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IMAGINE
Improved Methods for the Assessment of the Generic Impact of Noise in the Environment

Assessment Programme for Parameters of the "general" European vehicle fleet

***Deliverable D3* of the IMAGINE project**

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EXECUTIVE SUMMARY

Work package 5 of the IMAGINE project deals with Road noise sources and has the task “to provide default databases for the source description of road noise, i.e. vehicle category and possibly road surface type related, for a typical fleet of European road traffic, and provide guidelines on how to deal with situations deviating from the default value”.

Based on the data gathered in the Harmonoise project a first model has been made, which distinguishes two sources: rolling noise and propulsion noise. Both sources are described showing dependency on vehicle speed and vehicle class. Various correction factors are introduced, of which the most important are the road surface and vehicle acceleration.

Within the framework of Imagine various extra sources of information have been gathered in order to improve the model. The most important results are:

- Measurements on powered two wheelers. Both on board measurements and statistical pass-by measurements have been performed resulting in a first estimate of the model parameters.
- Detailed measurements on a truck in a semi anechoic chamber. Resulting in detailed spectral information on the behaviour of the powertrain. Additional measurements were performed during driving up- and downhill.
- Measurements on accelerating traffic. Statistical pass-by measurements where performed on traffic accelerating from a roundabout while measuring vehicle speed and acceleration. These insights will be used to tune the acceleration coefficient in the model
- Statistical data on vehicles fleet composition. Various sources have been found for information on the national differences in fleet composition in Europe. These data will be used to determine national correction factors from the “universal European model”.

An action plan has been set up in order to answer the remaining questions by additional measurements, analysis and data gathering. A summary of the remaining issues and remaining work items is given in Table VII in Chapter 5 of this report.

figure 1 – Detailed truck noise measurements in the semi anechoic chamber.

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INTRODUCTION

1.1 The IMAGINE project

For the production of strategic noise maps as required under the EU Directive 2002/49/EC, improved and harmonized assessment methods for environmental noise will be required. Noise from four major noise sources, road traffic, railway traffic, aircraft and industrial activities in agglomerations, need to be included in the noise mapping. For road and rail traffic, calculation methods have been developed in the 5th framework HARMONOISE project. Similar methods will be developed for aircraft and industrial noise in the IMAGINE project. For road and rail sources, noise source databases are being developed in IMAGINE to allow a quick and easy implementation of the models in all member states. IMAGINE will provide the link between HARMONOISE and the practical process of producing noise maps and action plans.

1.2 Work Package 5 – Road noise sources

Within the IMAGINE project, Work Package 5 is responsible for the development of the calculation methods and noise database for the assessment of road traffic noise. The general objective of WP5 is:

> *to provide default databases for the source description of road noise, i.e. vehicle category and possibly road surface type related, for a typical fleet of European road traffic, and provide guidelines on how to deal with situations deviating from the default value*.

In the past HARMONOISE project, the development of the road noise emission model has been addressed by Work Package 1.1. Their final deliverable [1] contains the general mathematical formulation of the noise emission model as well as some coefficients that are based on the available measurement data. This document defines the starting point of the work for IMAGINE WP5. Several partners in IMAGINE WP5 have been involved in this HARMONOISE Work Package.

The main task for IMAGINE Work Package 5 is to develop a database with the default coefficients needed for the application of the HARMONOISE model, as well as a set of correction factors for deviations from the default values, including regional effects. These coefficients and corrections will be based on new measurement data and re-analysis of data available through the various WP5 partners. Once these default coefficients and correction factors have been established, the model should provide a statistically reliable prediction of road noise emission, applicable throughout the whole of Europe and adaptable for future trends.

1.3 Relations with other Work Packages

The road noise emission model of WP5 will provide the noise source levels of a single vehicle at an instantaneous moment, based on the vehicle specifications and the traffic parameters, being vehicle speed and acceleration. The assessment of road noise over a whole road network requires the use of a traffic model that provides the number of vehicles on each road segment as well as their speed and acceleration. Our work is therefore closely related to that of Work Package 2, which provides the guidelines for the use of *demand and traffic flow* models.

Other Work Packages in the IMAGINE project that are related to WP5 are Work Package 1, which provides the guidelines and specifications for the actual mapping procedures and GIS methods, and Work Package 3, which describes the measurement methods for validation and improvement of the noise assessment and for monitoring the L_{den} and L_{night} noise indicators.

For more information on the IMAGINE project and other Work Packages, see the website [2].

2 The road noise emission model

2.1 The current model

2.1.1 General layout of the road noise emission model

The road noise emission model shall describe the noise emission of an "average" European road vehicle in terms of a sound power level. This description of the emission model will fit tightly to a propagation calculation method developed in the Harmonoise project.
The emission model consists of a set of mathematical equations representing the two main noise sources:

a. rolling noise due to the tyre/road interaction;
b. propulsion noise produced by the driveline (engine, exhaust, etc.) of the vehicle;

.

Aerodynamic noise is incorporated in the rolling noise sources, since the chosen method of determination of the sound power level determined from coast-by events makes it impossible to distinguish between the two. The effect of aerodynamic noise on the source height can be neglected since detailed measurements have demonstrated that the sources for flow noise are also located in the wheel arches and under the car.

The mathematical formulas exhibit the following general form:

$$L_{i,m}(v,a) = A_{i,m} + B_{i,m} \cdot f(v)\,, \qquad (1)$$

with $f(v)$ being either a logarithmic function of the vehicle speed v in the case for rolling and aerodynamic noise, and a linear function with v in the case of propulsion noise. The sound power level $L_{i,m}$ is calculated in 1/3-octaves from 25 Hz to 10 kHz, where the subscript i indicates the spectral frequency band. The index m represents the vehicle type.

The rolling and propulsion noise production of the road vehicle at the reference speed of 70 km/h is represented by the values $A_{i,m}$. $B_{i,m}.f(v)$ represent the change in noise production due to a difference in vehicle speed relative to a reference speed.
In the paragraphs below we will go into the aspects of the noise production formulations.

2.1.2 The point source model

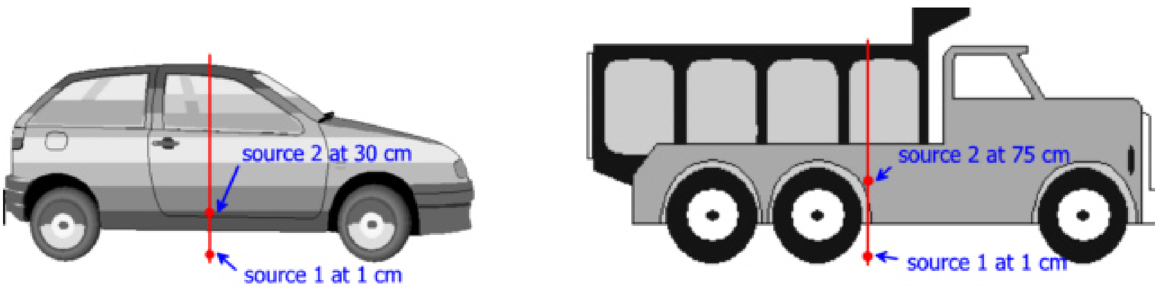


figure 2 – Drawing of noise source positions

For the calculation of the noise emission L_W, each vehicle is represented by two point sources, which are depicted in figure 2 above. The lowest source is located at 0,01 m above the road; the highest source is located at 0,3 m for light motor vehicles and at 0,75 m for heavy motor vehicles. For two-wheelers the height of the point sources is yet to be determined; since the contribution of rolling noise for these vehicles is assumed to be negligible, the main noise sources are probably located from 30 cm and upwards. Vertical resolution of the sources is relevant for the fit to the propulsion model. Ground effects, originating from the interference between direct and reflected components are strongly affected by variation is source height. Real sources, of course, do not exhibit such sharp distributions. This has been accounted for by using a smeared out source in the measurement procedure for estimating the source strengths.
Horizontal resolution is of no relevance since a traffic stream will be represented by a line source. This line source is located at the centre of the road lane.

2.1.3 Rolling noise and aerodynamic noise

For rolling noise, the general accepted and widely validated logarithmic relation between sound power and rolling speed is used. The emission L_{WR} is formulated as follows:

$$L_{WR} = A_R + B_R \cdot \log\left(\frac{v}{v_{ref}}\right), \qquad (2)$$

where, as stated above, the coefficients A_R and B_R are given in 1/3-octave bands for each vehicle class, and v_{ref} = 70 km/h.
As stated above, the aerodynamic noise of the vehicle is incorporated in this rolling noise equation.

2.1.4 Propulsion noise

The propulsion noise emission L_{WP} includes all contributions from engine, exhaust, gears, air intake, etc. For propulsion noise, the emission L_{WP} is formulated as follows:

$$L_{WP} = A_P + B_P \cdot \frac{v - v_{ref}}{v_{ref}}, \qquad (3)$$

where the coefficients A_P and B_P are given in 1/3-octave bands for each vehicle class, and v_{ref} = 70 km/h.
In this formulation, the speed dependence is a linear one. This is based on the combined effect of the effect of vehicle speed on engine speed and the effect of engine speed on noise. The first effect is mainly steered by the gear shifting behaviour of the vehicle or driver. Several field tests has shown that although the driver operates the vehicle in a limited engine speed range, there is a clear tendency for higher engine speeds at higher vehicle speeds.
The relation between sound production and engine speed is a logarithmic one.
The two combined is approached by the formula above. The larger deviations from this approached linear relation occur at very low speed (but they are less relevant for the LAeq level) and at high speeds (but here the rolling noise is dominating the overall noise production).

2.1.5 Correction factors

The equations (2) and (3) describe the sound power level of an European averaged vehicle under standard normalized conditions. The practical situations found at European roads will deviate considerably from these conditions in terms of orientation of the vehicle with respect to the immission position, the non stationary speed, engine technology, vehicle age, tyre mounting, road surface type and road surface condition and the meteorological conditions.

These deviations are accounted for by applying correction factors on the general sound power formulations. The correction factors will be shortly described below. For more detailed information, see [1].

- *Directivity*: To each of the two sources is assigned both a horizontal and a vertical directivity. The directivity is formulated as an angle dependent correction on the sound level. The total value integrated over both angles is 0 on a dB scale (1,00 in absolute terms). This function is different for propulsion and for rolling noise; for rolling noise, the directivity is mainly caused by the 'horn-effect', whereas for propulsion noise, screening of the noise sources by the vehicle body is the main effect. Most relevant effect is the vertical directivity that becomes relevant when calculating noise levels at facades of high rise buildings.

- *Temperature*: It is known that the ambient temperature affects the noise level of a rolling tyre. We follow the recommendations of ISO Working group TC43/SC1/WG27 that state that:

    - the correction is linear with temperature and can be based on the air temperature relative to a reference temperature of 20^{o}C.

    - that the correction is dependent on the type of road surface and the type of tyre.

  The correction factor is demonstrated to be dependant to some extent on the acoustic frequency, but this is considered a 2nd order effect that can be neglected in the general formulation.

- *Tyre type*: The characteristics of the tyres mounted on vehicles do differ in Europe. Especially the usage of winter tyres and studded tyres, common in Alpine and Scandinavian areas, affects rolling noise levels. Within the HARMONOISE model description, there is only a correction for studded winter tyres, of the form $\Delta L = a(f) + b(f)\cdot \lg(v)$ with *a* and *b* known as a function of frequency. In the IMAGINE modelling, additional coefficients to describe the effect of winter tyres and possibly other types, have to be evaluated.

- *Road surface*: One of the most prominent factors is the type of road surface. Effects up to 15 dB are found between the levels of vehicle noise on different surfaces. Rolling noise is mainly affected by the surface type, but also propulsion noise will differ due to local acoustic absorption of porous road surfaces. In the road surface effect the following aspects has to be taken into account:

    - The effect is depending on the vehicle type, the vehicle speed and exhibits a frequency dependency;

    - The effect depends not only on the road surface type, but also on the condition (wet/snow,…) and on the state of maintenance and wear.

  Since these issues are closely linked to road management, the describing procedure has been developed in conjunction with the SILVIA work package on Road Surface Classification (see SILVIA WP2, ref..). The formulation of the correction fit snugly to vehicle noise emission calculations developed in HARMONOISE and is as follows:

$$\Delta L = a(f) + b(f)\cdot \lg(v/v_{ref}) .$$

  Within IMAGINE available data from SILVIA and other sources will be gathered and several default values will be given.

- *Acceleration/deceleration*: An accelerating road vehicle emits more noise than one at constant speed. This is due to higher propulsion noise levels caused by the increased engine load and also relative higher engine speeds due to the up or down shifting behaviour . From on board noise and vehicle driving condition measurements it was found that for the propulsion noise level of passenger cars, within the range -2 to +2 m/s^2, this effect can be approximated with $\Delta L = C \cdot a$. For HDV's a different behaviour is expected since their shifting behaviour and engine braking capabilities are totally different. The rolling noise is assumed not to depend on acceleration or deceleration.

