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Harmonised **A**ccurate and **R**eliable **M**ethods for the EU Directive on the Assessment and Management **O**f Environmental **Noise**

DEFINITION OF TRACK INFLUENCE: TRACK COMPOSITION AND ROLLING NOISE

Deliverable 12 part 2 of the HARMONOISE project

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Summary

The purpose of categorisation as described in this report is not to provide a set of default transfer functions to be used for specific track contructions. The calculations demonstrate the importance of specifying the track construction types in terms of components. The components turn out to be of influence in different frequency areas. It is demonstrated that the different frequency areas become important at different speeds. As a consequence the influence of the components cannot be neglected.

When the Harmonoise model is used, the track administrator of each member state is responsible for the determination of its own track transfer functions, corresponding to the situations in the country. With the result of this reports, a framework for the determination of the transfer functions will be described.

To describe the influence of the track construction and the type of wheel on the total rolling noise TWINS calculations have been carried out. With the results categories are defined. The categories, given as sound power levels per third ocave band, will be put together in a database which serves as an input for the Harmonoise Engineering model.
The most standard track and wheel combination in the Netherlands is used to build a reference model. Variations in rail type, sleeper type, pad stiffness, pad loss, and ballast stiffness are calculated. Practical situations are used as a starting point to define the scale of variations.

All parameters turn out to be of significant influence, dependent on the speed of the train (the speed determines the frequencies of excitation). Parameters with low frequency characteristics like sleeper and ballast turn out to be important at low speeds. Parameters with high speed characteristics dominate at higher speeds. In this way 8 track categories have been chosen on basis of 16 different track transfer functions. The parameters which define the categories are rail type, pad stiffness and sleeper type. For ballast stiffness and vertical pad loss the average values have been chosen default since for these parameters the real values are hardly definable in practice.

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1 Introduction

One of the tasks of Workpackage 1.2 is to define a track categorisation for different track constructions. To do this influence of track parameters on the sound power level must be known under different circumstances. Originally, track compositions of different countries were planned to be studied. However, due to a lack of foreign data this idea turned out to be impracticable.

To describe the contribution from wheel and track to the rolling noise, track and wheel transfer functions are introduced. The transfer functions are given in sound power levels in third octave bands, which can be added to the roughness sound power to give the total rolling noise sound power. For a single wheel rail contact, the transfer functions are calculated by TWINS models translating the excitation energy caused by roughness to the rolling noise sound power of wheel and track respectively. The influence of the track composition is studied while the wheel is taken constant. Models from previous researches like *STV*, *Metarail*, are used and developed in more detail.

Calculations are carried out with TWINS 3.0. In TWINS (Track Wheel Interaction Noise Software) rolling noise sound power from wheels and tracks is calculated on basis of their designs. Starting from a validated model, the influence of changes in the track composition is studied, resulting in a a change in the wheel and track contribution. The main point of the study is found in real situations and realistic values, whereas the physical interest is taken inferior.
The results lead to a suggestion for track categorisation, and conditions for the measurement protocol. The effect of interaction between the most influent parameters is described, and the influence of the speed is studied.

2 TWINS model

When building a TWINS model, validation to SPL measurements is necessary. The model is tuned in such a way that the modelled values fit the measurement values. The tuned (reference) model is a starting point for further variations of the model parameters.

On the basis of a previous TWINS 2.2 model from the Dutch STV project, a new version is built under TWINS 3.0. The Dutch model using Dutch standard (conventional) main line track, serves as the reference model from which variations of the track parameters are calculated. By using unity roughness as excitation the wheel and track transfer functions are direct results of the calculations.
The shape of the transfer functions change when combined with roughness and A-weighting. To study the influence of the transfer functions for categorisation, real rolling noise values are needed in order to know which parts of the sound power spectra are of importance for the total sound power level. So to draw conclusions for categorisation, roughness values and A-weighting are added to the transfer functions.

2.1 Validation of the Dutch model

In the STV project the sleeper isolation between rail and sleeper was investigated. In the measurements, carried out in STV to validate the TWINS model, rail decay and vibration isolation of the sleeper have been determined. The pad stiffness, ballast stiffness, loss factors (rail, pad, sleeper and ballast) and the cross receptance level, were tuned in such a way that the TWINS calculations fitted with measured decay rate and vibration isolation. Finally the calculated decay rates are used.

2.1.1 Modules

The used models in TWINS for the calculations are

– **module**	– **model**
– roughness	not used (only unity roughness)
– wheel receptance	– wrec
– rail receptance	– rodel
– interaction	– lynx
– wheel response	– wrol
– rail response	– rwave
– wheel radiation	– wxrad
– rail radiation	– proluf /srad
– sleeper radiation	–
– add components	– filar

Table 1: Calculation modules used in TWINS

2.2 Output

The output of the calculations is given as transfer functions per one-third octave band per wheel/rail contact: a wheel transfer function, and a track transfer function. For the purpose of this study the sound power level from rail and sleeper are summated to form the track transfer function.

Dependent on the number of source positions in the final Harmonoise model, the sound power spectra for wheel and track can be added to one total transfer function spectrum.

3 Results

3.1 Reference model

The reference model is based on an ICM wheel on standard Dutch track (the Holland Spoor track model). Variation of the model is done by varying one parameter of the reference model at a time. More detailed information can be found in appendix A.

component	reference model	values	source	variation by
wheel	ICR/BNL	normal web, tread braked	Hollands Spoor	-
rail	UIC54		Hollands Spoor	UIC60
pad	FC9 (nominal values)	vertical stiffness: 0.35E+09 [N/m]	Hollands Spoor	0.14E+10 [N/m] 0.1E+09 [N/m]
		lateral stiffness: .2500E+08 [N/m]		-
		vertical loss: 0.19		0.3
		lateral loss: 0.16		-
sleeper	NS90	concrete monobloc	Hollands Spoor	bibloc
static load		.1125E+06 [N]	Hollands Spoor	-
ballast	normal	vertical stiffness: .2137E+09 [N/m]		0.5000E+08 [N/m] 0.5000E+09 [N/m]
		lateral stiffness: .1265E+09 [N/m]		-
		vertical loss: 1.000		-
		lateral loss: 1.000		-
speed		100 km/h		40 km/h, 50 km/h, 63 km/h, 80 km/h, 125 km/h, 160 km/h, 200 km/h, 250 km/h, 315 km/h
total roughness		unity roughness		disc braked; Silent track/ freight
				tread braked; Silent track/ freight

Table 2: Data used for the reference model

The transfer functions of the reference model for wheel and track are given in the following figure. Transfer functions are given for frequencies up to 5000 Hz, because at higher frequencies no excitation takes place.

