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HARMONOISE: DEVELOPMENT OF A STATE-OF-THE-ART SOURCE MODEL FOR TRAFFIC NOISE

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1 INTRODUCTION

This paper describes the source model that has been developed within WP1.1 of the EC part funded project Harmonoise(1). TRL has provided the UK input and this has been supported by DfT and DEFRA. It entails the description of sound power of various categories of vehicle in terms of speed and acceleration. Corrections are applied for the road surface texture and condition including temperature and for directivity both in the horizontal and vertical plane. The sources on the vehicles are simplified into two point sources: a lower and higher source. The lower source is mainly due to tyre/road noise and the higher source is mainly propulsion noise. The height of the propulsion noise source depends on the vehicle category.

The sound power of the sources in a given direction are then used to calculate levels at any given receiver using a ray based propagation model developed in WP3 of Harmonoise. The road surface acoustic impedance is included in the propagation model. A road segment will be composed of a series of point sources of different types depending on the percentage of vehicles of varies categories and their speed. All these sources are integrated to arrive at the final averaged A-weighted traffic noise level.

2 CATEGORIES OF VEHICLES

The vehicles are divided into the categories shown in Table 1. It is likely that initially only the main categories will be used. Later, data on subcategories will become available. It can be seen that separate categories have been reserved for low noise vehicles and electric vehicles. It is to be expected that the proportion of these vehicles will grow over time and relevant data can be added.

There are three main categories corresponding to light (category 1), medium heavy (category 2) and heavy vehicles (category 3). Category 1 and 2 vehicles all have two axles except in the case of vehicle/ trailer combinations. Generally class 2 vehicles have 6 or more wheels (4 on the rear axle). Category 3 contains the heaviest vehicles which have more than 2 axles.

At the present time limited data is available to describe the emission from sub-classes and consequently predictions are only available for the main vehicle classes. An exception is that rolling noise sound power levels are given as a function of the number of axles for category 3 vehicles.

Vehicles with high exhausts (stack exhausts) are placed in sub-categories since the effective position of the propulsion noise source is likely to be significantly higher above ground than for vehicles with exhausts mounted close to the chassis.

Electric vehicles are also placed in a sub-category since the characteristics of the propulsion noise will be significantly different from diesel or petrol fuelled vehicles.

Table 1: Vehicle categories

Main category	No.	Sub-categories	Notes
Light vehicles	1a	Cars (incl MPV:s up to 7 seats)	2 axles, max 4 wheels
	1b	Vans, SUV, pickup trucks, RV, car+trailer or car+caravan[1], MPV:s with 8-9 seats	2-4 axles[1], max 2 wheels per axle
	1c	Electric vehicles, hybrid vehicles driven in electric mode[2]	Driven in combustion engine mode: See note
Medium heavy vehicles	2a	Buses	2 axles (6 wheels)
	2b	Light trucks and heavy vans	2 axles (6 wheels)[3]
	2c	Medium heavy trucks	2 axles (6 wheels)[3]
	2d	Trolley buses	2 axles
	2e	Vehicles designed for extra low noise driving	2 axles[5]
Heavy vehicles	3a	Buses	3-4 axles
	3b	Heavy trucks[4]	3 axles
	3c	Heavy trucks[4]	4-5 axles
	3d	Heavy trucks[4]	≥6 axles
	3e	Trolley buses	3-4 axles
	3f	Vehicles designed for extra low noise driving	3-4 axles[5]
Other heavy vehicles	4a	Construction trucks (partly off-road use)[4]	
	4b	Agr. tractors, machines, dumper trucks, tanks	
Two-wheelers	5a	Mopeds, scooters	Include also 3-wheel motorcycles
	5b	Motorcycles	

[1] 3-4 axles on car & trailer or car & caravan. [2] Hybrid vehicles driven in combustion engine mode: Classify as either 1a or 1b. [3] Also 4-wheel trucks, if it is evident that they are >3.5 tons. [4] If a high exhaust is noted, identify this in the test report. Categorize this as 3b', 3c', 3d' or 4a' . [5] For example, low noise ("whisper mode") delivery trucks and buses.

