

Development of an European road traffic emission model within the framework of the EU 6th Framework project IMAGINE.

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The European Commission's 6th Framework project IMAGINE aims at calculating immission levels from the most important environmental noise sources. For the assessment of road traffic noise, a model has been developed in the past 5th Framework Harmonoise project which calculates the rolling noise and propulsion noise emission for all common vehicle types in 1/3-octave bands as a function of vehicle speed and acceleration. Corrections to the emissions for vehicle and road parameters as well as meteorological conditions are provided. Within IMAGINE a database is created, based on new measurements and analysis of readily available data, with the coefficients and correction factors needed to enable the use of the emission model for all vehicle categories and conditions in urban traffic. Special attention is paid to the variations of vehicle and tyre types over the European regions and their influence on the average noise levels. Together with an appropriate traffic flow model, for which the guidelines are also developed within IMAGINE, and the existing Harmonoise propagation model, the result can be used for noise mapping and noise abatement action plans which will be required by the EU Noise Directive in the near future. The paper will describe the base model, the current status of the ongoing project and prospects of final results.

1 Introduction

The European Noise Directive [1] requires regular reporting of noise exposure from the population in the larger agglomerations and along major infra-structure systems.

The EU DG Research has facilitated the harmonized reporting of noise exposure by financing the development of a harmonized calculation tool.

During the first phase in the 5th Framework project HARMONOISE, a propagation method was developed, together with the procedures to describe the road and railway sources. During the next phase in the 6th framework project IMAGINE aviation and industry are added as noise source and road and rail vehicles will be further elaborated.

The present paper will address the acoustic description of road vehicles as a noise source to be inputted in a propagation modeling to obtain immission levels at certain reception positions.

Within this subject two distinct parts can be distinguished:

1. the acoustic sound power level of an individual vehicle;
2. the composition of individual vehicles into a traffic flow.

The latter subject is addressed in a work package on traffic flow management that is led by TNO Mobility and Transport Safety (NL).

The first subject is worked on in the Work Package 5 on road vehicle noise emission, which is led by M+P

and where TRL (GB), TU-Gdansk(PL), Autostrade (I), Volvo Trucks (S), University of Leeds (GB) and Leicester city (GB) cooperate.

The objective of this work package is to describe the noise production of a road vehicle in terms of 1/3 octave levels of the sound power, as a function of vehicle speed and acceleration, vehicle type and taking into account influencing factors from road surface type, regional variations and meteorological conditions.

The basis of the work package is the formulation and procedure developed within the Harmonoise project, which is described in §2 below.

2 Harmonoise description

2.1 Emission formulas

The modeling of a road vehicle noise source developed within HARMONOISE distinguishes a noise source originating from tyre/road interaction and a noise source due to the power train. Aero dynamical noise is considered as a third source, but in the modeling procedure it was combined with tyre/road noise.

The source descriptors basically follow the following formulation:

$$L_w = A + B \cdot f(v) + C_i \quad (1)$$

With A and B coefficients in 1/3 octave bands, depending on the vehicle type, f being a specific function of the vehicle speed and C presents the effects

of driving condition, road surface, regional variations and meteorological conditions.

A full description of the HARMONOISE source model for road noise can be found in the project deliverable [2] which is available through the project website [8].

2.2 Rolling noise formulation

Based on this general approach the extended formulation for rolling noise was found to be:

$$L_{W,rolling,i,m} = (a_{i,m} + \alpha_{i,m}) + (b_{i,m} + \beta_m) \lg\left(\frac{v}{v_{ref}}\right) + C_{region,m} + C_{meteo,m} \quad (2)$$

with:

- $a_{i,m}$ and $b_{i,m}$ coefficients representing the rolling noise production of the vehicle on the reference road surface;
- $\alpha_{i,m}$ and $\beta_{i,m}$ representing the speed dependent effect of the road surface;
- i and m indicate the 1/3 octave band index and the vehicle class index, respectively;
- C_{region} : effect of regional variation in tyre types (e.g. winter tyres in Scandinavian and Alpine regions in winter);
- C_{meteo} : effect of meteorological conditions, such as temperature and surface wetness;
- v_{ref} : reference speed of 70 km/h.

