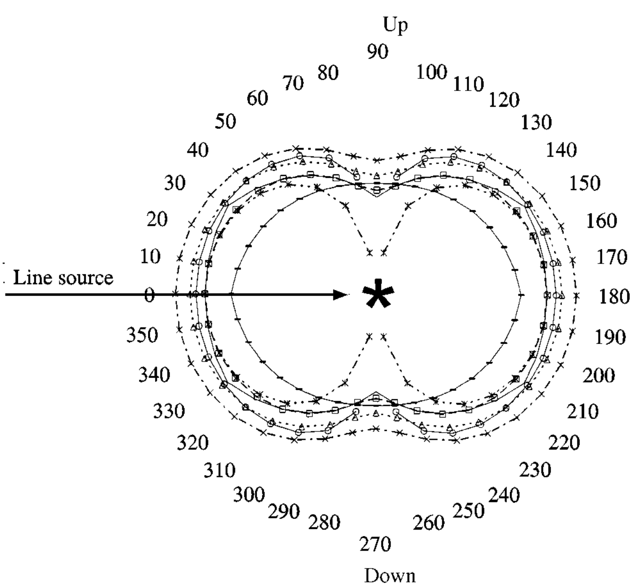

Figure 4. The vertical directivity index: ——, France-GdB; – – –, Austria; · · · · ·, Germany; – · ×– ·, Switzerland; – ·× –, Netherlands; ——, France-Mithra; ——, UK-DOT.

4. COMPARISON OF THE PROPAGATION MODELS

The propagation models can be analyzed by considering their attenuation terms separately. Most models use the following terms: geometrical spreading,

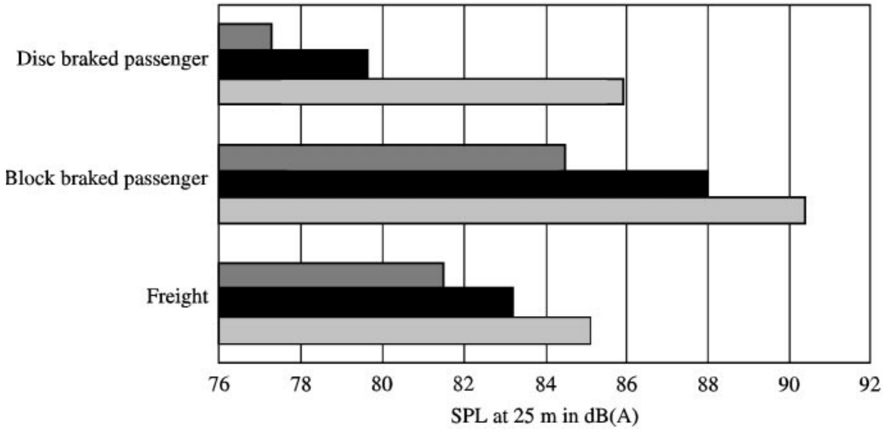

Figure 5. The values for the sound pressure level at 25 m of the centre of the track: ▩, minimum; ■, mean; □, maximum.

atmospherical attenuation, ground attenuation, screening attenuation, reflection and meteorological correction.

In order to give an overview, Table 2 gives the formulae used in the standards compared. Note that these are not all the formulae, since an attenuation term may have several for each separate conditions. The table gives only the most commonly used formula. For example the screening attenuation formula is only given for the case when a receiver is in the shadow zone, i.e., the line source–receiver crosses the barrier.

The comparison of the geometrical spreading and atmospherical attenuation gives unsurprising results. The attenuation for doubling the distance lies for all models between the 3 and 5·5 dB(A), due to the atmospherical and ground effects. The atmospheric attenuation is dependent on the atmospheric conditions in each country. The air attenuation over 250 m shows a reasonable spread, but for the frequency dependent models the attenuation stays almost the same up to 1000 Hz and differs slightly at higher frequencies.

For the dB(A) models the ground attenuation is equal to -2 and -5 dB(A) over a 250 m absorbing ground. An exception is the Ashdown model with $-0{\cdot}7$ dB(A). All total models used the distance and the height of the source and receiver in their calculations. The Danish, Guide du Bruit and the Department of Transport models do not calculate a (negative) ground attenuation when the ground is reflective. Except for the Mithra model, the spectral models use the same principle to calculate the ground attenuation. It is based on the research of Parkin and Scholes [15] and differs only slightly because of the different source height. The Mithra model uses formulae of Chien and Soroka [16] and calculates, in the standard situation, a higher attenuation than the other spectral models.