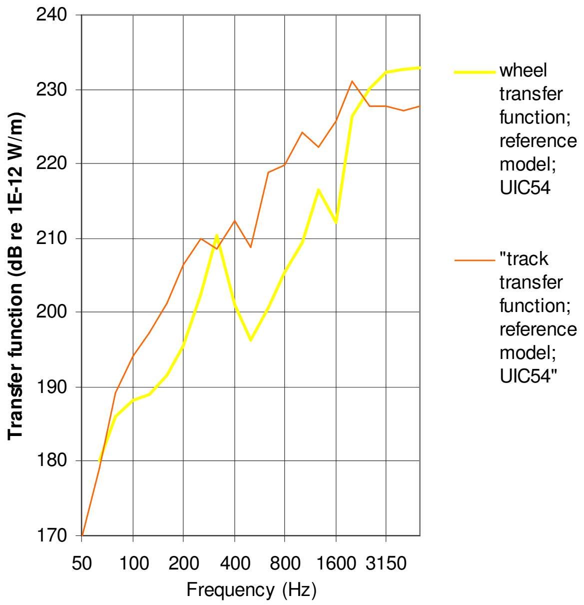


Figure 1: Wheel and track transfer functions, reference model

In this reference situation the track transfer function (thin line) is larger than the wheel transfer function for frequencies up to 2000 Hz.

The results presented here are transfer functions with high dB levels, increasing with frequency. Combination with average roughness, which decreases with frequency, gives rise to the better known, flatter functions.

3.2 Track transfer functions

Variation of track parameters gives insight in the influence of the parameters on the frequency spectra of the wheel and rail transfer functions. Physical parameters like rail type, pad stiffness, pad loss factor, sleeper type, ballast stiffness and ballast loss factor are studied.

3.2.1 Rail type

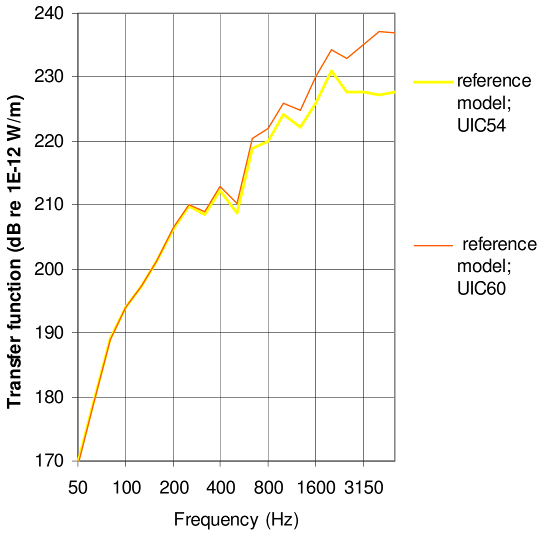


Figure 2: Variation of rail type in reference model

The effect of replacing the UIC54 rail type to UIC60 is given in de figure above. UIC60 gives higher sound power levels at higher frequencies. From 400 Hz up to 2 kHz the effect can be contributed to the difference in radiation efficiency, due to difference in the radiation surface and of the radiation factor of both rail types. To our estimation, this variation is around 1 dB per third octave band).

In these TWINS calculations the Rodel model is used for the rail receptance. As this model does not take into account the pin-pin effect caused by regular rail fastening, the results of the calculations are probably overestimated at frequencies higher than 1.5 – 2 kHz.

3.2.2 Pad stiffness

Variation of the pad stiffness in the reference model shows that at 200 – 630 Hz higher pad stiffness gives larger sound power levels, whereas at larger frequencies lower pad stiffness gives higher levels. The larger frequency part is the important part for the total sound power level of the spectrum.

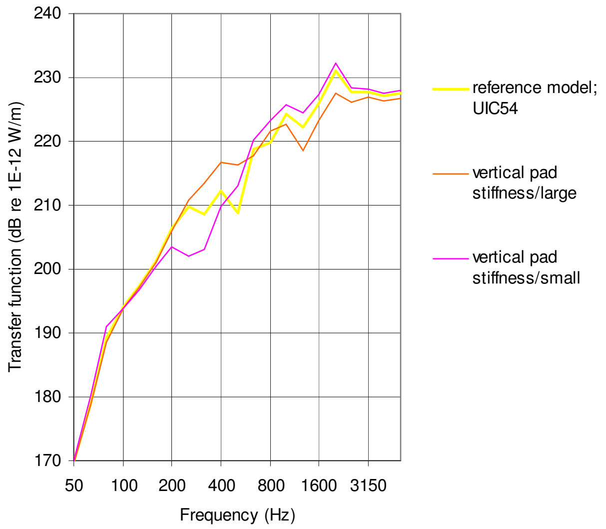


Figure 3: Variation of pad stiffness in reference model, red line: σ=0.14 E10N/m, purple line: σ =0.1 E09 N/m

In these calculations of the vertical pad stiffness effect, the lateral pad stiffness is kept constant. Variation of the lateral pad stiffness in accordance to the vertical pad stiffness would lead to slightly larger effects.

3.2.3 Vertical pad loss

As can be seen in the figure variation of the vertical pad loss factor hardly has any variation on the transfer function, when considering realistic and achievable values of pad damping.