2.3 Propulsion noise formulation

For propulsion noise a linear relation with the speed of the vehicle was observed leading to the following formulation:

$$L_{W,propulsion,i,m} = a_{i,m} + b_{i,m} \cdot \left(\frac{v - v_{ref}}{v_{ref}}\right) + c_i \cdot a + C_{region,m} + C_{road,m} \quad (3)$$

with:

- $a_{i,m}$ and $b_{i,m}$ coefficients representing the noise production of the vehicle at a constant speed;
- $c_{i,m}$ representing the influence of vehicle acceleration and deceleration;
- i and m presents respectively the 1/3 octave band index and the vehicle class indices;
- C_{region} : effect of regional variation in vehicle parameters (i.e. higher average vehicle weight in Sweden than in Greece; different % of diesel engines, etc.);

- C_{road} : influence of road surface on near-field propagation of propulsion noise;
- v_{ref} : reference speed of 70 km/h.

3 IMAGINE project

3.1 General structure

In Figure 1 the structure of the IMAGINE project is schematically depicted. Each of the Work Packages (WP's) 4 through 7 are responsible for the four different noise sources. WP1 is responsible for the GIS mapping part, WP2 for the traffic flow modelling guidelines and WP3 for the general measurement, monitoring and validation methods. More information on IMAGINE can be found on the project website [9].

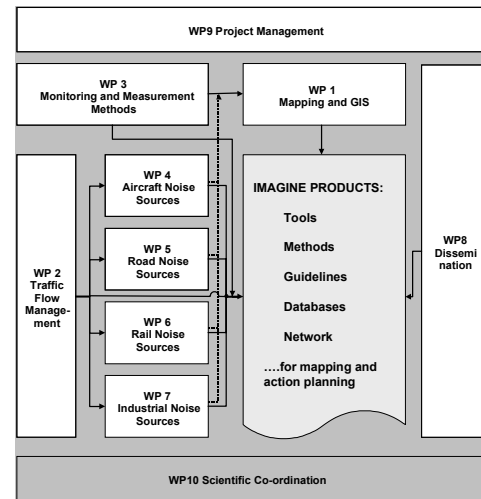


Figure 1: Structure of the IMAGINE Work Packages

3.2 Road noise source modelling

Within the HARMONOISE project, default values for the coefficients described in §2.2 and §2.3 have been developed based on limited data sets. Within IMAGINE, Work Package 5 is responsible for creating the database with accurate coefficients for all vehicle classes that can be used to predict noise emission levels representative for the average European vehicle under reference circumstances, and with a set of corrections to account for deviations from the reference circumstances and significant deviations of the local vehicle fleet from the European average.

Part of this work will be re-analysing of measurement data available through the WP5 partners, while new measurement data are also needed, especially for:

- propulsion noise of heavy duty vehicles;
- powered two-wheelers;

- variations in the noise production of the general traffic stream over different regions.

4 Preliminary results

4.1 Propulsion noise of heavy duty vehicles

The propulsion noise of heavy duty vehicles (HDV) has been studied under different circumstances to determine the influence of vehicle parameters as speed, acceleration, engine speed and also of the weight of the truck load and of the up- and downhill road grade. These experiments have been done [4] in the Volvo truck laboratory using both a power train rig (Figure 2), where only the truck driveline is installed, and in a noise chamber where a full truck is put on a roller (Figure 3).



Figure 2: Powertrain rig in the laboratory



Figure 3: HDV tractor in the truck noise chamber

Sound level measurements were performed with several microphones placed in a virtual parallelepiped reference box around the truck, according to ISO 3744 [5], from which the sound power level is then calculated.

First, measurements have been performed at constant speeds ranging from 5 to 85 km/h. At each vehicle speed the “most suitable gear” was chosen, which for that vehicle type corresponds to an engine speed of about 1100 to 1300 rpm.

When plotting the resulting sound power levels in dB(A) against the logarithm of the vehicle speed, similar to Eq. (2) but for overall levels, a higher correlation was found for the full truck measurements than for the power train rig ($R^2 = 0.81$ vs. $R^2 = 0.45$).

Repeating the same measurements in the truck noise chamber with one gear lower for 10-70 km/h, which may be representative of a more agile driving style, resulted in an average increase of 1.4 ± 0.3 dB(A).

