inter-noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

modeling the noise emission of road vehicles and results of recent experiments

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ABSTRACT

The impact of road traffic on the acoustic quality in the environment is practically always determined by a calculation procedure. A reliable calculation result requires a reliable source strength determination. The paper will present an overview of the state-of-the-art emission description developed in the EU R&D project IMAGINE.
Special attention will be given to the incorporation of the impact of vehicle technology developments in the modeling. In the oral presentation recent data will be presented and discussed in terms of a possible shift with respect to data obtained 15 and 30 years ago.

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1. INTRODUCTION

Assessment of the acoustic impact of present and future road systems is in virtually all cases based on a calculation procedure. The basic scheme for calculating the immission level at the receiver point is to determine the acoustic source power of vehicles on a road and to subtract from it the attenuation due to the propagation:

$$L_{immission} = L_{emission} - D_{propagation} \quad (1)$$

The basic starting point for the assessment of the emission term is the noise production of a single vehicle. This noise production is assumed to be composed of two sources. One source comes from the interaction of the rolling tyre with the road and is referred to as *rolling noise*. The second source is the noise due to the propulsion system of the vehicle, generated by components such as engine, gearbox, cooling system, exhaust, etc., and is referred to as *propulsion noise*.

In the 5th and 6th European Framework Program for Research and Developments two projects, *Harmonoise* and *Imagine*, were conducted that among other noise sources beheld the development and harmonization of calculation procedures for the noise impact of road traffic on the environment. In specific work packages a group of institutes and companies have investigated these noise sources and worked on their mathematical definition in such a way that a direct link to the overall environmental noise calculation procedure, as developed in other work packages, is feasible. Furthermore, an easy implementation in computer software systems for noise impact assessment should be possible.

In an earlier Internoise paper [1] some aspects of the Harmonoise/Imagine model were already discussed. This paper aims to give an overall view of the model.

2. FORMULATION OF VEHICLE NOISE

The Imagine model is designed to represent the noise production of the average European vehicle, covering all relevant vehicle classes and describing it in a frequency range from 25 Hz to 10 kHz in 1/3rd octave bands. The basic formulation used in the model for both rolling noise and propulsion noise has the following form:

$$L_{W,i,m}(v,a) = A_{i,m} + B_{i,m}.f_1(v,v_{ref}) + C_{i,m}.f_2(a) \quad (2)$$

meaning that the noise emission level L_W is a function of speed v and acceleration a and is defined as a sum of a constant term, a speed-related term and an acceleration related term. The speed related term is chosen such that its value is zero at a reference speed v_{ref} of 70 km/h. The coefficients A and B are dependent on the type of vehicle and the frequency; the index m denotes the vehicle category number and the index i denotes the 1/3-octave frequency band number.

For rolling noise a logarithmic relation with vehicle speed is generally considered as the best fit:

$$L_{W,rolling}(v) = A_{rolling} + B_{rolling}.\lg\left(\frac{v}{v_{ref}}\right) \quad (3)$$

For propulsion noise a logarithmic relation with the engine speed is basically the best description, but such a relation has the limitation that the engine speed of a vehicle cannot be determined from the road side during measurements. Furthermore, since the engine speed is strongly dependent on driving behavior and vehicle-specific parameters (e.g. gear shifting, power-to-mass ratio), much more detailed input data are needed to be able to use the model. These data are in almost all cases not available.

From measurement data generated in an extensive research program on vehicle noise production during city driving, we determined the propulsion noise contribution and plotted the noise levels at 7.5 m distance against the vehicle speed and vehicle acceleration. This was done for about 10 different passenger cars and 3 light duty vehicles (vehicle weight up to 7 tons). Results for the passenger car group and the light duty vehicle group are given in figure 1.