The screening attenuation is, for all models except the Danish, based directly on the path length difference. The differences between the models are the conditions under which the screening attenuation is calculated and the formulae used. The screening insertion loss is the difference between a situation with and without a screen. This includes the difference in ground attenuation, which gives

TABLE 2

Simplified overview of the separate attenuation formulas used in the predictions models

Model	Δ_{geo}	Δ_{atm}	Δ_{ground}	Δ_{screen}	Δ_{refl}	Δ_{meteo}
Austria	$-10\,\lg[4\pi r^2]$	$-\alpha_{atm} r$	$\Delta_{ground,\,s} + \Delta_{ground,\,r} + \Delta_{ground,\,m}$*	$-10\,\lg\left[\dfrac{1}{20N_v + 3}\right]$	$10\,\lg[1+\rho]$†	—
Denmark	$-10\,\lg\left[\dfrac{d}{10}\right]$	—	$-12\,\lg\left[\dfrac{d}{1+d/10}\right] + 3\,\lg[h_m] + 7{\cdot}76$	$-10\,\lg[d_{sb}]$ $-10\,\lg\left[\left(z + \dfrac{1}{4(d_{sb}+1)}\right)\dfrac{1}{1+z/3}\right]$ $-7{\cdot}54$	$+3$	—
France-GdB	$-k\,\lg\left[\dfrac{d}{25}\right]$	—	Monogram	$-15\,\lg\left[\dfrac{\sqrt{2\pi N_v}}{\tanh[\sqrt{2\pi N_v}]}\right] - 5$	—	—
France-Mithra	$-10\,\lg[4\pi r^2]$	$-\alpha_{atm} r$	$-10\,\lg\left[(p_1^2 + p_2^2)\Big/\left(p_1^2 + \lvert\Re\rvert^2 p_2^2 + 2\lvert\Re\rvert p_1 p_2 \times \cos(k\,\partial r + \phi)\sin\dfrac{\pi\,\partial f\,\partial r}{c}\Big/\dfrac{\pi\,\partial f\,\partial r}{c}\right)\right]$	$-20\,\lg\left[\dfrac{\sqrt{2\pi N_v}}{\tanh(\sqrt{2\pi N_v})}\right] - 5$	$10\,\lg[1+\rho]$†	—
Germany	$-10\,\lg[2\pi r^2]$	$-\dfrac{r}{200}$	$\dfrac{h_m}{r}\left(34 + \dfrac{600}{r}\right) - 4{\cdot}8$	$-10\,\lg[3 + 60\,z\,K_w] - \Delta_{ground}$	$10\,\lg[1+\rho]$†	—

TABLE 2
Continued

Model	Δ_{geo}	Δ_{atm}	Δ_{ground}	Δ_{screen}	Δ_{refl}	Δ_{meteo}
ISO	$-10\,\lg[4\pi r^2]$	$-\alpha_{atm}\,r$	$\Delta_{ground,\,s} + \Delta_{ground,\,r} + \Delta_{ground,\,m}$*	$-10\,\lg\left[3 + \left(\frac{20}{\lambda}\right) C_3 z K_w\right] + \Delta_{ground}$	$10\,\lg[1 + \rho]$†	$C_0\left(1 - 10\,\frac{h_s + h_r}{r_p}\right)$
Netherlands	$-10\,\lg[d]$	$-\alpha_{atm}\,r$	$\Delta_{ground,\,s} + \Delta_{ground,\,r} + \Delta_{ground,\,m}$*	$-C_b\,F(N_v) + C_p$‡	$10\,\lg[1 + \rho]$†	$5\left(1 - 10\,\frac{h_s + h_r}{r_p}\right)$
Nordic	$-10\,\lg[4\pi r^2]$	$-\alpha_{atm}\,r$	$\Delta_{ground,\,s} + \Delta_{ground,\,r} + \Delta_{ground,\,m}$*	$-10\,C_h\,\lg\left[\frac{1}{20N_v + 3} + \frac{1}{20N_r + 3} + \frac{1}{20N_l + 3}\right]$	$+3$	—
Switzerland	$-10\,\lg[r]$	$-0{\cdot}007\,r$	$-\frac{30}{h_m + 1}(1 - e^{-r/300})$	$-9\,\lg[3 + 160\,z]$	—	—
UK-Ashdown	$-10\,\lg\left[\frac{d}{25}\right]$	$\frac{-d}{130}$	$\frac{-d}{130h_m}$	$-11z^{0.262}$	$+1.5$	—
UK DpT	$-10\,\lg\left[\frac{d}{25}\right]$	$0{\cdot}2 - 0{\cdot}008d$	$-0{\cdot}6\,G(6 - h_m)\,\lg\left[\frac{d}{25}\right]$	$-0{\cdot}88 + 2{\cdot}14\,\lg[0{\cdot}001 + z]$	$+2{\cdot}5$	—