2.1.6 Vehicle classes

Within the Harmonoise project the following vehicle classes were distinguished. See table below.

table I - Vehicle classes identified in the Harmonoise project

Main category (type)	No.	Sub-categories: Example of vehicle types	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[2]
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[4]	2 axles
Heavy vehicles	3a	Buses	3-4 axles
	3b	Heavy trucks[5]	3 axles
	3c	Heavy trucks[5]	4-5 axles
	3d	Heavy trucks[5]	≥ 6 axles
	3e	Trolley buses	3-4 axles
	3f	Vehicles designed for extra low noise driving[4]	3-4 axles
Other heavy vehicles	4a	Construction trucks (partly off-road use)[5]	
	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] For example, there are some delivery trucks designed for extra low noise (meeting more stringent standards than the current EU limiting levels) combined with a driving mode called "whisper mode"

[5] If a high exhaust is noted, identify this in the test report. Categorize this as 3b′, 3c′, 3d′ or 4a′

It is clear that such a scheme cannot be used in practice since this level of detail will probably not be available on the scale of the road network.

A limited level of detail on vehicle class intensity can be compensated by general information on vehicle fleet composition and then be applied as correction on the noise emission. For instance differences in average axle configurations between road types or between regions can be implemented with a 10lg(N) factor to be applied on the EU average HDV emission figure.

2.1.7 Regional variations

Regional variations have been identified within Harmonoise as being important for the model to be valid for all European countries and regions. No regional corrections were developed within Harmonoise, however. This is a separate, new task for our Work Package.

The current model and corrections factors aim to predict the noise level of each vehicle class under many different circumstances, representative for the "average European vehicle". But the "average" vehicle in one country may be different than that of the neighbouring country. In the Nordic countries, for instance, there is a significant period of year when winter tyres or studded tyres are used for passenger cars, while this is not the case in the Mediterranean area. Therefore, the average tyre noise prediction from our model will be too low for the Nordic countries, and too high for Southern Europe, since it is the average of the Nordic and Southern data.
Thus a regional correction is needed, based on i) the *statistical difference* of tyre usage (i.e. the % of passenger cars using studded tyres during the winter months) and ii) the rolling noise increase of a single passenger car using studded instead of regular tyres.

Basing the regional corrections on statistics is necessary i) to obtain corrections that are reliable and representative for a certain region, ii) to be able to develop corrections for every region, since it is impossible to do noise measurements everywhere, and iii) to be able to develop and adapt these corrections in the future, or for situations which we have currently no statistical data for. Thus, these regional corrections will also allow for correction of the model for future trends in vehicle statistics.

Parameters that have been identified as possibly varying over various regions and/or time are:

- properties of the vehicle fleet:
    - vehicle age / state of maintenance
    - vehicle weight / Power-to-Mass ratio
    - engine type
    - engine displacement volume
    - % of replacement exhaust (esp. for PTW)
- tyre properties
    - use of winter tyres
    - use of studded tyres
    - use of traction tyres (block profile) for HDV
    - tyre width (possibly related to vehicle weight)

This list may not be complete. If additional parameters are found to be of importance, they will be added.

2.2 Identification of data needs

In Task 5.1 of our project, the Harmonoise model has been evaluated with respect to the gaps there are in the data. These gaps will then be filled with existing data available through the WP5 partners, or through new measurements if necessary. For each vehicle category, the reliability of the coefficients has been discussed, and the items that have too limited data have been identified as data needs:

- rolling noise coefficients for medium and heavy duty vehicles (cat. 2 and 3);
- propulsion noise coefficients for all vehicle classes, especially Powered Two-Wheelers
- acceleration coefficients for all vehicle classes;
- regional differences:
    - statistical data from as many regions/countries as possible;
    - noise measurements for the significant deviations in statistical parameters;
    - roadside noise measurements from different regions for comparison.

3 Data acquisition and measurement results

3.1 Available data sets

The data needs indicated in § 2.2 should be filled with data from new measurements, or from datasets that already exist and will (possibly) become or have become available to IMAGINE Work Package 5. The results of recent new measurements will be presented in the remainder of this chapter. A list of existing data sets that are available for analysis is given in table II below. This list may not be fully complete; other datasets may be included in the future. Data that have already been included in the Harmonoise project are not included here.

This is only a list of known datasets that could be of use to our model. Availability of these datasets is not guaranteed and will have to be checked with the respective owners before use.

table II – List of available data (possibly) to be used by WP5

	description	***source(s)***	***period***
1	Rolling noise levels of 15 truck tyres on 12 surfaces	M+P (contract of Neth. Transport Ministry)	2003
2	Data base on driving conditions of PTW's	IMMA, approval is obtained for usage in WP5 only	2000
3	“pull away” tests of (medium) Heavy Duty Vehicles	TRL	
4	SEL measurements on general traffic	M+P & TRL, for the SILVIA project	2004
5	CPB measurements at CIRRUS test fields	Autostrade	
6	coast-by measurements of some trucks	TRL	
7	rolling noise measurements on LMV and trucks for ACEA	M+P	
8	propulsion noise data on light motor vehicles	TUG, in their Vehicle Noise Model (VENOM)	
9	powertrain measurements for ACEA	TRL	
10	RoTraNoMo data on propulsion noise of all vehicle categories	RoTraNoMo, through M+P	

3.2 Overview of data acquisition campaigns

To fill the remaining data needs described in §2.2, several data acquisition campaigns have been performed by partners in Work Package 5 (see table III below) . Separate reports have been written for some of these campaigns, for which only the most important results will be presented here.

table III – List of WP5 data acquisition campaigns

	description	***partner(s)***	***period***
1	on-board measurements of Powered Two-Wheelers	M+P	October – December 2004
3	propulsion noise laboratory measurements of Heavy Duty Vehicles	Volvo	January – June 2005
4	outdoor noise measurements of Heavy Duty Vehicles at test track / roundabout	Volvo / SP	June – September 2005
5	SPB measurements at UK highway	TRL	September 2005
6	SPB measurements on general traffic	SP	2nd half 2005
7	SPB measurements on general traffic	TUG	2005
7	SPB measurements on scooters, motorcycles & other traffic	JRC	September 2005
8	pass-by measurements of Powered Two-Wheelers	M+P	August – September 2005
9	pass-by measurements of accelerating traffic	M+P	October 2005
10	statistical data gathering	M+P, TRL, JRC	November 2004 – now

The analysis for these data campaigns has started and will continue in the next year. The final WP5 report (Deliverable D11) and database with coefficients will be based on these analyses. For the current report, all results that are currently available will be presented in the next paragraphs.

3.3 Propulsion noise measurements of Powered Two-Wheelers

3.3.1 Introduction

The vehicle category of Powered Two-Wheelers contains all motorised two-wheelers, being either mopeds with 50 cc engine cylinder volume, "urban" motorcycles with about 100 – 250 cc, and heavy motorcycles with 250 cc and more (could be up to 1500 cc). For Powered Two-Wheelers, rolling noise is considered as negligible with respect to the propulsion noise (see [8]), and will therefore be neglected in our model.

Within the Harmonoise project, no data for Powered Two-Wheelers was included. At the start of IMAGINE, practically no noise data on Powered Two-Wheelers was available. One large measurement campaign by the IMMA[6] with on-board city cycle and highway measurements of 15 different types of PTW has become available, but unfortunately contains no noise data. Some type approval test data from manufacturers could perhaps be gathered, but they are generally difficult to obtain. Another problem is that many two-wheelers have modified exhausts, or RESS (Replacement Exhaust Silencing System) which largely increase the noise. In fact, the IMMA and ACEM[7] state in [7] and [8] that 35% of all motorcycles and 65% of all mopeds in Europe have illegal, extra noisy RESS; the noise increase of

[6] International Motorcycle Manufacturers Association

[7] Association des Constructeurs Européen de Motocycles

the replacement exhaust is estimated up to 10 – 15 dB(A). Representative noise data can only come from roadside measurements on actual PTW traffic.

Within IMAGINE WP5, a new measurement campaign for Powered Two-Wheelers has started therefore, which is two-fold:

1. on-board measurements with a few selected vehicles, extensively equipped to gather detailed data of noise and vehicle parameters, to see what the main parameters for the noise production of PTW are and to estimate the influence of vehicle speed and acceleration;
2. roadside pass-by measurements, to gather statistically reliable and representative levels and speed coefficients for a general fleet of PTW vehicles.

3.3.2 On-board measurements

On-board measurements have been performed by M+P in October – November 2004, and have been previously reported [3]. The content of the measurements and most important results are given here.

Measurement setup

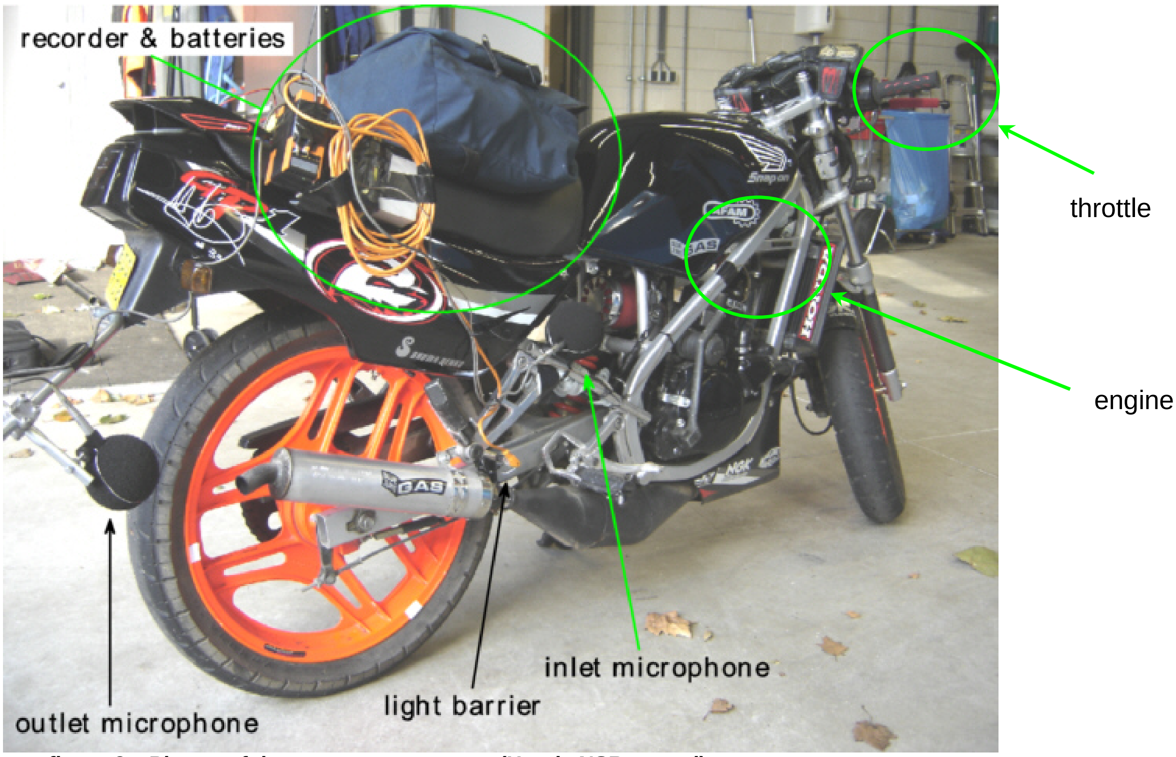


figure 3 – Picture of the measurement setup (Honda NSR moped)

In figure 3, the measurement setup for the on-board measurements is shown. The setup consists of:

- *noise measurements*: two microphones: one at ± 15 cm from the outlet, the other at ± 15 cm from the air inlet,
- *vehicle speed*: a light barrier near the rim of the rear tyre, and reflectors placed on the rim,
- *engine speed*: a coil placed around the ignition wire to measure (by self-induction) the amount of ignition sparks,
- *engine load*: measurement of the throttle position by means of a pot meter with a variable resistance.

These five signals are fed into a portable DAT recorder, placed in a backpack along with a battery pack. Measurements are stored with a data point interval of 0.05 s. A calibration signal is recorded to enable calibration of the microphones afterwards. A couple of extra pass-by runs measuring the sound power level at 7.5 m distance, 1.2 m height, are performed in order to determine the sound level difference between the (average) in-/outlet noise and the roadside noise for each vehicle. All measured noise levels are then corrected with this factor. The noise levels given in this paragraph thus are the sound power levels at 7.5 m distance, to allow for a comparison with other measurements.

For these on-board tests, three vehicles are used. These vehicles are listed in table IV below.

table IV – Properties of the test vehicles

brand	***type***	***transmission***	***# cylinders***	***displacement volume***
Gilera Runner 50SP	scooter	variomatic	1	49 cc
Honda NSR	moped	manual 6-speed	1	69 cc
Triumph Tiger T400	motorcycle	manual 6-speed	3	885 cc

A test route has been chosen near the M+P office in Vught, the Netherlands. The route is 6.7 km long and mainly consists of urban 50 km/h roads, including sections with maximum speeds of 30 km/h and 70 km/h also. For the Triumph motorcycle test, the 30 km/h section is left out and a 100/120 km/h highway section is included.