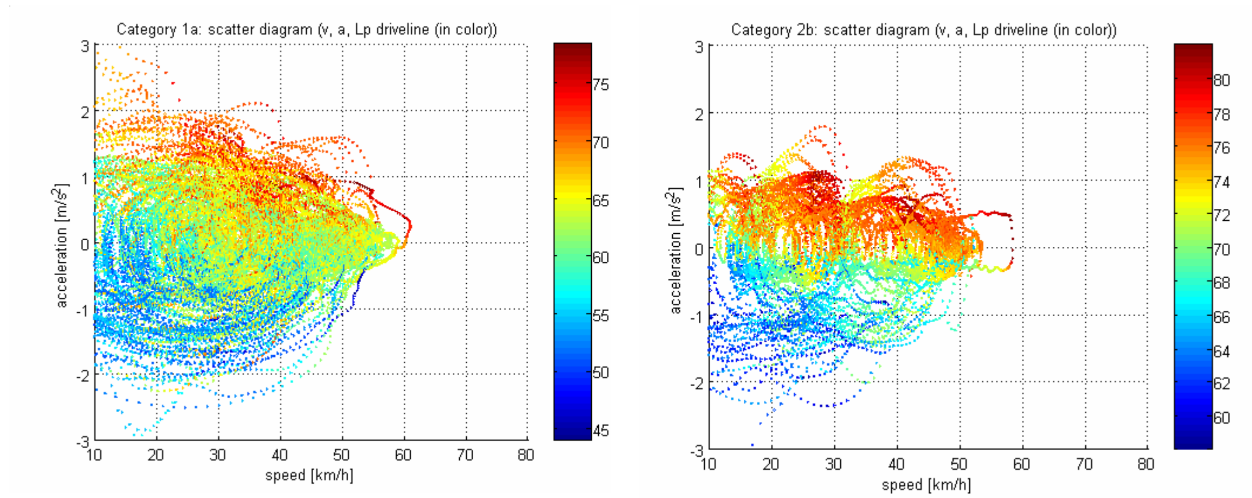

Figure 1 : propulsion noise level (normalized to a value of L_{Amax} at a distance of 7,5 m) for two groups of vehicles as a function of vehicle speed and vehicle acceleration. The noise level is indicated by the color of the data point. Data were assessed during city driving; each 0,1 s a data point was measured. Left: passenger cars, right: light trucks.

We found that the best fit of propulsion noise level vs. vehicle speed v and acceleration a was obtained with the following linear function:

$$L_{A,\max}(v,a) = A + B.v + C.a \tag{4}$$

In the final formulation, we used a reference speed of 70 km/h, leading to the following formulation:

$$L_{W,propulsion}(v,a) = A_{propulsion} + B_{propulsion} \cdot \left(\frac{v - v_{ref}}{v_{ref}} \right) + C_{propulsion}.a \tag{5}$$

The coefficients $A_{rolling}$, $B_{rolling}$, $A_{propulsion}$ and $B_{propulsion}$ and $C_{propulsion}$ are defined for three vehicle categories and for each 1/3rd octave band from 25 Hz to 10 kHz. For the 4th category, motorized two-wheelers, only the propulsion noise component is assessed since the contribution of rolling noise is negligible. The four vehicle categories are described in Table 2 below.

Table 2: Model parameters for the two configurations

Category name	description
Light motor vehicles	Passenger cars, delivery vans 3.5 tons, SUV’s, MPV’s including trailers and caravans
Medium heavy vehicles	Medium heavy vehicles, delivery vans > 3.5 tons, buses, touring cars, etc. with two axles and twin tyre mounting on rear axle
Heavy vehicles	Heavy duty vehicles, touring cars, buses, with three or more axles
Powered two-wheelers	mopeds, tricycles or quads 50 cc
	motorcycles, tricycles or quads > 50 cc

For the calculation of the noise emission with this model, we assume the following reference situation:

- constant speed on a flat (non-sloped) road;
- a “virtual” road surface consisting of a mix of SMA 0/11 and DAC 0/11 surface;
- a dry surface and an air temperature of 20°C;
- vehicles representing an average of the entire European vehicle fleet; for category 1: 185 mm tyre width, 19% diesel engines, 10% delivery vans, no studded tyres; For vehicle category 2: 2 axles, rear axle double mounted with drive tyres, category 3: 4 axles, one axle with drive tyres.
- 1% illegal exhausts for cat. 1, 2 and 3 and 35% for cat 4.

Using the formulas above, the total noise emission can be calculated, under the reference conditions mentioned.

To account for deviations from these reference conditions a series of correction factors can be applied:

- regional corrections for vehicle fleet properties different from the European average, such as age, weight, tyre mounting etc.,
- meteorological corrections (air temperature, surface wetness),
- corrections for driving behavior, mainly acceleration / deceleration and up- and downhill driving, and
- corrections for the influence of the road surface.