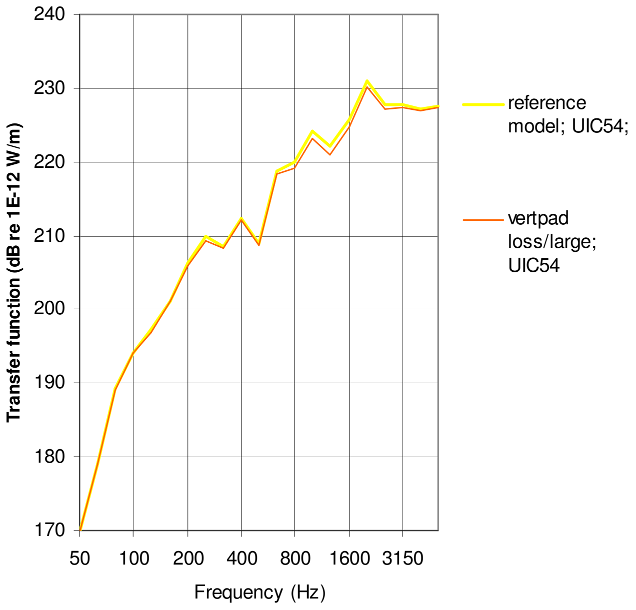


Figure 4: Variation of vertical pad loss: reference model: …=0.19; varied pad loss: ……. = 0.3

3.2.4 Ballast stiffness

Influence of the ballast stiffness is found in the low frequency part of the spectrum. We see that an increase of the ballast stiffness leads to a reduction of the transfer function (caused by a reduction of the rail receptance).

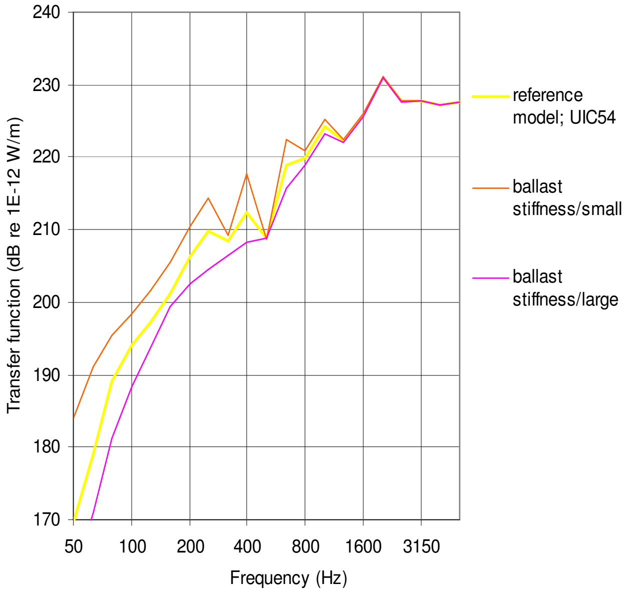


Figure 5: Variation of ballast stiffness in reference model; red line: σ=0.5 E08; purple line: σ=0.5 E09

3.2.5 Sleeper type

Variation of the sleeper type from monobloc to bibloc leads to a change in the track transfer function at frequencies smaller than 1250 Hz. Bibloc turns out to be more silent than monobloc, with reductions of 10 dB at frequencies smaller than 300 Hz. The wooden sleeper turns out to be more silent than the monobloc sleeper, and noisier than the bibloc.

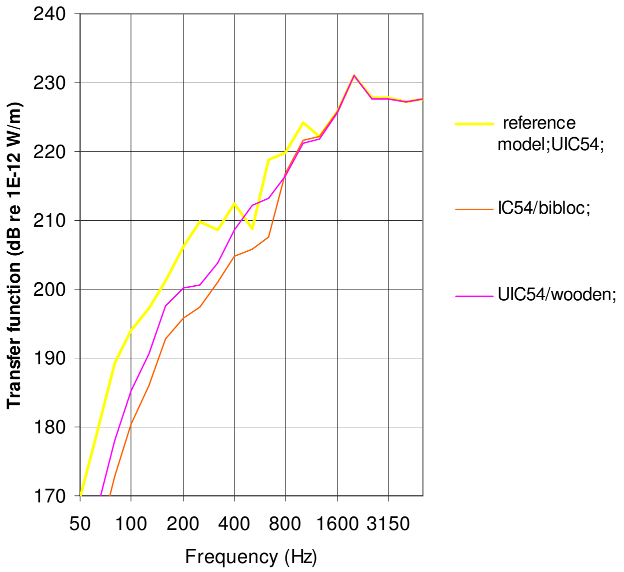


Figure 6: Variation of sleeper type in reference model

The lower levels for the bibloc sleeper can be attributed to the smaller radiation surface and to the absence of the modal behaviour of the bibloc sleeper. These effects are larger than the influence of the mass on the sleeper receptance (the receptance increases with decreasing mass of the sleeper), which is only 0.5 – 1 dB.

3.3 Variation of more than one parameter

The rail type is a rather linear system with respect to size and radiation efficiency. Therefore, replacing the UIC54 track from the reference model to UIC60 track provides a second reference model, which serves as a basis for the variation of parameters.

3.3.1 Rail type and pad stiffness

In the UIC60 model the influence of the pad stiffness on the transfer function is found from 200 up to 5000 Hz. Difference between UIC54 and UIC60 is the influence of the pad stiffness on the sound power levels. For UIC54 the influence is found up to 5000 Hz.