Results

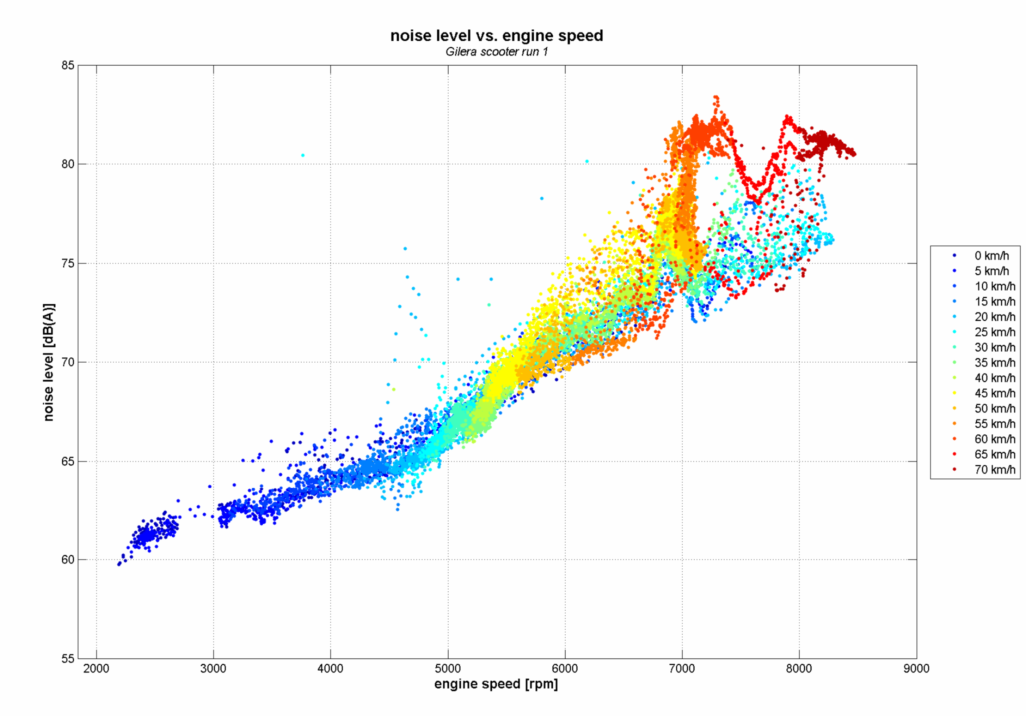


figure 4 – Sound power level vs. engine speed for the Gilera Runner SP50 scooter; colours denote the vehicle speed

In figure 4 the sound power level (calculated at 7.5 m distance) is plotted versus the engine speed for the Gilera 49 cc variomatic scooter; colours indicate the vehicle speed, increasing from blue to red.

From this figure, it is clear that the sound power level for a variomatic scooter increases rather linearly with engine speed; only at high vehicle and engine speeds, an extra noise increase can be seen.
For our project, however, it is necessary to know the noise as a function of *vehicle* speed, rather than *engine* speed, since the noise model needs to be combined with a traffic model that gives only the vehicle speed and acceleration. One option is to use a gear shifting behaviour model to translate the vehicle speed into engine speed. But since such a model will be largely dependant on the precise vehicle parameters, such as power-to-mass ratios, and since such detailed data will generally not be available to the IMAGINE end-users, it was chosen to relate the sound power level directly to the vehicle speed and acceleration, thereby accepting that this may not be the best describing parameters.

A multi-regression analysis was therefore performed on these data, using the propulsion noise formula (3), including the correction factor for acceleration. The formula to fit is thus given by

$$L_{WP} = A_P + B_P \cdot \frac{v - v_{ref}}{v_{ref}} + C_P \cdot a, \qquad (4)$$

where a denotes the vehicle acceleration in m/s^2. The multi-regression analysis then gives the best fit A_P, B_P and C_P coefficients, as well as a correlation coefficient R^2 and a residue (the standard deviation of the residual errors around the trend line).

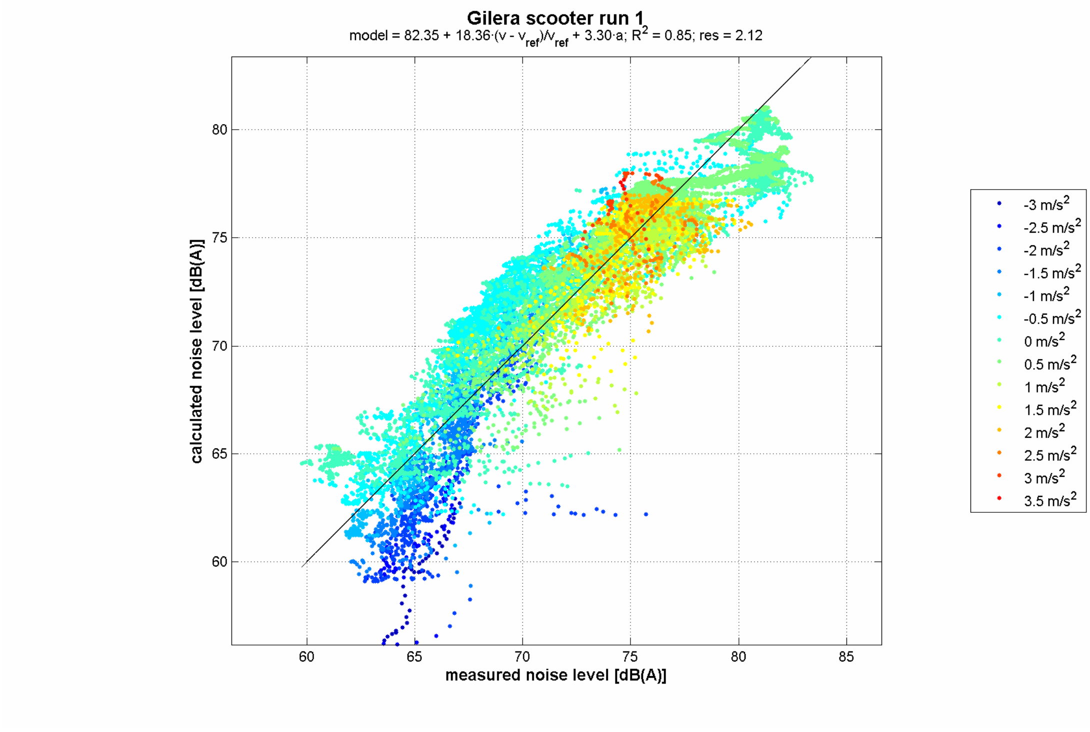


figure 5 – Linear model of the sound power level as $L_p = a + b \cdot v + C \cdot acc$; correlation $R^2 = 0.85$, residue = 2.1 dB(A)

For the other two vehicles used in this test (see table IV), similar graphs were presented in the measurement report [3]. Since both of these vehicles are manually shifted, in stead of the variomatic gearbox for the Gilera, the engine / vehicle speed relation is somewhat more complicated.

In table V the results for the multi-regression analyses are given for each vehicle. From these results, it is concluded that:

- the residue for each trend line ranges from 2 to 5 dB(A) which is acceptable, given the range of 25 – 30 dB(A) of occurring SPL; the correlation factors are around 0.8, indicating that the $A + B \cdot v + C \cdot a$ formula is a good descriptor for the propulsion noise;
- the Honda NSR produces more noise than the other two vehicles, 7 and 10 dB(A) resp. at the reference speed of 70 km/h; this is mainly caused by the RESS mounted on the vehicle, which causes a large increase in exhaust noise;
- the speed coefficients for the Gilera and Honda are approximately equal, where that of the heavy motorcycle is much lower; however, from the figures in [3] it can be seen that the speed coefficient is higher for low speeds; if we limit the data to max. 80 km/h, the speed coefficient raises to 17.4 dB(A) per 70 km/h;
- the noise increase with vehicle acceleration ranges from 1.8 to 4.8 dB(A)/ms^{-2}; this result does not seem to vary significantly over the speed/acceleration ranges.

table V – Overall propulsion noise levels (SPL) as a function of vehicle speed and acceleration for all three test vehicles, with correlation coefficient and residue

vehicle	***trend line***	***correlation R^2***	***residue***
Gilera Runner SP50	$L_P = 82.4 + 18.4 \cdot (v - v_{ref}) / v_{ref} + 3.3 \cdot a$	0.85	2.1 dB(A)
Honda NSR	$L_P = 89.5 + 19.5 \cdot (v - v_{ref}) / v_{ref} + 4.8 \cdot a$	0.78	4.7 dB(A)
Triumph Tiger	$L_P = 79.4 + 10.4 \cdot (v - v_{ref}) / v_{ref} + 1.8 \cdot a$	0.82	2.9 dB(A)

3.3.3 Pass-by measurements of Powered Two-Wheelers

In June, August and September, pass-by measurements were performed at two locations. The location for the first two measurements the A28 highway in The Netherlands, where the traffic to and from a large motorcycle event was captured. The second location was a piece of scenic route, on a sunny day, with a lower speed limit. The combination of both measurements contains the entire speed range from 40 to 120 km/h.

Measurements were done according to the Harmonoise protocol, measuring SEL levels at 1.2 and 3.0 m height, 7.5 m from the centre of the road. For each measurement, the position of the vehicle on the road was noted, since motorcycles tend to drive either on the left or right side of the road lane. The sound power level was then corrected for the vehicle-microphone distance to the reference of 7.5 m with +3 dB per doubling of the distance. The type of motorcycle was also noted, estimating from its looks and noise, being either a “regular” touring motorcycle, a “sports” type, or a “chopper”. The road surface at both locations was dense asphalt concrete.

Motorcycle drivers, especially at special events, tend to drive in groups rather than alone. When SEL levels are used, the average level can be representatively calculated, as long as all vehicles in the group are similar. For our results, we have only included passages with one or two vehicles.

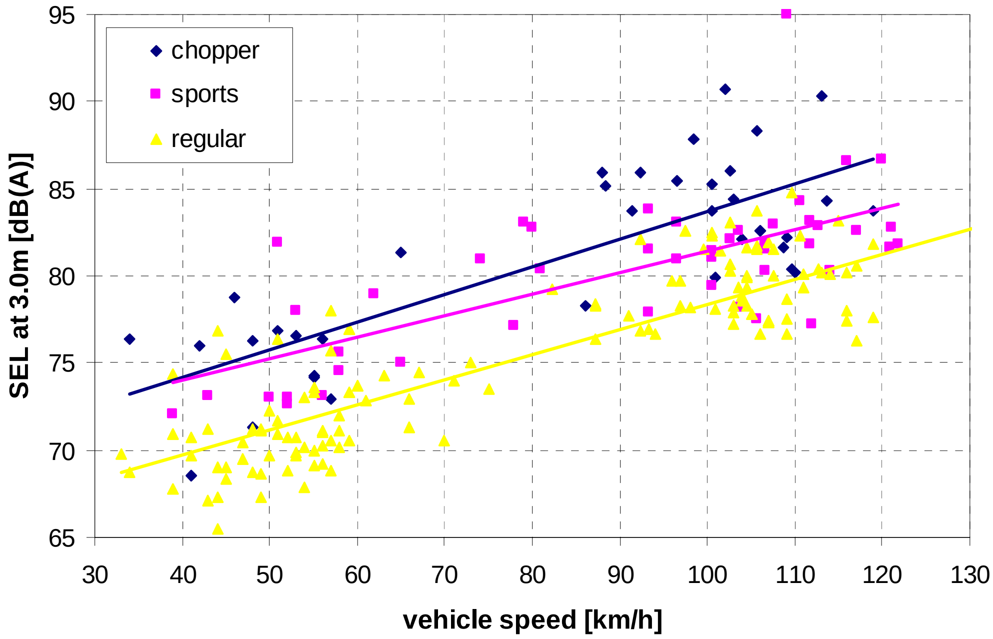


figure 6 – Pass-by measurements of PTW: SEL levels measured at 3.0 m height vs. vehicle speed

In figure 6 the SEL levels measured at 3.0 m heights are plotted versus the vehicle speed, for both measurement sets taken together. Separate linear trend lines have been plotted for the three PTW types. In total, 36 "chopper", 46 "sports" and 130 "regular" vehicles were measurement. In figure 7 below, the 1/3-octave band spectra for these three types are given for 40 and 70 km/h; in the left graph, the average spectrum of a few mopeds passing by is also included.

Though the PTW “type” cannot always be correctly labelled by the looks, it seems that there is a clear difference between the three types that have been determined. The “chopper” type shows an increase of 10 dB(A) relative to the “regular” type in the low frequency range (100 – 400 Hz), indicating significantly more exhaust noise, plus an increase of 2 dB(A) in the remaining frequency range. The “sports” type shows less exhaust noise, but with some distinct peaks at the firing frequency. For the higher frequency range, it produces more noise than the "chopper" type.