3 BASIC SOURCE MODEL

In order to be able to combine the source model with an appropriate propagation model it is necessary to describe the source as a number of point sources. In Harmonoise two source heights are used for each vehicle category. One is 0.01 m above the road surface and the other is either at 0.3 m for light vehicles or 0.75 m for heavy vehicles. For heavy vehicles with high exhausts (stack exhausts) an additional position at 3.5 m should be used. However, emission data for these vehicles are not yet available. 80% of the rolling noise is assumed to radiate from the lower source whereas 20% is assumed to radiate from the higher source. This allows for some "smearing" of the source which in practice rarely takes the form of a discrete point source. The rolling noise for the reference condition is described by the equation:

$$L_{WR}(f) = a_R(f) + b_R(f)\log\left[\frac{v}{v_{ref}}\right] \quad (1)$$

where v_{ref}= 70 km/h. The coefficients $a_R(f)$ and $b_R(f)$ for each main vehicle category are contained within a Harmonoise WP1.1 report (not yet published). The difference between category 2 (2 axle medium heavy vehicles) and category 3 (heavy vehicles with >2 axles) depends on the number of axles. It is assumed that L_W increases as 10 log (number of axles). The default assumption is that a category 3 vehicle on average has 4 axles. Large city buses will often have 3 axles and long distance freight trucks will on average have at least 5 axles. The adjustment across all frequency bands is given by:

$$(a_R)_{Category3} = (a_R)_{Category2} + 10\log\left(\frac{number\ of\ axles}{2}\right) \tag{2}$$

Note that there is no adjustment to the coefficient b_R .

For propulsion noise 80% is assumed to radiate from a source at a heights of 0.3 m for light vehicles and at a height of 0.75 m for heavy vehicles. Figure 1 shows a plot of the sound emission of a stationary goods vehicle indicating the distribution of the propulsion noise based on measurements with a microphone array(2). Note that 20% of the sound power is assumed to radiate from the low source 0.01 m above the road surface. In contrast to rolling noise it has been found that propulsion noise is best described as a linear function of speed:

$$L_{WP}(f) = a_P(f) + b_P(f)\left[\frac{v - v_{ref}}{v_{ref}}\right] \tag{3}$$

where the speed coefficient b_P is the same for category 2 and category 3 vehicles whereas a_P is different.