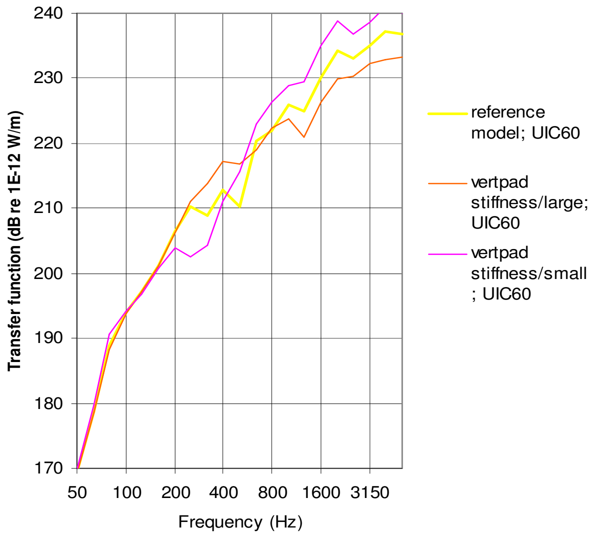


Figure 7:Variation of vertical pad stiffness in UIC60 model

3.3.2 Rail type and sleeper type

The next figure shows calculations for UIC54 and UIC60 models with monobloc sleepers, against calculations for the same models with bibloc sleepers. For frequencies higher than 1000 Hz, the rail type (UIC54 or UIC60) dominates the transfer function. For frequencies smaller than 1000 Hz the sleeper type dominates the spectrum.

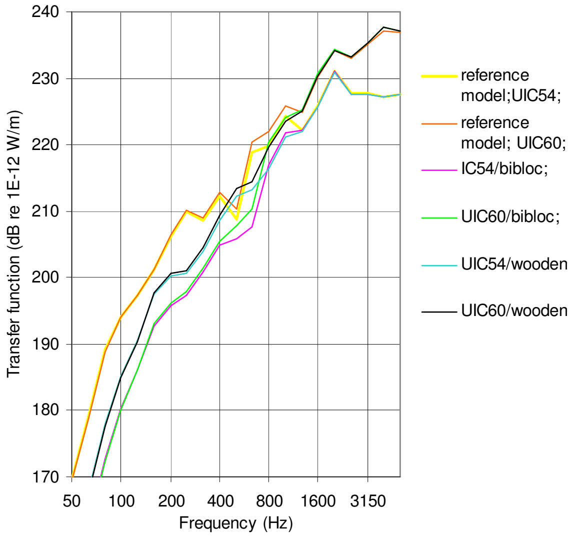


Figure 8: Variation of rail type and sleeper type

3.3.3 Rail type and ballast stiffness

The next figure shows different values for the ballast stiffness together with two different rail types. Just like the effect of the sleeper type, at high frequencies (larger than 1000 Hz) the rail type dominates the transfer function, whereas at low frequencies the rail type plays no role. At low frequencies the ballast stiffness determines the track transfer sound power level.

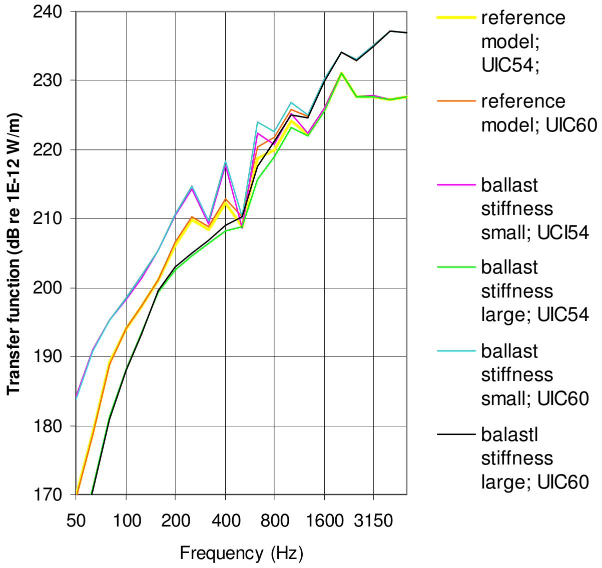
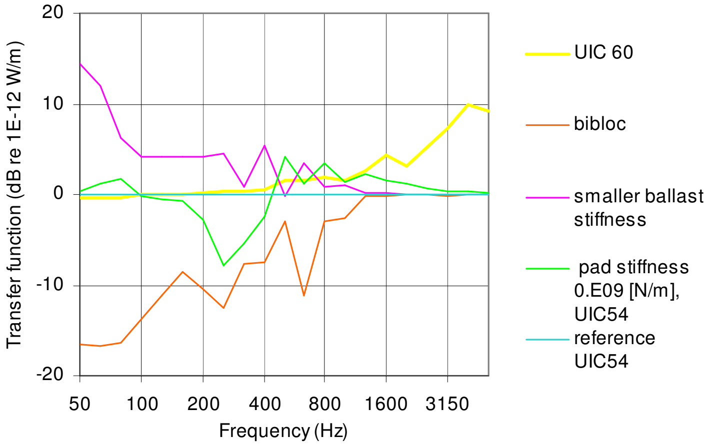


Figure 9: Variation of rail type and ballast stiffness

3.3.4 Relative change in track transfer level

The differences between changed transfer function and the reference track transfer function are shown in the next figure.



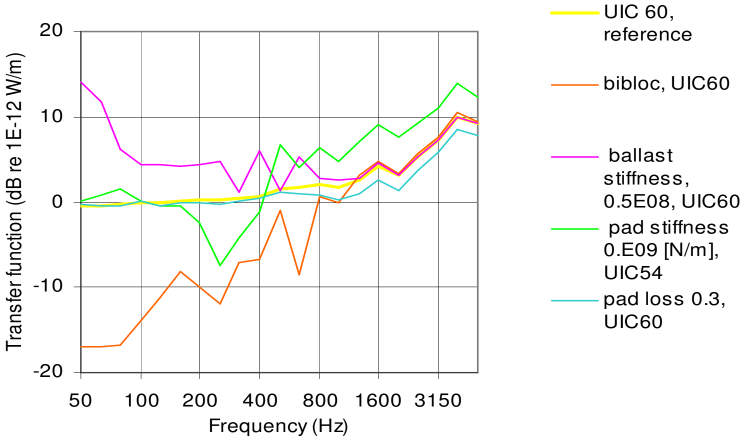


Figure 10: Difference between the reference model and varied versions of the model. Figure a: UIC54 reference model. Figure b: UIC60 model.