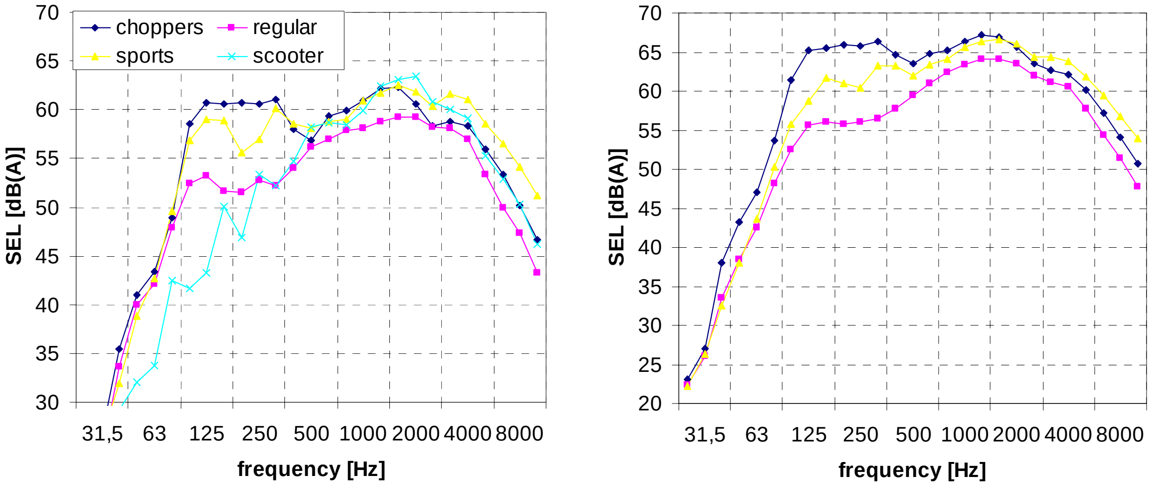


figure 7 – 1/3-octave band spectra per PTW type at 40 km/h (left) and 70 km/h (right)

3.4 Propulsion noise of Heavy Duty Vehicles

3.4.1 Content of measurements

In the first half of 2005, Volvo has performed several propulsion noise tests in their indoor truck laboratory. The results have been reported separately in [6]. The contents of these measurements and the most important results will be presented here.

Three different test programs were accomplished, using the ISO 3744 method for measuring sound power levels:

1. propulsion noise measurements using only the driveline configuration (see figure 8);
2. propulsion noise measurements using a full truck in the truck chamber;
3. city cycle simulations in the truck chamber.

figure 8 – Volvo noise laboratory: the driveline rig (left) and the truck chamber (right)

For the first two tests the propulsion noise source levels were determined driving at constant speed, while varying parameters such as the vehicle load, road gradient, gear shifting behaviour, etc. The city cycle tests were performed in the truck chamber, where the driver was instructed to do a standard programme representative for driving in an urban area. This programme included acceleration from 0 – 70 km/h, constant speed, engine braking, etc. (see [6] for details).

3.4.2 Results

As was stated above, similar tests were performed in the driveline rig and in the truck chamber. The two methods showed some differences in measured noise levels mainly at low frequencies, where the noise levels of the driveline rig were much lower. This is because the exhaust noise is not included in the driveline rig, whereas it is included in the truck chamber measurements. For our model, the measurements in the truck chamber seem most representative; we will therefore not discuss the driveline rig measurements here.

Constant speed measurements

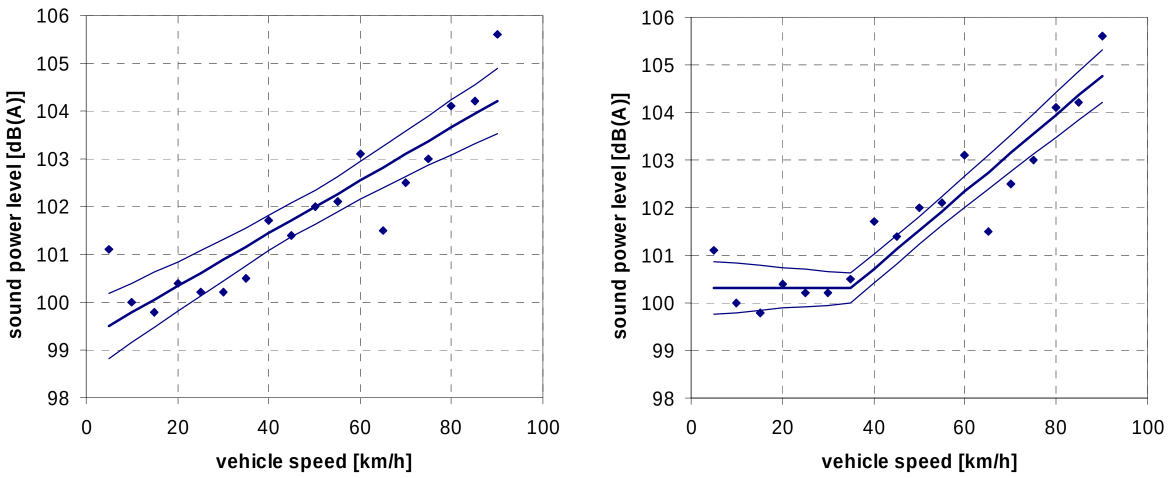


figure 9 – Sound power level at constant speed, measured in the truck chamber, versus vehicle speed; left graph shows a linear trend, right graph assumes constant level below 35 km/h; thin lines show 95% confidence interval

First, the sound power level was measured driving at constant speed in "most suitable" gear. The selection of "most suitable" gear is based on experience with many trucks and driver behaviour, and is basically the lowest engine speed where the driving behaviour of the truck is still comfortable and acceptable. This usually means the gear is selected to keep the engine speed around 1100 rpm.

In figure 9 the sound power level measured in the truck chamber is plotted versus the vehicle speed. In the left graph a linear trend is included, according to the propulsion noise equation (3). This trend line gives a residual error of 0.7 dB(A) and a R^2 of 0.81. The 95% confidence interval around the trend is also shown. Looking at the data points, however, it may just as well be argued that the sound power level does not increase with vehicle speed at all below 40 km/h. This is represented by the trend line in the right graph, which gives a residual error of 0.6 dB(A) and a R^2 of 0.87, and is therefore a better fit.

In figure 10 the 1/3-octave band frequency spectra are shown for three different speeds (30, 50 and 70 km/h), where the black lines are the A-weighted values. The thick line shows the spectrum measured in "most suitable" gear, whereas the thin line shows the spectrum while driving in one gear lower, thus with higher engine speed. The engine speed is given in the graph legends, and shows a clear peak in the spectrum in the 63 Hz and 80 Hz band (the 3rd engine order). Using one gear below the "most suitable" gear results in an average increase of 1.4 dB(A) over the entire speed range.

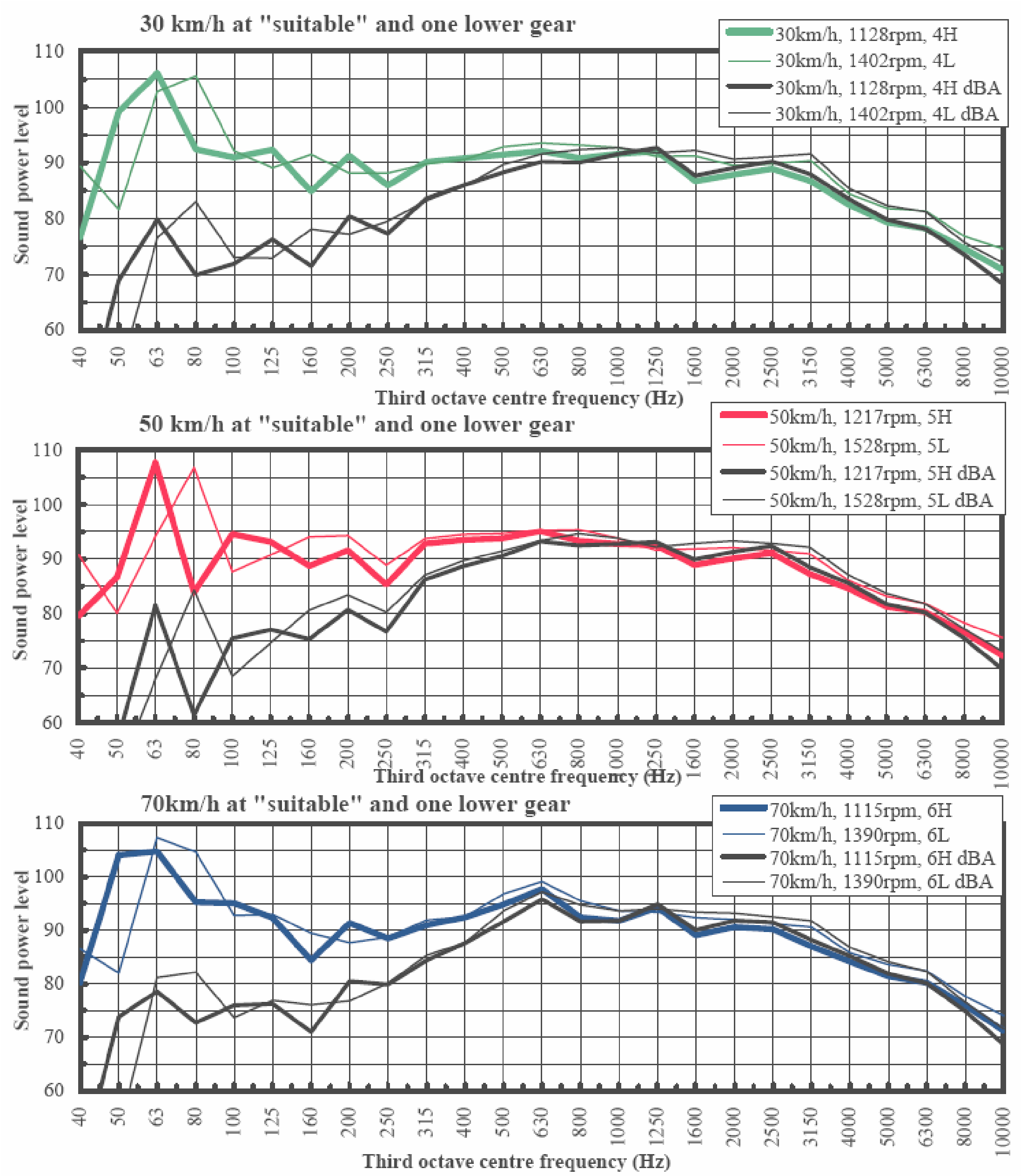


figure 10 – Sound power levels in 1/3-octave frequency bands, measured in the truck chamber at three different constant vehicle speeds, driving in "most suitable" gear (thick lines) and one gear lower (thin lines); graphs show both A-weighted and unweighted dB values

Road gradients

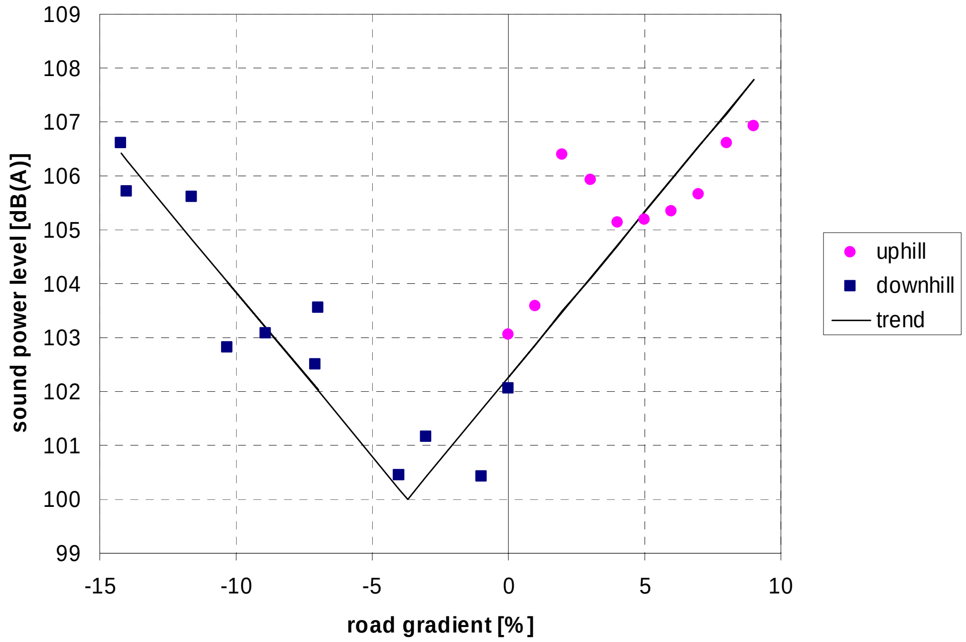


figure 11 – Sound power level measured with different simulated road gradients, both uphill (positive) and downhill (negative)

In the truck chamber, a road gradient (uphill or downhill) can be simulated using a dynamometer, governed by a computer road load model. In figure 11 the measured sound power level is plotted versus the road gradient, driving at a vehicle speed of approximately 50 km/h, while adapting the gear such that this speed can be kept constant. The total weight of the truck was 18 tons.

As can be concluded from this figure, the sound power level increases while driving downhill as well as when driving uphill. The increase of noise while driving downhill is caused by the engine brake of the truck, which will be turned on if the downward slope is too steep to maintain a constant speed. For a passenger car, this will occur only at very steep slopes; this effect will therefore generally not be present for light motor vehicles.