Simulations of different uphill and downhill road grades were also done with the HDV tractor at 50 km/h. Linear regression of the results showed that for uphill driving, the SPL increased with 0.31 dB(A) per % road grade ($R^2 = 0.55$). For downhill driving, using only engine braking to maintain a constant vehicle speed, the SPL increased with 0.38 dB(A) per negative % road grade ($R^2 = 0.79$). Note that for some steep roads, the vehicle speed had to be taken somewhat lower to be able to keep a constant speed.

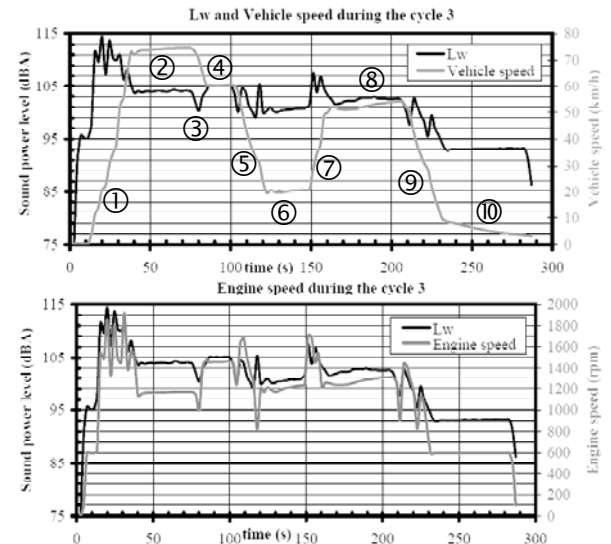


Figure 4: Results of city cycle showing source power level (L_w) and vehicle speed (top) / engine speed (bottom), nrs. refer to driving conditions listed below

Finally the truck noise chamber setup was used to simulate a condensed city cycle, which included:

1. engine start and full throttle accel. to 70 km/h;
2. constant 70 km/h for 30 s;
3. engine braking to 60 km/h;
4. constant 60 km/h for 15 s;
5. engine braking with downshifting to 20 km/h;
6. constant 20 km/h for 30 s;
7. full throttle acceleration to 50 km/h;
8. constant 50 km/h for 45 s;
9. engine braking with downshifting to stop;
10. low idling for 30 s and engine stop.

In Figure 4 the resulting sound power levels in dB(A) are shown for this city cycle by the black curve, which was repeated 3 times. In the top graph, the grey curve indicates the vehicle speed; for the bottom graph, the grey curve indicates the engine speed.

A thorough analysis of this and additional data will be done in the near future in order to determine the speed slope and acceleration coefficients for HDV needed for the IMAGINE source model.

4.2 Powered two-wheelers

Powered two-wheeler (PTW) noise will be dominated by propulsion noise; rolling noise for this vehicle category is considered irrelevant. The measurement program for PTW noise consists of:

1. on-board measurements on a select group of vehicles;
2. roadside (SPB) measurements on a statistically representative group.

The first measurements have been done at the end of 2004 and give insight in the noise generation of a specific set of vehicles and the influence of driving and gearshift behaviour.



Figure 5: On-board noise measurement setup

The measurement setup is shown in Figure 5. The vehicle speed and acceleration, engine speed and throttle position (associated with the engine load) are determined together with the noise level close to the inlet and outlet.

The measurements are done with a scooter, moped and a 885cc motorcycle. The route chosen is 6.8 km of urban roads, with an additional highway section for the motorcycle. The on-board noise levels are transferred into roadside noise levels at 7.5 m distance by means of a number of pass-by measurements where both 7.5m and close proximity positions were measured simultaneously.

In Figure 6 and Figure 7, the engine speed in rpm for each 0.05 s interval is plotted against the vehicle speed

in km/h for one measurement run; the greyscale indicates the noise level¹.