From previous studies with TWINS we know that each track component influences the level of the track transfer function in its own specific frequency range. From the figures above the frequency ranges can be clearly described:

changed parameter		**frequency range**
vertical pad stiffness	both rail types	200 - 400 Hz
	UIC54	500 – 800 Hz
	UIC60	500 – 5000 Hz
rail type		1000 - 5000 Hz
sleeper type		50 - 800 Hz
ballast stiffness		50 - 500 Hz

Table 3: Influence of the change of parameters on a change of more than 3 dB on the sound power level (indication).

3.4 Influence of measures

1. Slab track

Slab track is the general name for a track superstructure without ballast. Although slab track is regarded as a standard application for metro and tram systems, the number of *railway* slab tracks is still small, but it is growing. Especially on new (high-speed) lines ballastless tracks are applied.

Various slab track designs have been explored in the past two decades, and are still being explored. Some designs are based on concrete bibloc sleepers, laid on a reinforcement grid, that are afterwards concreted (e.g. Rheda 2000 in Germany [9]). Other designs use subsequent concrete slabs of a few metres length (e.g. Gemona in Italy). In both these types of design, the rail is supported at discrete positions by fasteners, like with ballasted track. Also continuously supported track has been applied, e.g. Best in the Netherlands. Here, the rails are laid in a gutter in the continuous slab, and are embedded in cork rubber.

From the view point of noise emission, the various slab track designs differ from ballasted track mainly with respect to the following:

- the concrete slab (with or without embedded sleepers) is much stiffer than the ballast bed with sleepers. Usually the higher stiffness of slab tracks is (partly) compensated by the application of smoother rail pads. This will generally lead to increasing rail vibrations compared to ballasted track.
- the coefficient of absorption of the concrete surface of the slab is much lower than that of ballast. For the purpose of compensating the increase of noise due to more reflective energy, sometimes absorptive material is applied on the surface of the slab.

The net effect on noise emission is dependent on the design characteristics of the slab track. Generally, a few dB higher levels are found than for ballasted tracks with concrete or wooden sleepers. E.g. the German calculation scheme *Schall 03* assumes an increase of noise emission of 3 dB(A) for trains on a slab track (without absorptive material) relative to trains on track with concrete sleepers.

Generally speaking, the track transfer function of slab track will differ from ballasted track. Because of the variation between different designs of slab tracks, it will be necessary either to measure or to model the specific slab construction. The same measurement protocol as for ballasted track can be used for this purpose.

3.5 Wheel transfer functions

For ballasted track, the wheel transfer function doesn't change significantly when the track construction changes [4]. In the data collection campaign of the STAIRRS project, results of the measurements demonstrate that variation of the vehicle type (and thus the wheel type) hardly has any influence on the wheel transfer function [8].
This is confirmed by the figure below shows various track and wheel transfer functions for different configurations of track. The wheel transfer functions do not change significantly for frequencies higher than 800 Hz (the wheel contribution starts to be of importance above 1600 Hz).

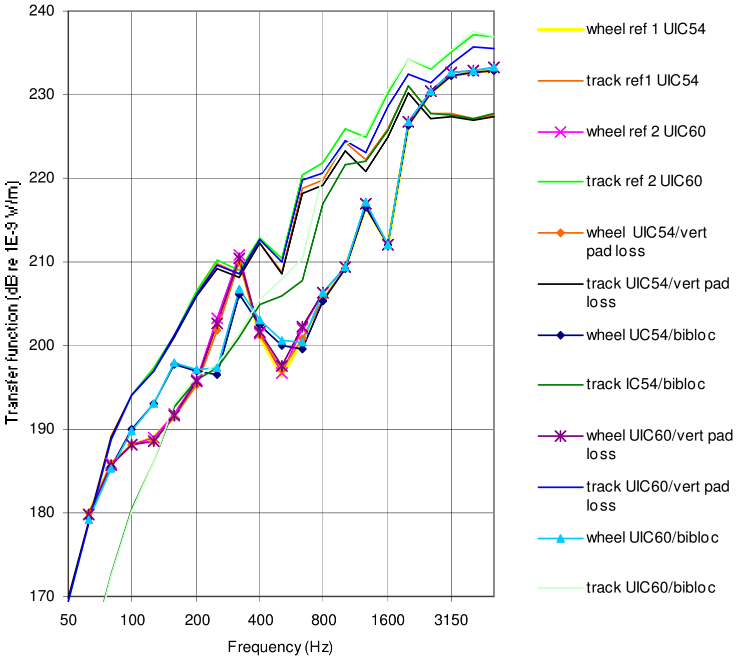


Figure 11: Wheel and track transfer functions for different configurations of track.

4 Analysis of the results

Different components give contributions to the track transfer at different frequencies. Ballast and sleeper mostly have influence at frequencies smaller than 1000 Hz. Rail type and vertical pad stiffness influences the track transfer at frequencies higher than 1000 Hz. The vertical pad loss only has significant influence on the track transfer in the situation with UIC60.
The interaction between the low-frequency interactors (ballast stiffness and sleeper type) and high-frequency interactors (rail type) is not found, because their influences areas are well enough separated.

The vertical pad stiffness has influence at 200 to 5000 Hz, for the UIC60 rail, and at 200 to 3000 Hz for UIC54 rail. Besides, the effect of pad stiffness on UIC 60 is much larger. So the effects of pad stiffness and rail type on the track transfer are not independent.

When varying the track composition, changes in the sound power level will occur in different parts of the frequency spectrum, dependent on the varied component. Variations may occur in a low-level frequency range of the spectrum and thus not always influence the integrated level of the spectrum. Therefore, the influence of the low-level frequencies is studied in the next chapter.

5 Categorisation

5.1 The influence of roughness and A-weighting

The influence of speed on the transfer functions is negligible. The one effect included in TWINS is the wheel receptance, which is 0.1 dB per third octave band. At high corrugation levels non-linearity occurs [7]. At normal corrugation the speed dependence for rolling noise can be entirely attributed to a frequency change in the roughness.