In order to estimate the influence of the road gradient on the propulsion noise level, a trend line is estimated that increases linearly with the road gradient, either downhill or uphill, causing the V-shaped curve. The minimum of this curve is placed at a small negative value, which gives the best fit to the data: as long as the engine brake is not used, the propulsion noise will decrease with decreasing road gradient, since the engine has to deliver less force. The curve in this figure is optimized to minimize the residual error: the slope is 0.61 dB(A) / % road gradient, equal to both sides, with a minimum of 100,2 dB(A) at -3.7% road gradient. The residual error is 1.0 dB(A) with a R^2 of 0.88.

The occurrence of the minimum SPL at a certain negative slope (i.e. downhill) can be understood as follows: at small downward slopes, the truck engine has to deliver less force to keep at a constant speed, since part of the resistence will be overcome by gravity; as long as it is not necessary to use the engine braking system, the noise level will thus decrease because of a decreased engine load. The value of -3.7% slope for the minimum does intiutively seem somewhat low, however, and should, if possible, be verified from other data.

City cycle tests

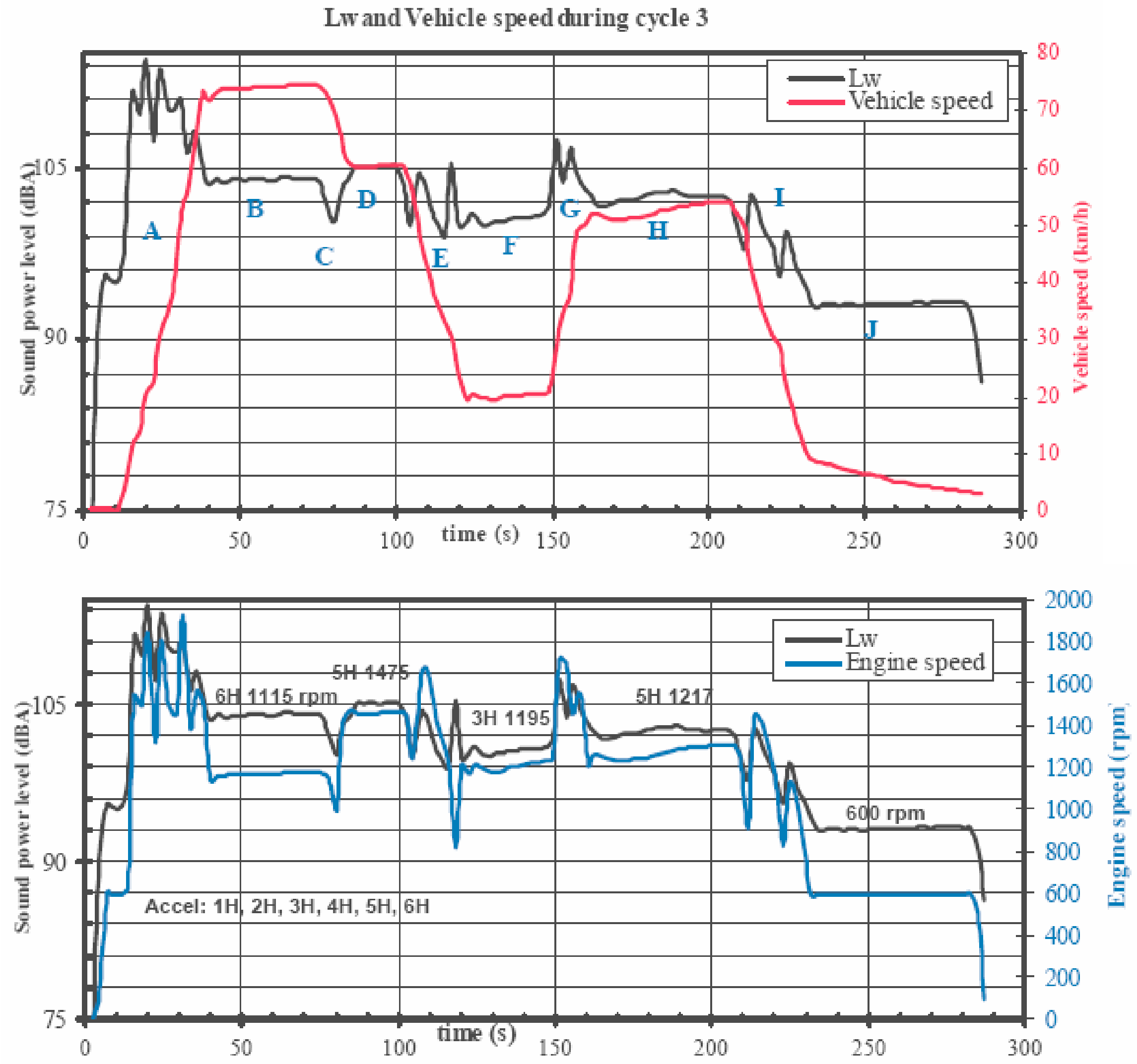


figure 12 – Sound power level during the cycle (A, G = accel., B, D, F, H = const. speed, C, E, I = eng. brake and downshifting, J = low idle)

As was explained above, the city cycle test consisted of a standard program to be performed by the truck, including acceleration, constant speed and engine braking. In figure 12 above the sound power level (black line), vehicle speed (red line) and engine speed (blue line) are plotted vs. time for one test run. The different sections of the program are labelled A to J.

The vehicle speed ranged from 0 to 75 km/h, and the sound power level ranged from 93 dB(A) during stationary idling to 114 dB(A) during full throttle acceleration. The noise level is higher during acceleration (A and G), as would be expected. During deceleration the noise level is also increased as can be seen in sections E and I, if one realises that it should actually decrease with the vehicle speed.

In the future, a multi-regression analysis of the form (4) will be conducted to estimate the *B* and *C* coefficients for the speed and acceleration dependence, also as a function of frequency.

3.5 Accelerating traffic

3.5.1 Measurement setup

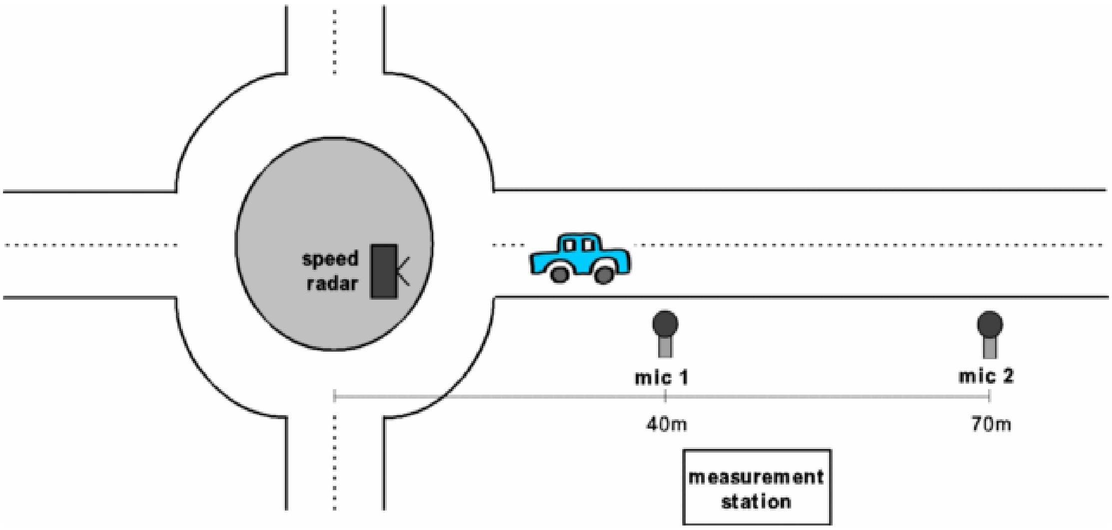


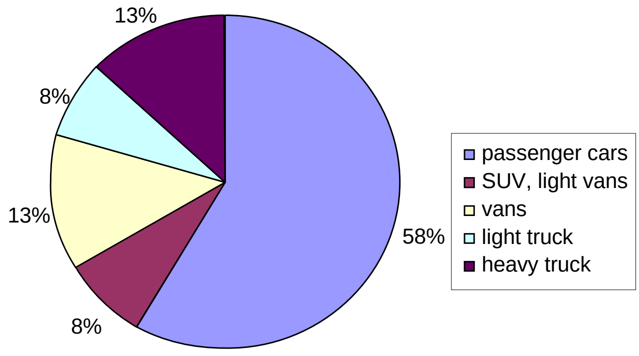
figure 13 – Measurement set-up for pass-by measurements of accelerating traffic

Recently, in October 2005, pass-by measurements of accelerating road vehicles were performed by M+P. Noise measurements of accelerated traffic are relevant for the noise model for two reasons:

1. to correctly and representatively determine the $\Delta L_P = C \cdot a$ correction for vehicle acceleration, for actual traffic and for all vehicle classes;
2. to investigate the influence of vehicle parameters (engine type, age, etc.), which will influence the propulsion noise; propulsion noise will be mainly important for vehicles under acceleration, thus the largest noise variations due to vehicle differences are expected.

The measurements were conducted at a roundabout on a 100 km/h suburban road (N320 Culemborg – Kesteren) in the Netherlands. The measurement setup used is shown in figure 13. The pass-by sound exposure level (SEL) in 1/24-octaves was measured at two positions, 40 and 70 meters from the centre of the roundabout. The vehicle speed was measured along the 70 meter track using a speed radar that was placed on the roundabout, in-line with the road lane; the signal was transferred wirelessly to the measurement station. During the measurements, the vehicle category of each vehicle was noted as well as the number plate, allowing the gathering of specific vehicle details, such as age, weight and fuel type, afterwards.

3.5.2 Results



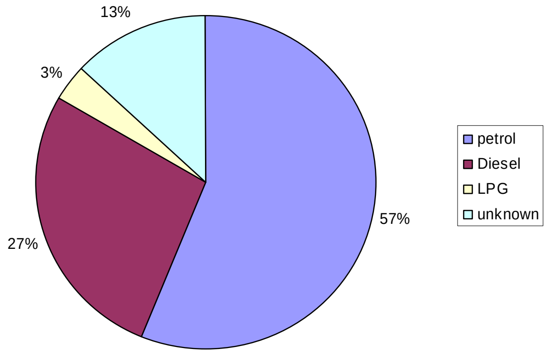


figure 14 – *Left*: Distribution of vehicle classes measured, *right*: distribution of engine fuel types for passenger cars only; total number of vehicles was 300

In figure 14 some statistics for these measurements are given, taken from the number plate information. The circle diagram on the left shows the distribution of vehicle types, where the total number of vehicles passing was 300, of which 58% were light motor vehicles. The graph on the right shows the distribution of engine fuel types for the passenger cars.

Measurements were post-processed, where the speed signal was somewhat smoothed and the instantaneous acceleration was determined by differentiation. The $L_{A,max}$ values for both microphone heights at both measurement positions were determined in 1/3-octave bands. For now, $L_{A,max}$ values are used instead of *SEL*, though *SEL* values will somehow be included in future analysis.

Figure 15 shows the vehicle speed in km/h scattered versus the acceleration in m/s^2 of all passenger cars with the colour of each dot indicating the sound exposure level in dB(A). As can be seen from this graph, the vehicle speed and acceleration are highly correlated; generally, a vehicle with higher acceleration will have a higher vehicle speed at the microphone. The measurements for both microphone positions are found around the two dashed grey lines, where the farthest microphone shows higher vehicle speeds and lower acceleration. The highest noise levels are found for high vehicle speeds and/or high acceleration.