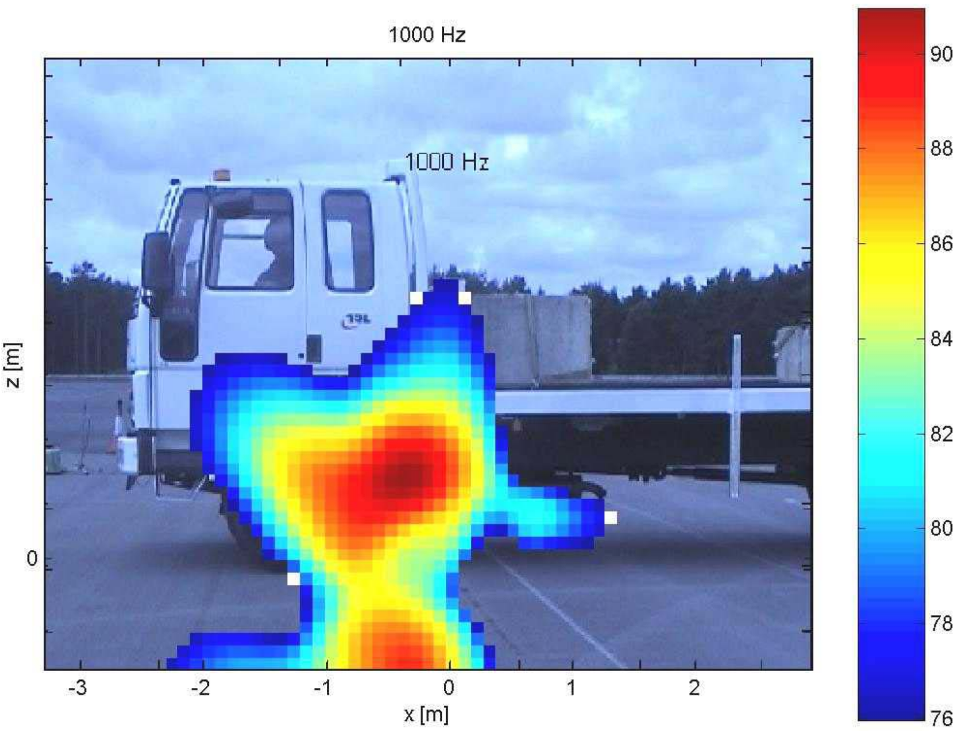

Figure 1: Third octave band level contours at 1kHz for a stationary test on Ford Cargo indicating position of engine source and image in the road surface

As would be expected propulsion noise is assumed to be independent of the road surface. The effect on the radiation of propulsion and rolling noise over a porous road surface is taken into account by introducing a suitable road surface impedance into the propagation calculations. Some examples of rolling and propulsion noise for light, medium and heavy vehicles at a typical urban speed of 50 km/h are shown in Figure 2.

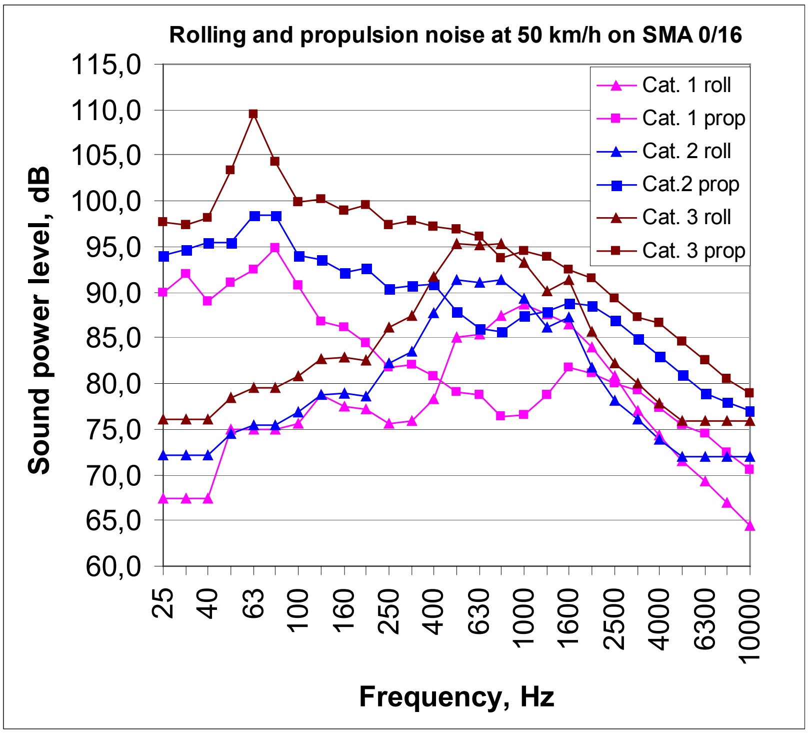

Figure 2: Sound power levels for rolling and propulsion noise

It can be seen that below about 500 Hz propulsion noise dominates whereas at mid frequencies rolling noise becomes relatively more important and dominates for the light and medium heavy vehicles. At higher speeds the contribution of rolling noise to the total sound power radiated is greater across all vehicle classes.

4 SOURCE MODEL CORRECTIONS

4.1 Road Surface Corrections

The road surface taken as the reference for calculating rolling noise sound power has a maximum chipping size of 11 mm/s and is a surface having the acoustic characteristics based on the average of dense asphalt concrete (DAC) and stone mastic asphalt (SMA) with an age of 1 year or more but showing no signs of deterioration. Table 2 gives the correction to the rolling noise sound power levels for category 1 vehicles in terms of a simple dB correction across all frequency bands by surface type and maximum chipping size. Note that due to lack of appropriate data there are no corrections for heavy vehicles. In addition there is at present no correction for hot rolled asphalt (HRA). It is hoped to extend the range of corrections in the EC part funded IMAGINE project which will build on the results obtained in Harmonoise.