The reader is referred to [1] and [2] for a detailed listing of these factors. Note that the use of these correction factors is optional: when no detailed input data for these correction factors are available, the general formula can be used to calculate the noise emission for the reference situation.

3. THE FINAL MODEL

The coefficients in the formulas (3) and (5) are determined from an extensive measurement program involving statistical pass-by measurements at the road side on locations in the Netherlands, Italy, Poland, Sweden, Greece and the United Kingdom. Specific data for the rolling noise of tyres are determined on test tracks in Netherlands and Germany. Information on the behavior and noise production of passenger car and heavy vehicle drive trains under varying driving conditions was collected on test benches at Volvo 3P in Göteborg and TUG in Gdansk. Using on-board data acquisition, the noise emission of several light and medium heavy vehicles, as well as a series of powered two-wheelers, was measured as a function of vehicle and engine speed, among other parameters, during city driving tests performed by M+P.

An example of the spectral distribution of the coefficients for category 1 are given below.

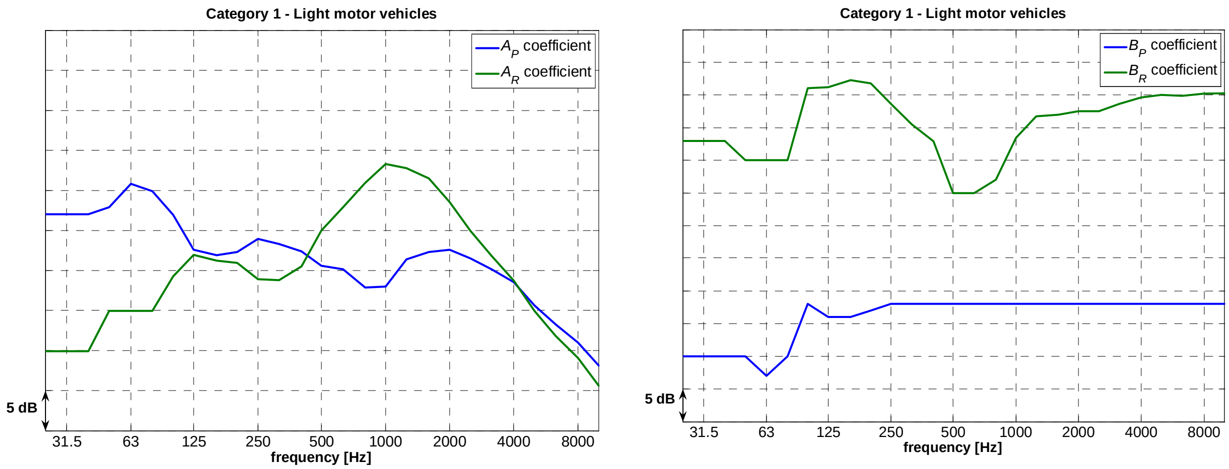

Figure 2 : The left graph represent the (non A-weighted) emission values at 70 km/h for both propulsion noise and rolling noise for each 1/3-octave frequency band; the right figure gives the speed coefficients as a function of frequency (see formula´s (3) and (5)).

It becomes clear from the left graph that the level of propulsion noise (A_P) exceeds the rolling noise (A_R) only at very high and at low frequencies. In the lower spectral range the exhaust component, related to the firing frequency of the engine, is clearly visible around 63 Hz. At high frequency the noise radiation from the engine and gearbox casing becomes relevant. In the middle frequency range, that dominates the total A-weighted value, the rolling noise component is the most important.

The curved behavior of the propulsion noise speed coefficients (B_P) in the low frequency range (50 – 200 Hz) represents the increase of the engine firing frequency with increasing vehicle speed. In the spectral distribution of the speed coefficient for rolling noise (B_R), one can distinguish the relatively low values around 500 Hz, which is the frequency range where mechanical tyre/road processes dominate. The high values for B_R above 1500 Hz are caused by the aero dynamical (airflow related) processes, that generally have higher speed exponents in the order of 4 to 6.

For light and heavy trucks similar graphs are available in [2]. They basically show the same behavior, although the coefficients for propulsion noise are significantly higher. At the reference speed of 70 km/h they have about the same A-weighted total value as the rolling noise.