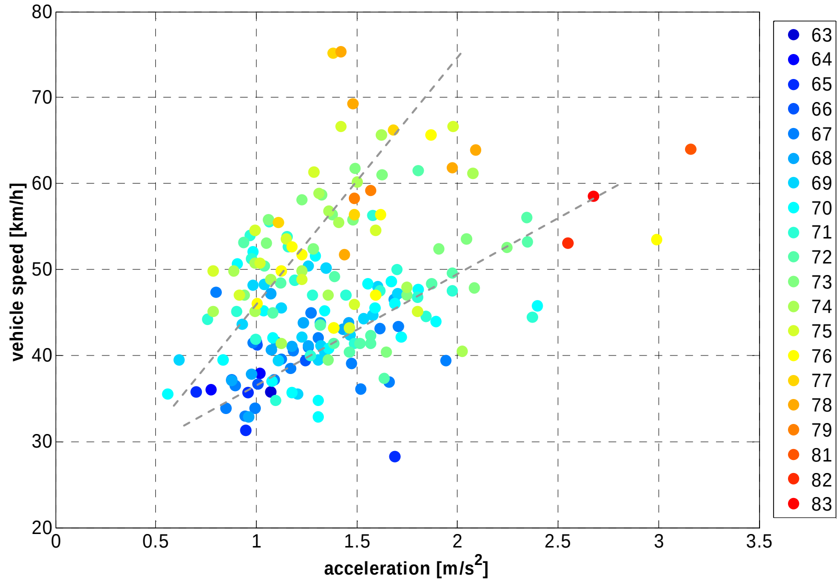


figure 15 – Vehicle speed vs. acceleration for all passenger cars, colours indicate LA_{max} passby levels in dB(A)

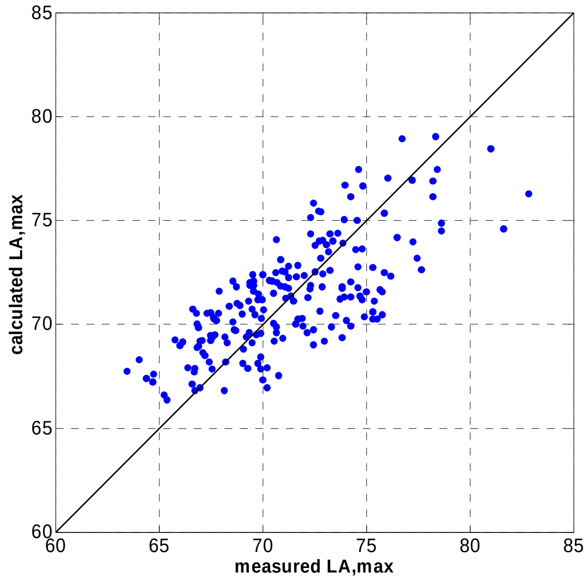


figure 16 – Results of multi regression analysis $L_{A,max} = A + B\cdot(v - v_{ref})/v_{ref} + C\cdot a$ with $R^2 = 0.53$ and a residual error of 2.5 dB(A)

A simple multi-regression analysis was performed on the data. The equation used was that for the propulsion noise, eq. (3), since this is expected as the dominant noise source for accelerating traffic at low speeds; the difference between a linear and logarithmic speed dependence will only be small for this speed range, anyway. The best-fit trend line is:

$$L_P = 75.1 + 19.1\cdot\left(v - v_{ref}\right)/v_{ref} + 1.4\cdot a\,,$$

with R^2 = 0.53 and a residual error of 2.5 dB(A). The fit is not very good, so the resulting A, B and C values are not very reliable. The acceleration coefficient C of 1.4 dB(A) / ms^{-2} seems low relative to previous values [1]; due to the correlation between vehicle speed and acceleration, some of the acceleration effect may have been incorporated in the vehicle speed effect.

To overcome this problem, we have tried to extract the acceleration effect by subtracting from the measured $L_{A,max}$ the speed-dependant Dutch reference value, given by $L_p = 75.8 + 33.0 \cdot \log(v/v_{ref})$ with $v_{ref} = 80$ km/h. The difference between this reference and the measured $L_{A,max}$ is plotted versus the acceleration in figure 17. Further analysis and additional measurements will be performed to better understand the influence of acceleration on the noise emission.

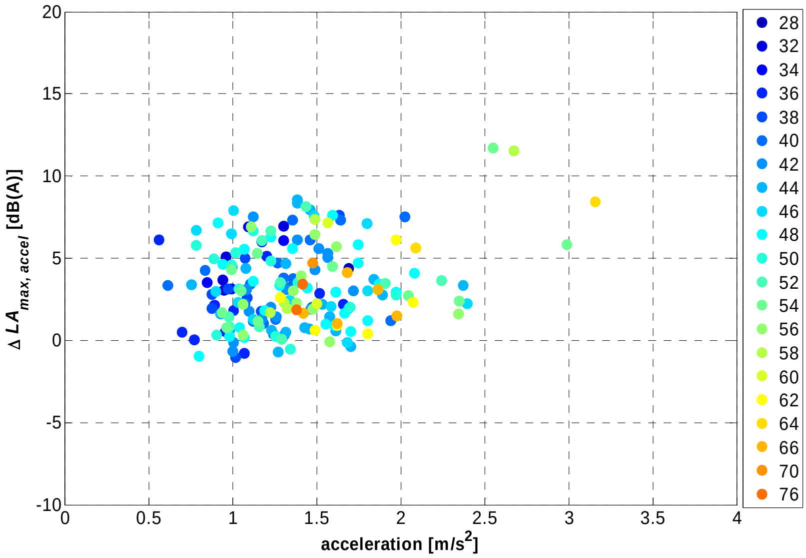


figure 17 – Difference between measured $L_{A,max}$ and $L_{a,max}$ calculated according to Dutch reference, plotted versus acceleration with colours indicating the vehicle speed in km/h (Cat 1A vehicles)

3.6 Statistical data

3.6.1 Introduction

As was explained in § 2.1.7, the research on regional differences will be based on statistical data of vehicle and tyre parameters over the various European countries. Parameters that are of influence are:

- vehicle age,
- vehicle weight,
- fuel type (petrol / Diesel / other),
- tyre width,
- tyre profile type: mainly distinguishing between block / line profiles for HDV tyres,
- summer / winter tyres, and studded tyres in the Nordic countries.

Various WP5 partners have been working on the collection of statistical data from their own country and others. The collection of data is still ongoing, but some examples will be given below.

3.6.2 Engine fuel type

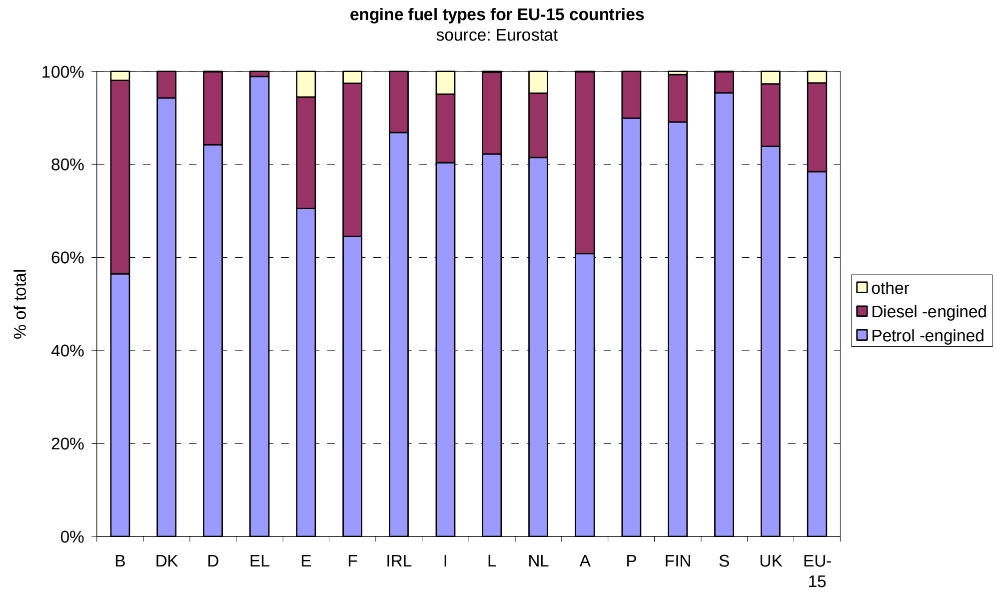


figure 18 – Distribution of fuel types for light motor vehicles in service in 2001 in the EU-15 countries (source: Eurostat)

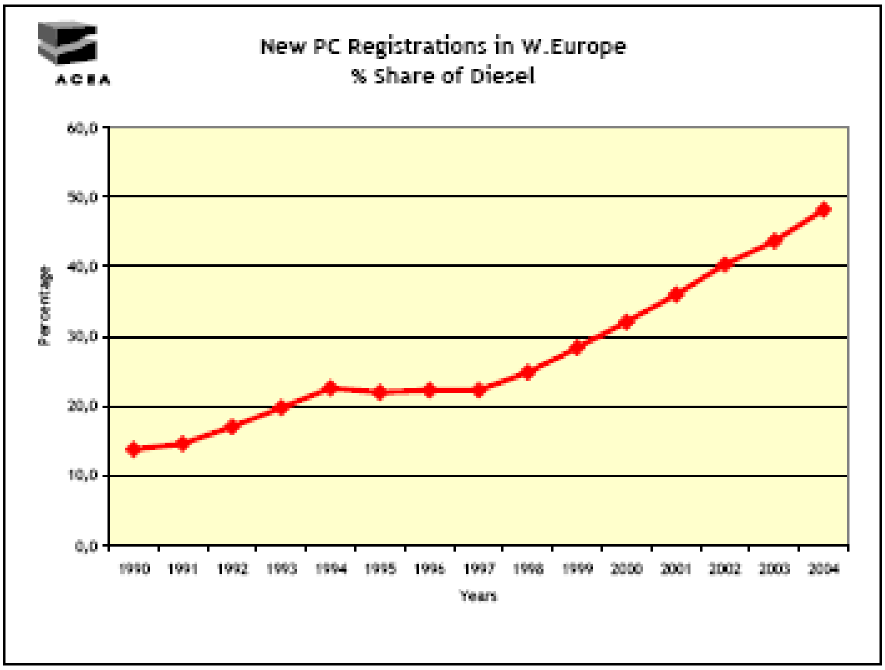


figure 19 – Share of diesel engine for new passenger car registrations in Western Europe (source: ACEA)

3.6.3 Vehicle age

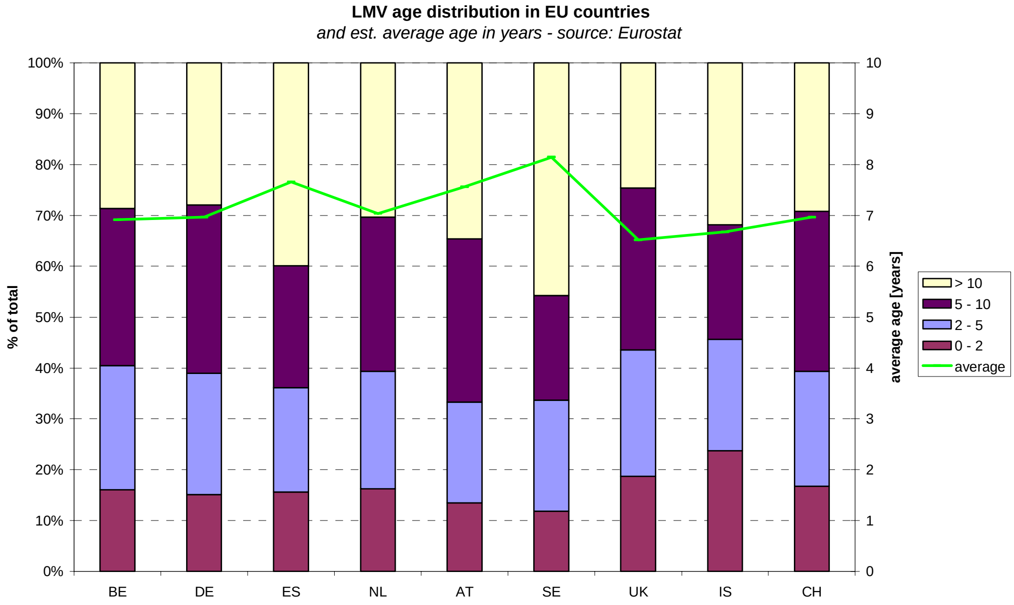


figure 20 – Vehicle age distribution and est. average for light motorvehicles (source: Eurostat, 2001)

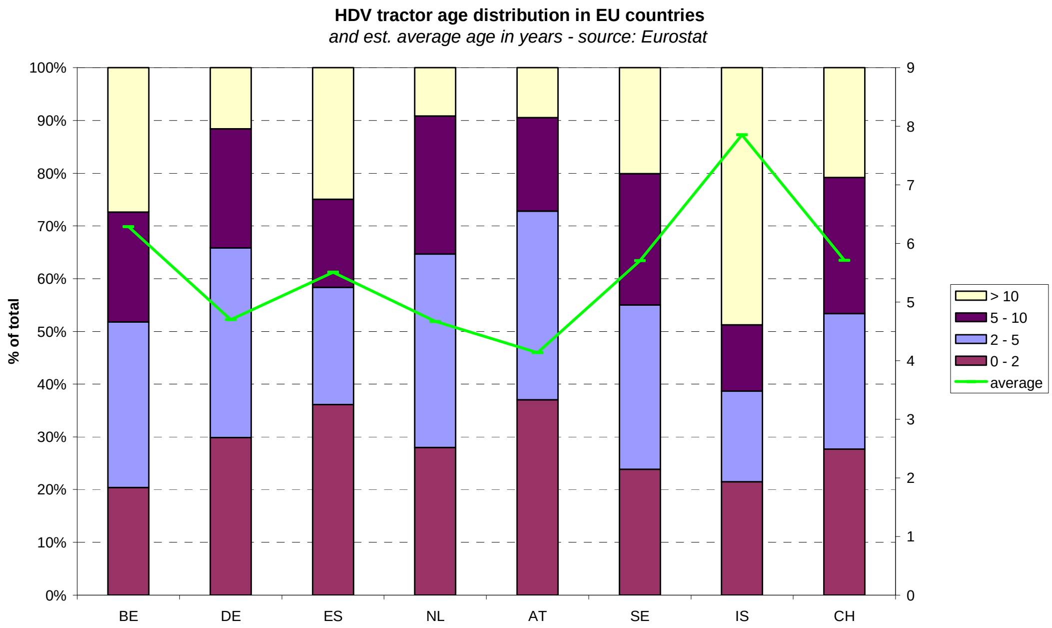


figure 21 – Vehicle age distribution and est. average for HDV tractors (source: Eurostat, 2001)