As an example of the correction a 14 mm SMA would have a correction to rolling noise of +0.3 + 3x0.25 dB i.e.+1.05 dB.

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Table 2: Corrections within the reference cluster for category 1 vehicles

Road surface	**Correction relative to the reference**
Harmonoise reference with chip size 11 mm, (mean value of DAC and SMA)	± 0 dB
DAC	-0,3 dB
SMA	+0,3 dB
Chip size	+0,25 dB/mm above 11 mm -0,25 dB/mm below 11 mm
Age	- 1 dB for surfaces newer than 1 year

For other surfaces outside this narrow range of 'reference surfaces' tables are given listing corrections by third octave band centre frequency for cars and trucks at 70 km/h. For example corrections are currently available for porous asphalt, surface dressing and brushed and exposed aggregate concrete.

There are no corrections for age for impervious surfaces except if they are less than 1 year old. For porous surfaces clogging causes an increase in noise with age. A suitable equation to describe this change is:

$$\Delta L_{AT} = \Delta L_{A0}(1-(0.25T-0.016T^2)), T \leq 7\,years \tag{4}$$

where ΔL_{A0} is the A-weighted sound pressure level relative to the reference surface at the time T=0 years. Note that this correction only applies if the chipping size is similar to the reference surface.

Rolling noise is affected by temperature. Both asphalt and tyres become softer with increasing temperature thus decreasing the rolling noise sound power level. This correction should be frequency dependent. However, due to lack of detailed data the correction to be applied equally on all frequency bands is

$$\Delta L_{WR}(\theta) = K(\theta_{ref} - \theta) \tag{5}$$

where

ΔL_{WR} = sound power level correction due to rolling noise, dB

θ = the measured air temperature, ºC

θ_{ref} = the reference temperature, 20ºC

K = the temperature coefficient

There are a wide range of temperature coefficients for many different road surfaces. For category 1 vehicles it is normally 0.1 and 0.06 for DAC and SMA surfaces respectively. For category 2 and category 3 vehicles the coefficients to apply are 50% of that of category 1.

There is also a correction for passenger cars travelling on wet surfaces i.e. when there is a distinct layer of water on the road. The increase relative to a dry surface ΔL_{wet} is given by:

$$\Delta L_{wet} = 10\log\left(\frac{110}{v}\right) + 20\log\left(\frac{f}{2000}\right) \quad f > 2000\text{ Hz},\ 30 < v < 110 \tag{6}$$

$$\Delta L_{wet} = 5\log\left(\frac{110}{v}\right) \quad f = 1600\text{ Hz} \tag{7}$$

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$$\Delta L_{wet} = 2.5\log\left(\frac{110}{v}\right) \quad f = 1250 \text{ Hz} \qquad (8)$$

Note that this only applies at higher frequencies.

4.2 Acceleration Corrections

Propulsion noise increases during acceleration and decreases during deceleration. The correction is given by

$$\Delta L_{acc} = C \cdot a\,; \quad -2 \text{ m/s}^2 < a < 2 \text{ m/s}^2 \qquad (9)$$

where a = the acceleration/deceleration in m/s^2 and the coefficient C is given by Table 3. For category 3 vehicles an engine brake is often applied and in such cases the absolute value of the deceleration should be used thus increasing the level also when decelerating.

Table 3: Acceleration/deceleration coefficient

Vehicle category	*C*
Category 1	4.4
Category 2	5.6
Category 3	5.6

4.3 Directivity Corrections

The vehicle point sources are assigned both horizontal and vertical directivity. When integrated over a pass-by the integral of the directivity function is close to zero. The reference is the omnidirectional sound power level which, using the propagation model and integrated during a complete pass-by, yields the correct sound exposure level in the horizontal direction. It will be assumed that the vertical directivity is the same for all horizontal angles. Different directivity functions are used for rolling and propulsion noise. For example the horn effect is specific to rolling noise and a correction is given at the lowest source height at frequencies above1.6 kHz.