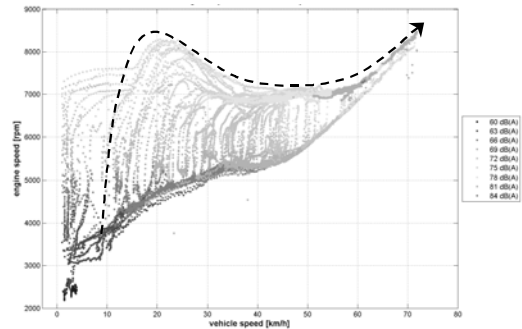


Figure 6: Engine speed vs. vehicle speed for a 49cc scooter with variomatic transmission

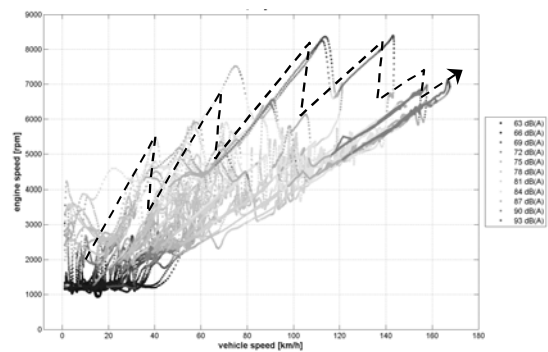


Figure 7: Engine speed vs. vehicle speed for a 885cc motorcycle with 6-speed manual transmission

A clear difference is seen in the engine speed / vehicle speed relation for the manual transmission of the motorcycle (Figure 7), where the fixed gear ratios of each gear can clearly be identified from the “see-saw” type graph, and the variomatic transmission of the scooter (Figure 6). On opening the throttle at low vehicle speed, the latter seems to increase its engine speed (to gain torque) before the vehicle speed actually starts increasing.

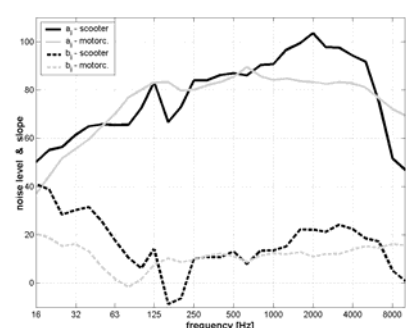


Figure 8: Coefficients a_i and b_i for both vehicles

¹ full colour images are available through www.mp.nl and www.silentroads.nl

By means of a linear regression of the noise level versus the vehicle speed, the coefficients $a_{i,m}$ and $b_{i,m}$ needed in equation (3) can be established. The results for the scooter and motorcycle are given separately in Figure 8, where the solid lines indicate the noise spectrum at 70 km/h ($a_{i,m}$) and the dashed lines show the slope of the noise level with the engine speed ($b_{i,m}$).

The curves for both vehicles show significant differences: at low frequencies, as well as between 1 and 4 kHz, the motorcycle shows lower noise levels and a lesser dependency on the vehicle speed. The scooter shows a peak in the spectrum at 80 - 160 Hz and a drop in the b_i slope. For both mopeds, the A-weighted sound power is dominated by the frequency range around 2 kHz, while the heavy motorcycle exhibits a broader frequency spectrum.

Due to the dominance of propulsion noise, the noise generation of PTW's is very dependant on the type of vehicle and engine. A larger dataset with measurements of vehicle and engine speed of 15 PTW types during urban and highway driving has recently become available and will be analysed in the near future to gain more insight in the variations of engine behaviour. More representative coefficients for the "average" two-wheeler will come from the planned roadside measurements on PTW in normal traffic.

4.3 Regional influences

The road noise emission model that will result from IMAGINE describes the noise generated by the "average European vehicle". However, some aspects of the vehicle and tyres vary greatly over Europe: the use of winter tyres is common in the Nordic countries, while very rare in the Mediterranean, for instance. And the vehicle age, and state of maintenance, will be different for regions with generally wealthier people.

An investigation of the variations in vehicle parameters and tyre usage statistics in European countries has started, concentrating on

- vehicle age, weight, fuel type, and engine capacity;
- tyre width, use of winter (or studded) tyres, % of blocked profiles for trucks.

Two examples are given here. In Figure 9, the distribution of vehicle age is given for light motor vehicles in a number of European countries. The percentage of vehicles belonging to a certain age range is shown, as well as the estimated average vehicle age for each country.

From this graph, a maximum difference of 1.5 years in average age between two different countries is seen. Previous research has shown [3] that the impact on noise is in the order of 0.4 dB per 10 years of age.