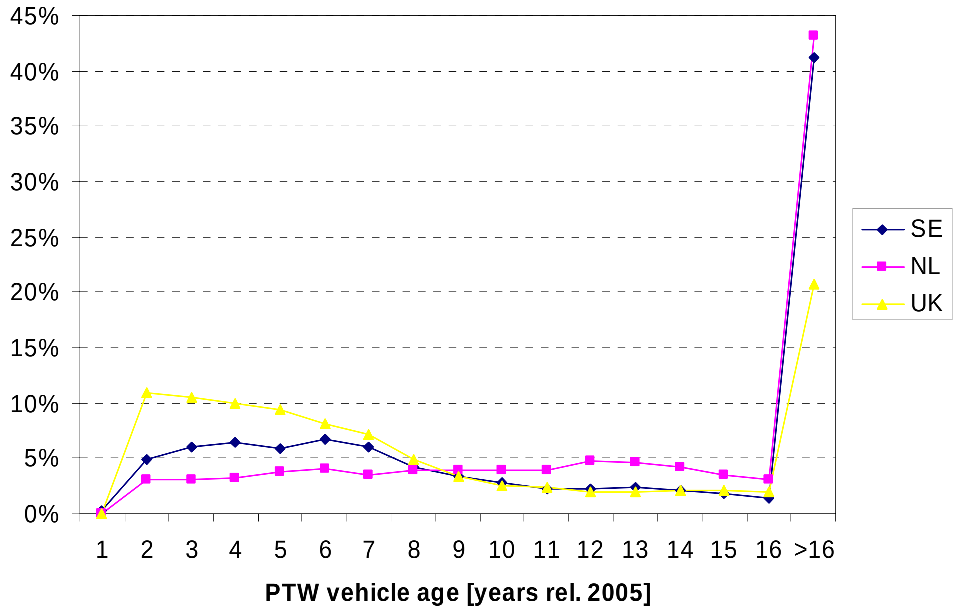


figure 22 – Vehicle age distribution for Powered Two-Wheelers in SE, NL and UK (source: [5], [9], [10])

3.6.4 Illegal RESS on Powered Two-Wheelers

table VI – Exhaust systems in the EU (%) (from [7])

	Moped	Motorcycle < 80 cc	Motorcycle 80-175 cc	Motorcycle > 175 cc	Total Motorcycles
Original equipment	33%	38%	47%	65%	58%
Homologated After Market	2%	2%	5%	8%	7%
Non-homolog. After Market	65%	60%	48%	27%	35%
Total	100 %	100 %	100 %	100 %	100 %

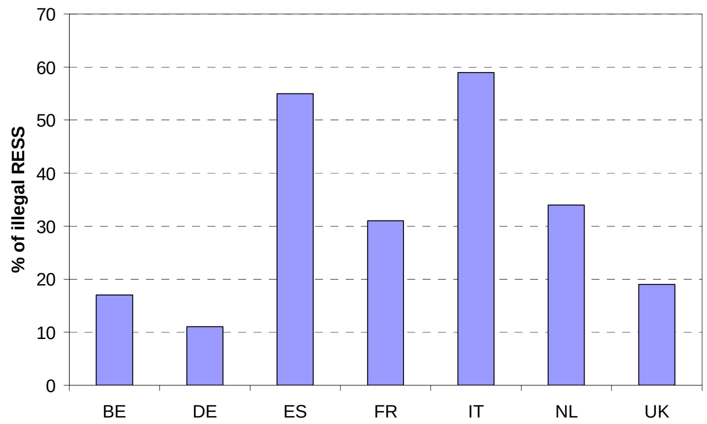


figure 23 - % of illegal RESS on motorcycles by Member State (source: [7])

3.6.5 Tyre width

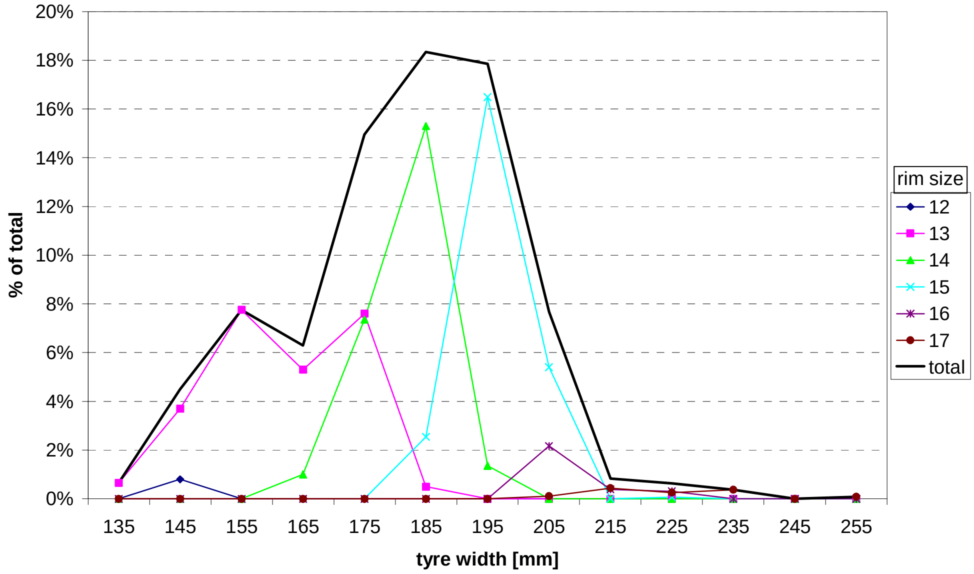


figure 24 – Distribution of tyre widths for light motor vehicles in Netherlands (source: Tyre Profile Center sales figures, 2002)

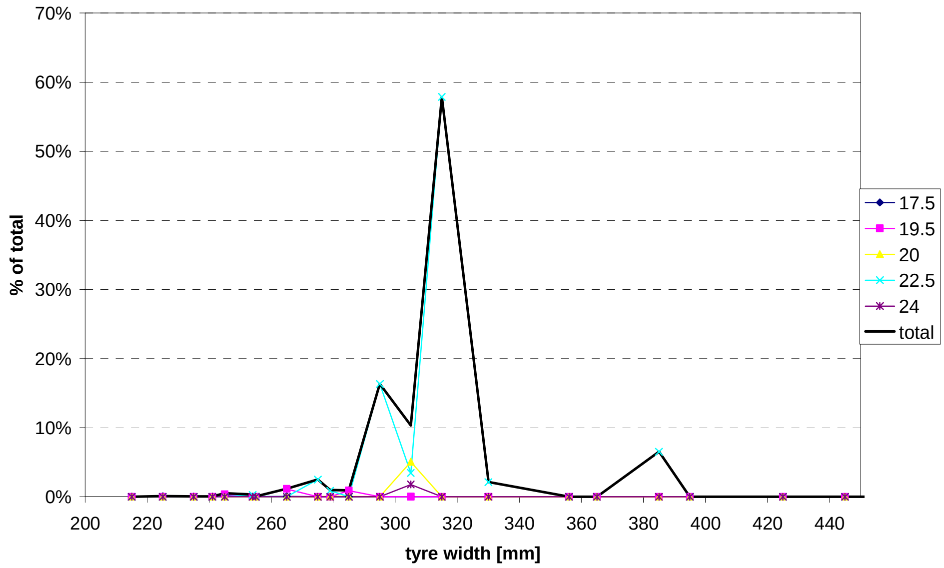


figure 25 – Distribution of HDV tyre widths in Sweden, HDV tractors only

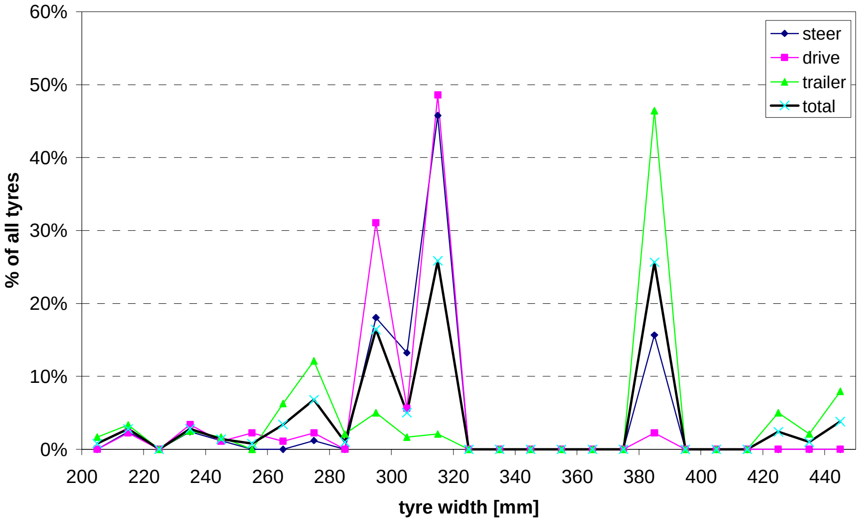


figure 26 – Distribution of HDV tyre widths in the Netherlands, all Cat. 3 trucks incl. trailers (source: M+P parking lot counts, 2002)

4 Analysis of model parameters

4.1 Introduction

In Chapter 2 the road noise emission model was presented. The main equations (2) and (3) give the rolling and propulsion noise emission levels, respectively, in 1/3-octave bands as a function of vehicle speed. The coefficient A_R, B_R, A_P and B_P are needed, therefore, in 1/3-octave bands from 25 Hz to 10 kHz. Furthermore, any coefficients for the correction factors, such as vehicle acceleration, road surface, etc. need to be calculated.

Within the Harmonoise project, values were given for most of these coefficients, based on the data existing at that time. In this chapter, we will use the data from the new measurements presented in the previous chapter to calculate these coefficients once again, and compare. This analysis is the start of the definition of the final coefficients (Task 5.4 of Work Package 5), and will continue in the near future, adding data from additional measurements and other existing data sets mentioned in § 3.1. In Table VII in the last chapter, a full overview of remaining data needs and analysis work per subject is given.

The definition of rolling and propulsion noise coefficients will be based as much as possible on dedicated data sets that represent a single noise source or parameter, such as the laboratory propulsion noise measurements for trucks, or on-board measurements for two-wheelers. Part of the coefficient calculation will be based, however, on roadside pass-by measurements of actual traffic, which measure the *overall* noise level at a certain distance. These measurements thus validate the result of the total model, including a sound transfer from noise source to roadside receiver. In § 4.3 the comparison of the model output with some roadside measurements will be presented.

4.2 Coefficients of general vehicle fleet

4.2.1 Vehicle classes

As a result of Harmonoise, five main vehicle classes have been defined (see table I) have been identified, which are divided into 18 subclasses. For the main category 4, *Other heavy vehicles*, it has been concluded within our Work Package that:

- i) too limited data will become available to generate statistically reliable predictions;
- ii) the vehicles within this class may differ to such a large extent that a representation by an average noise level may not be possible at all;
- iii) the contribution of this vehicle class to the final L_{DEN} and L_{night} values to be assessed with the model is probably negligible, with the only exception of special location (i.e. near a military base).

Based on these arguments, it was decided that this category will be removed from our model.

As a final result, our noise model will give the coefficients $A_{R,P}$, $B_{R.P}$ and C_P for each of the other four main vehicle classes. The sub-classes will only be used to develop (regional) corrections for the vehicle fleet of each main class; the percentage of each sub-class within the main class may be quite different for different countries.