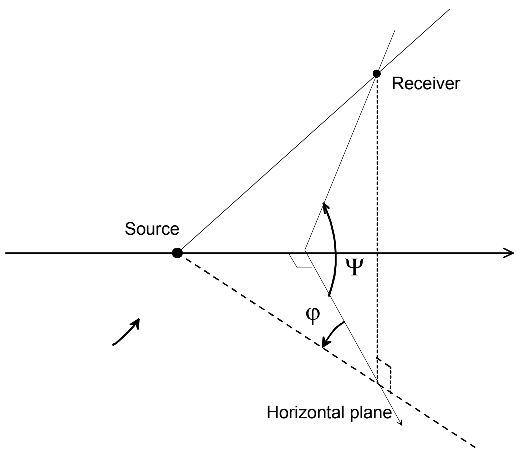

Figure 3: Geometry for directivity correction

The directivity function which is a function of angles, see Figure 3, and frequency, *f* is given by:

$$\Delta L(f,\varphi,\psi) = \Delta L_H(f,\varphi) + \Delta L_V(f,\psi) \quad (10)$$

and it is normalized to yield 0 dB contribution when integrated during pass-by and $\Delta L_V(0) = 0$ dB.

The horizontal directivity at the lowest source height is given by

$$\Delta L_H(\varphi) = 0;\ f \le 1250 Hz \quad (11)$$

$$\Delta L_H(\varphi) = (-3 + 5 \cdot abs(\sin(\varphi))) \cdot \sqrt{\cos(\psi)};\ f \ge 1600 Hz \quad (12)$$

Some examples of the vertical directivity at a range of frequencies for light vehicles are shown in Figure 4.

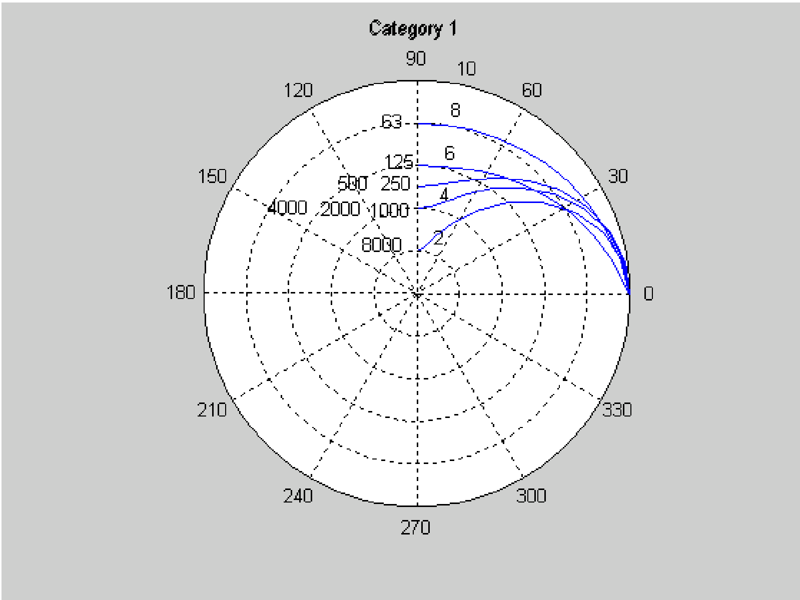

Figure 4: The vertical directivity of category 1 vehicles

4.4 Tyre Corrections

Tyre dimensions, tread block pattern and tyre construction have an influence on tyre/road noise generation. For example in a recent study of the effects of car tyre dimension it was found that on hot rolled asphalt with maximum chipping size of 20 mm and stone mastic asphalt with a maximum chipping size of 14 mm the average increase in noise level per 10 mm increase in tyre section width was approximately 0.5dB(A)[(3)]. It is likely that the average tyre width will vary across member states being perhaps wider in northern Europe than in southern Europe. Hence there may be a need to apply a regional correction to take any such systematic variations into account.

For winter tyres with studs a default correction in the form *a +blog(v)* is given. Note that the new EC part-funded project IMAGINE will provide regional correction factors for tyres and possibly for road surfaces.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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