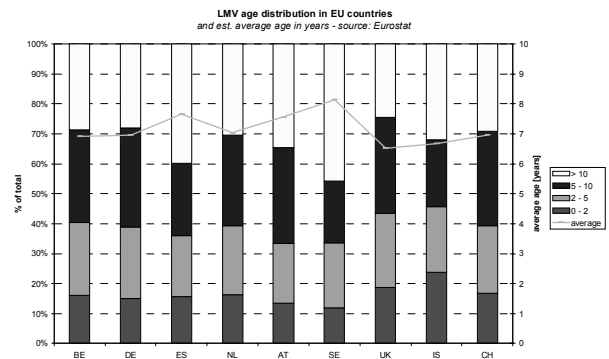


Figure 9: Age distribution for LMV in various European countries [source: Eurostat]

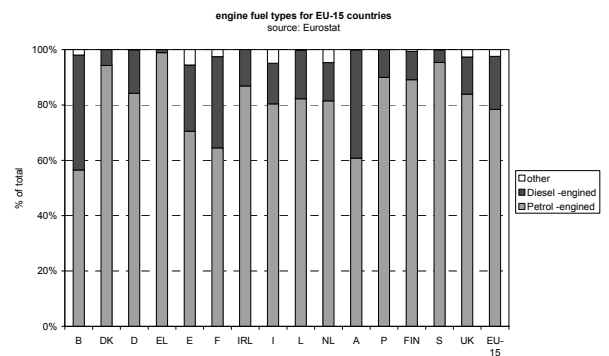


Figure 10: Distribution of engine fuel types for LMV

More relevant is the distribution of engine types. In Figure 10 the distribution for light motor vehicles in 15 EU countries is given. According to [3], the difference between diesel and petrol engines is 1.7 dB(A) at 40 km/h. This would result in a difference of 0.8 dB(A) between certain countries due to the engine type difference.

A more extensive set of statistical data from more regions and on other subjects is currently being gathered.

5 Integration with traffic flow modelling

As a next step in the IMAGINE project, the road noise emission model developed will be combined with traffic models, providing the speed and acceleration profiles for the entire traffic flow on a city road network. A separate Work Package (WP2) within IMAGINE is responsible for providing guidelines on how to use traffic models together with the noise model.

Partners in this WP have identified clear differences between the usual perspective of traffic and noise

modellers: where traffic modellers are usually interested in the performance of the road network in terms of congestion and origin-to-destination time, noise modellers are interested in the actual speed and acceleration values at each position [6]. The Work Package is currently developing strategies on how to get the required results out of the various levels of detail available in traffic models and what to do if less detailed data are available.

A first indication of the combined result is presented here. Recent measurements by INTEC and M+P have taken place in Gentbrugge (B) to compare the outcome of a microscopic traffic model with actual speed and acceleration values from several runs through traffic with an instrumented vehicle [7].

With the aid of the current HARMONOISE coefficients for passenger cars [2] the noise emission of one vehicle over a specific route has been calculated, as shown in Figure 11. The dark line shows the noise emission calculated from the actual measured speed and acceleration; the medium grey line shows the emission calculated from the average speed and acceleration resulting from repeated simulations with the traffic model. The other lines show the minimum and maximum values resulting from these simulations.

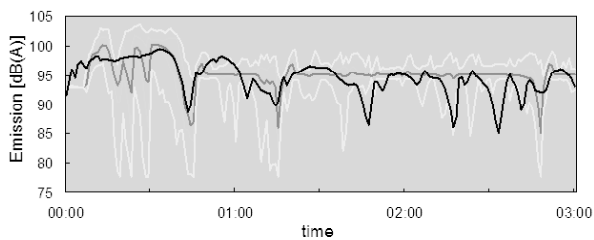


Figure 11: Noise emission calculated with actual speed/accel. (dark line) vs. various simulations

Such a detailed microsimulation model, though becoming more popular, will not always be available. The goal of the strategies being developed is, therefore, to achieve maximum accuracy and representativity with the available means. These strategies will include, for instance, the use of sound level corrections for different types of intersections, as a function of the intensity of incoming and outgoing traffic and other junction design parameters.

6 Discussion and conclusion

The work for the IMAGINE project is far from finished. The results presented above are merely an indication of the ongoing process. However, the analysis of the measurements presented give good confidence in the Harmonoise source model description and in a useable and useful end result, being an accurate description of the noise production of

the average European road vehicle and detailed corrections for all relevant parameters influencing the noise prediction. When combined with suitable traffic model data, the production of representative noise maps for road traffic noise for the European agglomerations will be possible, which will initiate the future action plans for road noise abatement.

References

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