Summation of the transfer function with roughness gives a differently shaped spectrum, in which low-level ranges of the spectrum may become more important. So, dependent on the roughness shape (and thus the speed) different components have influence on the integrated rolling noise level. The effect of varying the speed is studied coarsely.

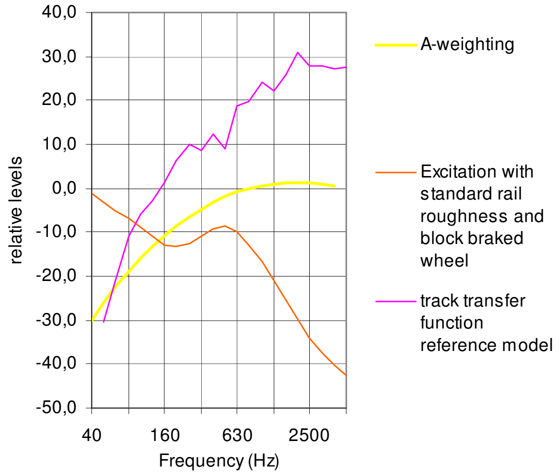


Figure 12: Comparison of excitation, track transfer and A-weighting (relative values).

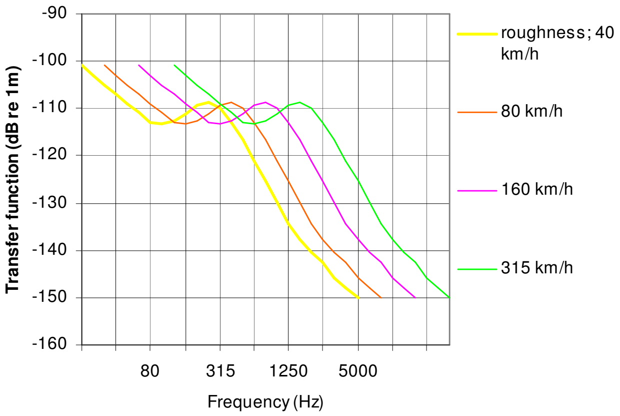


Figure 13: Shift of total roughness with speed.

In the following figure, average roughness and A-weighting are attributed to the reference track transfer function. An increase of the speed to 315 km/h results in a relative increase at frequencies larger than 1000 Hz. At low speed, the relative contribution of the low frequencies is larger. Apparently, at high speeds the peaks in excitation and transfer function coincide at the maximum of the A-weighting function, leading to much higher levels.

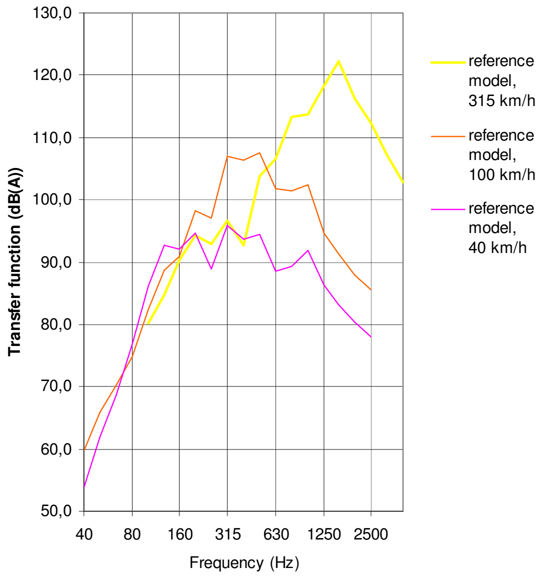


Figure 14: average roughness + track transfer function + A-weighting at different speeds

Other effects which make the low-level part of the spectrum more important are propagation circumstances and directivity. For example soft grounds and air absorption attenuate high frequencies and make the low frequencies relatively important at the receiver position. Low frequencies suffer less from diffraction than high frequencies, which influences the spectrum behind barriers and corners, etc.

This means that the total sound power level is not a good basis for categorisation. Variations in the whole spectrum must be considered.

Summation of the transfer functions with roughness and A-weighting gives the following figures. Figure 14a shows the reference model, and variations on it. Figure 14b shows the varied UIC60 model, and its variations, both at 100 km/h.

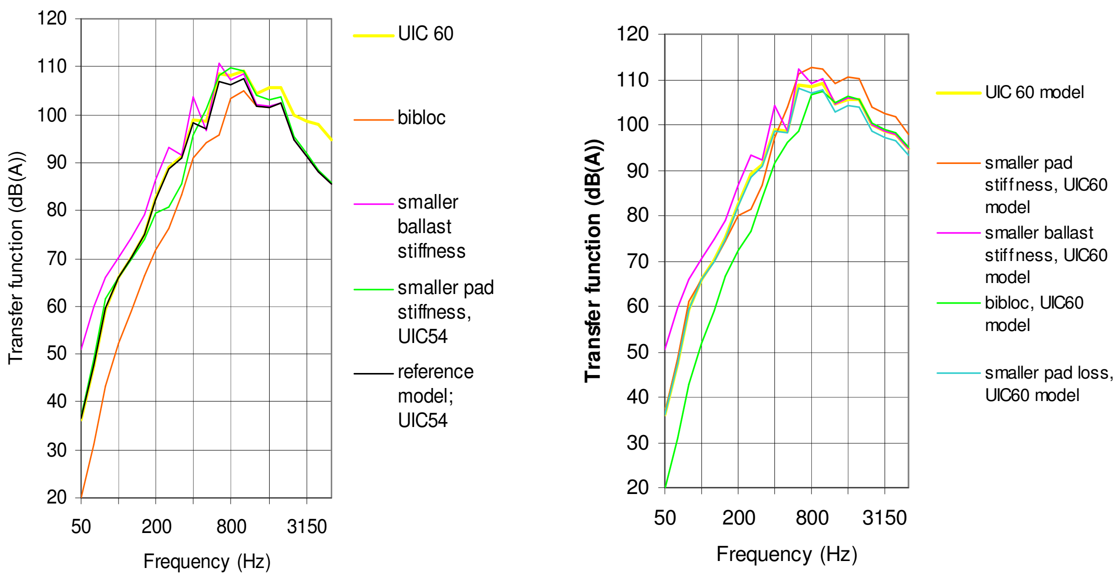


Figure 15: summation of transfer functions with average roughness and A-weighting at a speed of 100 km/h. Figure a: UIC54 reference model. Figure b: UIC 60 model.