* The formulas used for the source, middle and receiver region are based on Parkin and Scholes.
† A mirror reflection is used. When the propagation path of the reflection is different form the direct path, a separate contribution has to be calculated.
‡ $F(N_v)$ is a function of the Fresnel number and based on Makeawa.

a considerable difference between the frequency-dependent models, especially for propagation over absorbing ground where the models use a correction to the ground attenuation when a screen is present. The total models do not use a different ground attenuation when a screen is present, so the screening insertion loss is the same as the screening attenuation.

The models for the standard situation show maximum spread of the overall noise level of 9 dB(A), independent of the barrier height. The mean attenuation is −6·3 dB(A) for a screen with a height of 1·5 m and −16·9 dB(A) for a screen with a height of 5 m. These values are valid for a distance of 100 m between source and receiver, and a receiver height of 5 m. The screening attenuation of the frequency-dependent models is almost the same, any differences being due to the fact that some models incorporate the presence of a screen in the calculation of the ground attenuation. This effect is significant for absorbing ground. Inclusion of the ground effect in the screening insertion loss will give a reduction in the attenuation in the 250 and 500 Hz octave band in the case of absorbing ground.

Austria, Germany, ISO, Mithra and The Netherlands use a reflection factor which will increase the sound pressure level. The Danish, Ashdown and DoT models use a constant increase of the noise level and the Nordic model has a distance-dependent reflection attenuation. The other two models do not take reflection into account.

The Austria, ISO, Netherlands and Nordic models calculate for downwind conditions. This means that a curved sound beam is taken into account. When it is not desirable to calculate this enhanced sound level, but to calculate an average over a year, a correction has to be made. This meteorological correction takes the ratio of favourable and unfavourable weather conditions into account. Only the Netherlands and the ISO use this meteorological correction and they use the same formula.

5. CONCLUSION

The comparison of the noise emission has been made for three source types; disc-braked passenger trains, tread-braked passenger trains and freight trains. From each standard one type of train is chosen to be used in one of the above categories. Comparisons of the prediction models for the disc-braked passenger trains show a spread of 9 dB(A), while the block-braked passenger trains have a spread of only 6 dB(A). The emission levels of freight trains are very close to each other. They have a spreading of only 4 dB(A), which presumably is so low because of the international use of freight wagons.

The attenuation terms are compared separately. The attenuation due to geometrical spreading and air absorption gives unsurprising results. The ground attenuation is more interesting, especially for the frequency-independent models. These models have the same background and therefore show only a slight spread, which can be traced back to the difference in source height. The screening attenuation is based on the path length difference for all models except the Danish. The differences between the models are the constants and the conditions under which the screening attenuation is calculated. Some models do not use a different ground attenuation when a screen is present, so the screening insertion loss is the same as the screening attenuation. The screening attenuation is almost the same for the frequency dependent models, but the main difference depends on how the model compensates the screening effect with the ground attenuation.

This comparison could lead to a common of European regulation on noise prediction. The ISO propagation model could be used or a simpler ISO model used. The ISO model does not provide a source description. A European source model could be developed from the information collected, investigated and combined in this study. All the information about the source and the source position, directivity information and the speed dependency must be reviewed. Another advantage of the distinction between the source model and propagation model is that both parts can be developed or simplified separately.

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