The speed dependence of the rolling noise and the propulsion noise contributions for light motor vehicles and for heavy duty vehicles are given in the figures below (see Figure 3). It is clear that for light motor vehicles, rolling noise starts to dominate the overall noise emission for a vehicle speed of 30 km/h upwards. For heavy vehicles (cat. 3) this “break-even point” is around 75 km/h.

For specific situations deviating from the reference conditions, such as other types of road surfaces, higher fraction of diesel engines or more illegal exhausts, the propulsion and the rolling noise contributions can significantly deviate from these curves. At other types of road surfaces the rolling noise levels can be up to 5 dB higher or about up to 7 dB lower. At noise absorbing surfaces, also propulsion noise will be lower than at the reference situation.

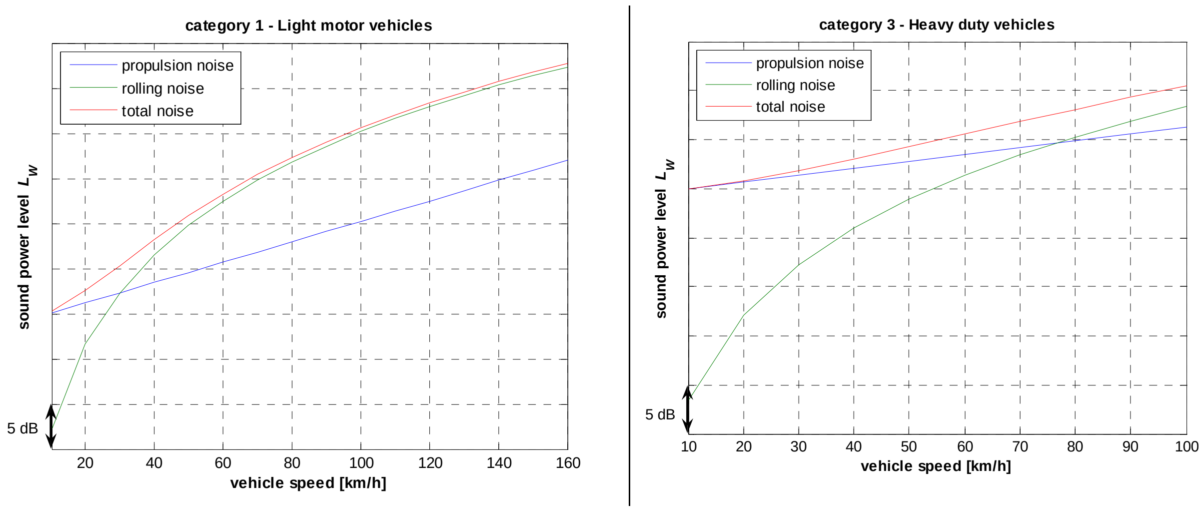

Figure 3: The graphs present the total A-weighted level of both rolling noise and propulsion noise components, as well as the total sound power, as a function of vehicle speed. The curves show the linear relation for propulsion noise and the logarithmic relation for rolling noise.

CONCLUSIONS

The Harmonoise/Imagine model for road vehicles represents a complete and consistent description of the noise emission of the average European road vehicle as a function of speed and acceleration and for the relevant vehicle categories. It is applicable to more then 95% of the situations encountered in noise mapping. It features a distinction between rolling noise and propulsion noise. Local variations in road surface properties, fraction of diesel engines for passenger cars, fraction of illegal exhausts for motorcycles, average vehicle weight, usage of winter tyres or studded tyres, vehicle age, surface wetness, air temperature and many more can be accounted for by correction coefficients.

The vehicle emission model can be applied in traffic streams, either through dynamic modeling of traffic stream behavior or through assumption of steady speed conditions.

The uncertainty of the model is estimated to be 0,5 dB on the total A-weighted level at 70 km/h. It increases to about 1,0 dB at individual 1/3rd octave bands. Also at lower and higher speeds the model becomes less accurate to about 1,0 dB at 40 and 120 km/h.

ACKNOWLEDGMENTS

We gratefully acknowledge the contribution from all partners of the Imagine Work Package 5, Volvo 3P and SP from Sweden, TU Gdansk from Poland, Autostrade and EU-JRC from Italy, TRL, Leicester City Council and University of Leeds from Great Britain and M+P from the Netherlands to this result. We thank the European Commission for their financial support.

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