So the magnitude of the influence on the total rolling noise is dependent on the roughness spectrum, and thus the speed.
To give an indication of the magnitude of influence of the parameters, the differences between the reference model variations on the model (summed with standard roughness and A-weighting) and are given in the next table. This procedure is repeated for low, middle and high speeds.

	reference model (dB(A))			**UIC60 model (dB(A))**		
varied parameter	**40 km/h**	**100 km/h**	**315 km/h**	**40 km/h**	**100 km/h**	**315 km/h**
reference model;UIC54	104	113	126	106	116	130
higher pad stiffness (0.14E+10 [N/m])	+2	0	-3	+1	-1	-4
lower pad stiffness (0.1^{E}+09 [N/m])	+1	+2	+1	+3	+3	+4
lower ballast stiffness (0.5 E+08 [N/m])	+3	+2	0	+3	+1	0
higher ballast stiffness (0.5 E+09 [N/m])	-2	-1	-1	-1	-1	0
higher pad loss	0	0	-1	-1	-2	-2
wooden sleeper	-3	-2	-1	-2	-2	0
bibloc sleeper	-4	-3	-1	-3	-2	0
UIC60	+2	+3	+4			

Table 4: difference of varied model with reference model at different speeds -summed with roughness and A-weighting-. The differences with the total track emission level are shown in dB(A).

The table is an indication for the error which is made when a parameter is not considered. In the variations, the extremes of realistic values for pad stiffness and ballast stiffness have been chosen.

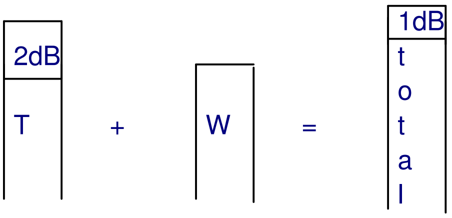
At low speeds the influence of the ballast stiffness and the sleeper type is larger, because the roughness shifts to lower frequencies.
The increase of track transfer levels for stiffer pads at low speeds can be understood by comparing the roughness spectrum at 40 km/h with the pad stiffness variation spectra. Both spectra show an increase at frequencies from 200 to 500 Hz. So stiff pads do have considerable influence at low speeds.
At high speed the influence of the pad stiffness and the rail type increases, while the influences of ballast stiffness and sleeper type are much smaller.

5.2 The influence of errors in the track sound power level

For categorisation the influence of the track components on the total track emission (see table 4), then the track emission on the total rolling noise, and finally the influence of the total rolling noise on the L_{den} value must be estimated.

As we can conclude from the table above, each of the studied parameters has 2 dB or more influence on the total track emission under certain circumstances. This means that the track errors are defined by the effort done to determine the described parameters.

Next, the total rolling noise is determined by summation of the track and wheel rolling noise. If wheel and track are comparably noisy (like in the Netherlands, where stiff pads are used), an error in the track emission of 2 dB results in an error in the total emission of 1 dB.



In most other countries, where pads tend to be softer, the track emission is larger than the wheel emission, so changes in the track emission have larger influence on the total rolling noise. And thus the track uncertainties dominate the rolling noise uncertainty.

Finally the influence of the total rolling noise on the L_{den} value can be discussed.
For calculating the L_{den} value, averaging is done for the vehicles, but the track site is always the same. Track uncertainties cannot be averaged out.

6 Accuracy

Validation of the model against field measurements for 34 wheel-track combinations has been described in [1]. The validation showed an improved accuracy of the TWINS 3.0 model. It was found that the difference between measured and predicted overall A-weighted sound pressure levels is less than 2 dB while the standard deviation is 1.9 dB. In predicting the noise, the decay of vibration with distance along the track can be either predicted or adjusted in the model according to measured data. The standard deviation can be reduced to 1.1 dB by using measured decay rates instead of predicted levels.

The basic report about parameter uncertainties is the validation of TWINS 3.0 by CJC Jones and DJ Thompson [1] [2]. In general it could be said that it is not possible to use TWINS 3.0 and expect an error of less than ±2 dB (A) on the total sound power and not less than ±2,5 dB (A) sound power for each component (wheel, rail, sleeper) contribution. Errors in TWINS results, for new models, depend strongly on which component is changed with respect to a validated model.

From the influence and accuracy of the parameters for the different models, conclusions can be made concerning the necessity of the input data. Some input data must be determined as accurately as possible, whilst other parameters do have little influence on the accuracy of the model.
Basically, something can be said on the basis of [2] and [3] only. This is summarised in Table 5.

Pad stiffness	± 1.5 dB
Rail type	± 1 dB
Wheel type	± 1.5 dB
Other components	Unknown, but expected to be not significant

Table 5: accuracy of components in TWINS

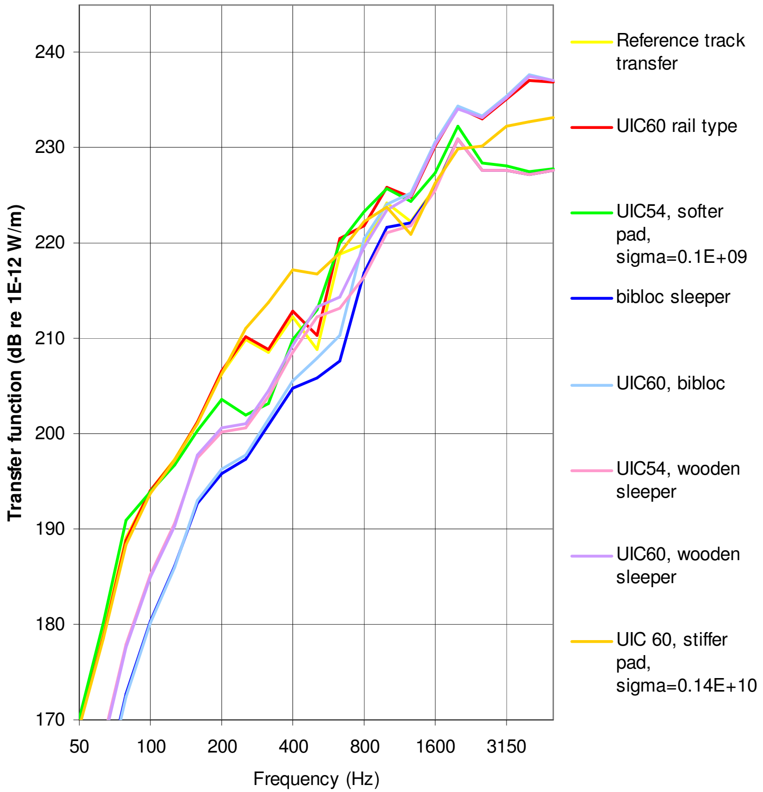
7 Conclusions for categorisation

The calculations demonstrate the importance of specifying the track construction types in terms of components. The components turn out to be of influence in different frequency areas. It is demonstrated that the different frequency areas become important at different speeds. As a consequence the influence of the components cannot be neglected.

When the Harmonoise model is used, the track administrator of each member state is responsible for the determination of its own track transfer functions, corresponding to the situations in the country. With the result of this reports, a framework for the determination of the transfer functions will be described.

8 track categories have been chosen on basis of 16 different track transfer functions. The parameters which define the categories are rail type, pad stiffness and sleeper type. For ballast stiffness and vertical pad loss the average values have been chosen default. The real values for these parameters are hardly definable in practice.

Category 1, the reference model, is described in chapter 3.1. The other categories are based on changes indicated in Table 6. The parameter set of category 4 comes close to those defined in Silent track reference track [6].



Figuur 16: 8 track categories on the basis of three different paremeters: rail type, pad stiffness and sleeper type

			frequency																				
category	**model**	**value**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**
1	reference model		170	179	189	194	197	201	206	210	209	212	209	219	220	224	222	226	231	228	228	227	228
3	soft pad	0.1 E+09 [N/m]	170	180	191	194	197	200	204	202	203	210	213	220	223	226	224	227	232	228	228	228	228
5	bibloc	bibloc sleeper	153	162	173	180	186	193	196	197	201	205	206	208	217	222	222	226	231	228	228	227	228
7	wooden	wooden sleeper	159	168	178	185	191	198	200	201	204	209	212	213	216	221	222	226	231	228	228	227	228
2	UIC60		169	179	189	194	197	201	207	210	209	213	210	220	222	226	225	230	234	233	235	237	237
4	UIC60;soft pad	0.1 E+09 [N/m]	170	180	191	194	197	201	204	202	204	211	216	223	226	229	229	235	239	237	239	241	240
6	UIC60;bibloc	bibloc sleeper	153	162	172	180	186	193	196	198	202	206	208	210	220	224	225	231	234	233	235	238	237
8	UIC60;wooden	wooden sleeper	158	168	178	185	190	198	201	201	204	209	213	214	220	224	225	230	234	233	235	238	237

Table 6: track categories with their sound power levels in third octave bands, on basis of rail type, sleeper type and pad stiffness.

Literature

[1] D.J. Thompson and C.J.C. Jones, 2001, *IWRN*, Extended validation of a theoretical model for railway rolling noise using novel wheel and track designs.
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[7] D.J. Thompson and Tianxing Wu, The effects of non-linearities at the wheel/rail interface on the generation of rolling noise, Internoise 2001.
[8] Pieter Dings, STAIRRS D11/Part 2, Classification, STR2TR261102AEA2.doc
[9] D. Briginshaw, Latest Design Of Rheda Slab Track Installed, International Rail Journal, November 2001.

Appendix A

parameters of the reference model

General Parameters

Train Speed	100.0	[km/h]
Static Load	.1125E+06	[N]
Young Mod. Steel	.2100E+12	[N/m2]
Density Steel	7700.	[kg/m3]
Poisson Steel	.3000	[-]

Rail Parameters

Mass per Metre	54.00	[kg/m]
Profile Radius	.3000	[m]
Vertical Bending Stiffnes	.4920E+07	[Nm]
Vertical Shear Coefficien	.4000	[-]
Vertical Loss Factor	.2000E-01	[-]
Lateral Bending Stiffness	.8700E+05	[Nm]
Lateral Shear Coefficient	.4000	[-]
Lateral Loss Factor	.1000E-01	[-]

Pad Parameters

Vertical Stiffness	.3500E+09	[N/m]
Vertical Loss Factor	.1900	[-]
Lateral Stiffness	.2500E+08	[N/m]
Lateral Loss Factor	.1600	[-]

Sleeper Parameters

Sleeper Type	Mono-Block	
Sleeper Spacing	.6000	[m]
Total Mass	280.0	[kg]
Length	2.480	[m]
Height	.2200	[m]
Width	.1600	[m]
Bottom Width	.2900	[m]
Block Length	.0000	[m]
Centre Height	.1750	[m]
Centre Width	.1500	[m]
Centre Bottom	.2200	[m]

Ballast Parameters

Vertical Stiffness	.2137E+09	[N/m]
Vertical Loss Factor	1.000	[-]
Lateral Stiffness	.1265E+09	[N/m]
Lateral Loss Factor	1.000	[-]

Roughness Calculation Parameters

Unity roughness is used

Rail Receptance Calculation Parameters

Cross Receptance Factor	-10.00	[-]