4.2.2 The Harmonoise coefficients

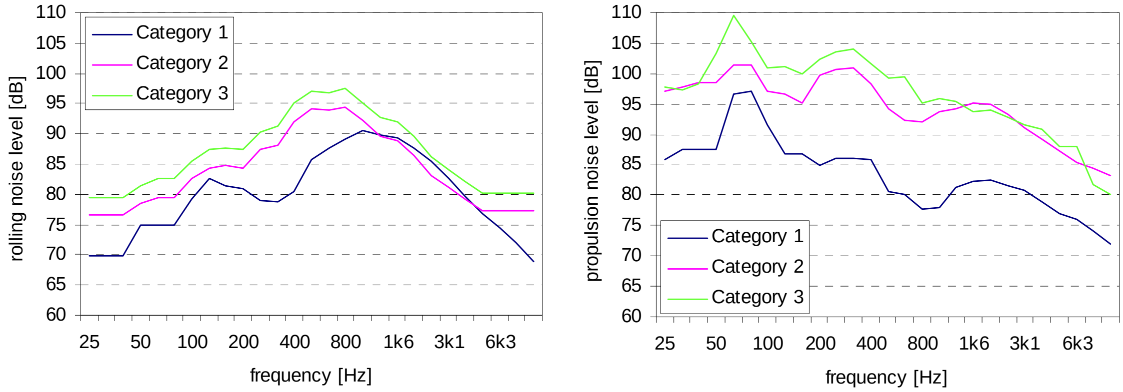


figure 27 – $A_{i,m}$ coefficients from the Harmonoise model, *left*: rolling noise, *right*: propulsion noise

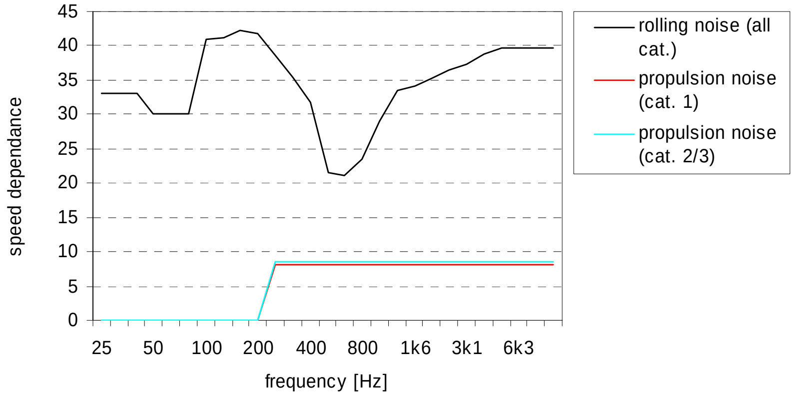


figure 28 – $B_{i,m}$ coefficients from the Harmonoise model; values for rolling noise are equal for all categories, those for propulsion noise are equal for cat. 2 and 3

In figure 27 and figure 28 above, the $A_{R,P}$ and $B_{R,P}$ coefficients developed within Harmonoise are given. These are the values for vehicle categories 1 (light motor vehicles), 2 (medium heavy vehicles) and 3 (heavy vehicles). Values for category 4 (Powered Two-Wheelers) are not yet given.

Figure 27 shows the A_R and A_P coefficients, in 1/3-octave bands, which are essentially the noise spectra of each vehicle class at the reference speed of 70 km/h. Figure 28 contains the speed coefficients B_R and B_P. The B_R coefficients for rolling noise are equal for all three vehicle classes. For propulsion noise, the speed dependence of categories 2 and 3 is equal and only slightly different from category 1. Below 250 Hz, the propulsion noise is assumed to be independent of vehicle speed (B_P = 0).

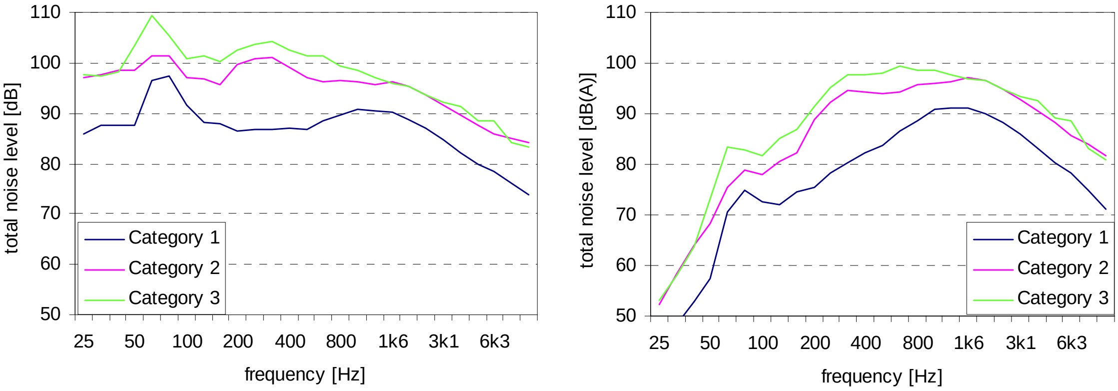


figure 29 – Total noise emission level (rolling + propulsion noise) at $v = v_{ref}$ = 70 km/h; left graph shows unweighted values, right graph shows A-weighted values

The energy sum of the A_P and A_R coefficients gives the overall sound power level for each vehicle class at 70 km/h, which is given in figure 29 above. The right graph shows the same values, but with an A-weighting, to give an indication of the actual audible noise.

In the paragraphs below, these coefficients will be compared to the results of the measurements presented in Chapter 2, to see whether an update of these coefficients is needed.

4.2.3 Powered Two-Wheelers

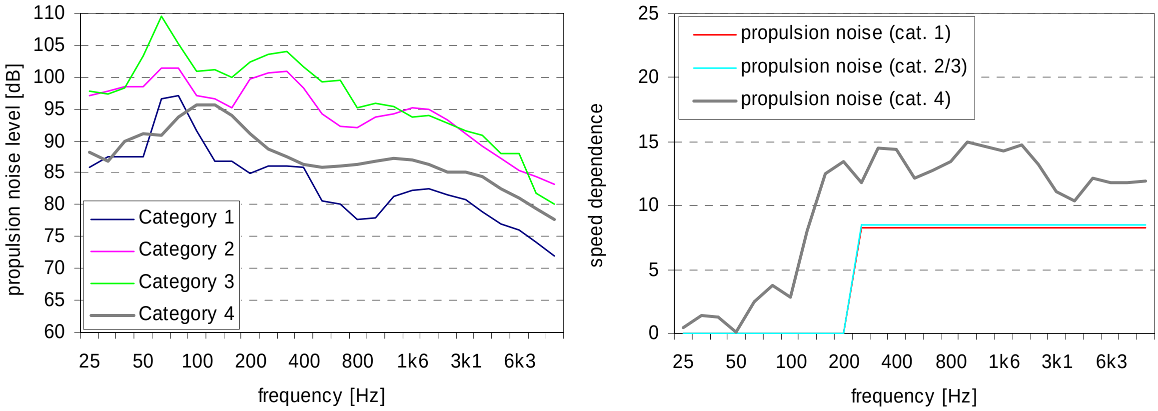


figure 30 – Propulsion noise coefficients $A_{i,m}$ (left) and $B_{i,m}$ (right), with Powered Two-Wheeler (cat. 4) data added

For the category of Powered Two-Wheelers, no values were derived in Harmonoise. The A_P and B_P coefficients derived from the pass-by measurements presented in § 3.3.3 are presented, which are the values for vehicle class 4b (heavy motorcycles) only; values for mopeds are still to be developed based on additional measurements. Rolling noise is assumed to be negligible for this vehicle class.

In figure 30 the A_P and B_P coefficients for the heavy two-wheelers are compared to the other vehicle classes. As can be seen from the left graph, the unweighted sound power level of the PTW class is somewhat higher than that for passenger cars (cat. 1), especially from 125 Hz upwards. The speed dependence in the right graph shows a similar shape as for the other categories, but around 4 dB / 70 km·h^{-1} higher and starting from a lower frequency (around 100 Hz).

To develop the values for our final model, a measurement campaign for mopeds will be necessary, and additional data for the heavy PTW would also enhance the current results.

4.2.4 Propulsion noise of Heavy Duty Vehicles

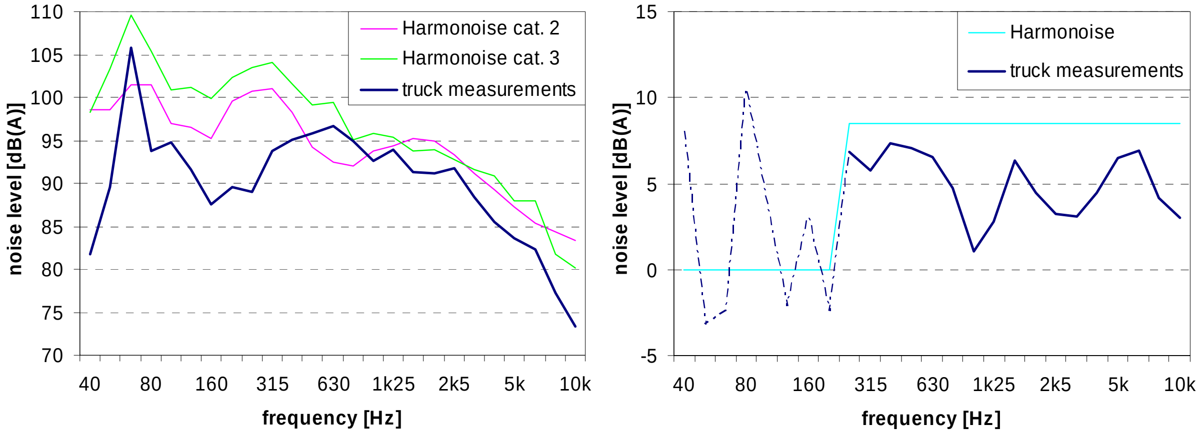


figure 31 – Propulsion noise coefficients $A_{i,m}$ and $B_{i,m}$ of Harmonoise cat. 2/3 compared to recent HDV laboratory measurements

In figure 31 the propulsion noise model coefficients of categories 2 and 3 are compared to the laboratory noise measurements in the truck chamber, as presented in § 3.4. These values are derived from a linear fit of the measured noise levels as a function of vehicle speed. It should be noted that correlation values were not very high; below 300 Hz, R^2 was below 0.5; the B_P values in the right graphs are therefore unreliable for these frequencies.

The overall sound power level in the left graph seems to be somewhat lower than the values currently in the model, especially in the 100 – 350 Hz range. This corresponds to the conclusions of the comparison in the measurement report [6]. The values will therefore be reviewed in our final model.

4.3 Validation of pass-by levels

4.3.1 Model calculation of pass-by levels

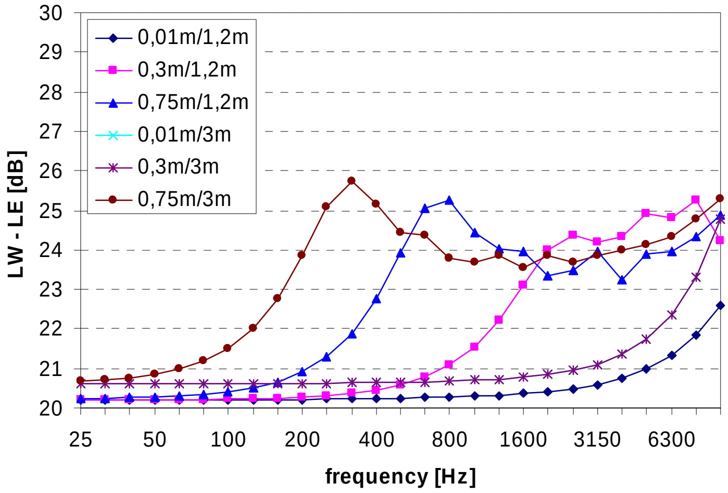
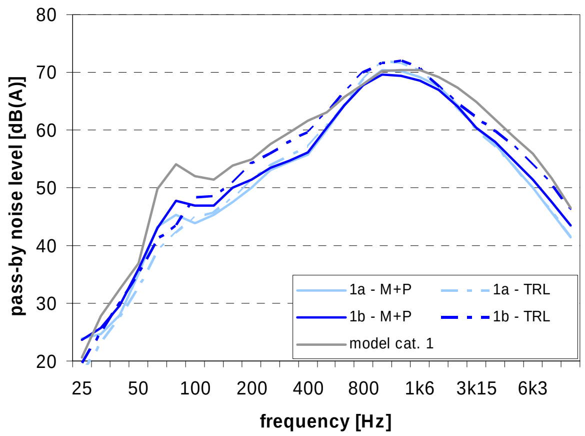


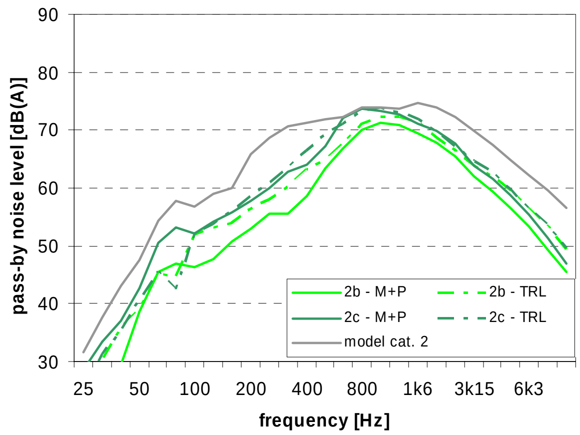
figure 32 – Transfer functions from the three possible source heights to 7.5 m roadside distance, for two microphone heights (1.2 and 3.0 m)

Some roadside pass-by measurements, according to the appropriate measurement procedure of *SEL* levels at 1.2 and 3 m height, with appropriate classification of each vehicle, have recently become available from M+P and TRL. M+P measurements were performed for the SILVIA project, on a 80 km/h road with DAC surface. The TRL measurements were performed on a SMA 0/10 surface. The resulting values will be compared to the results of our noise model using the Harmonoise coefficients.

In order to calculate the roadside SEL levels from our model, the rolling and propulsion noise will be calculated and distributed over both source heights (see § 2.1.2). A transfer function from these source heights to the measurement positions at 7.5 m roadside is also necessary, and was provided in the data sheets underlying the Harmonoise report [2]. These transfer functions are plotted in figure 32.

4.3.2 Comparison with SPB measurements





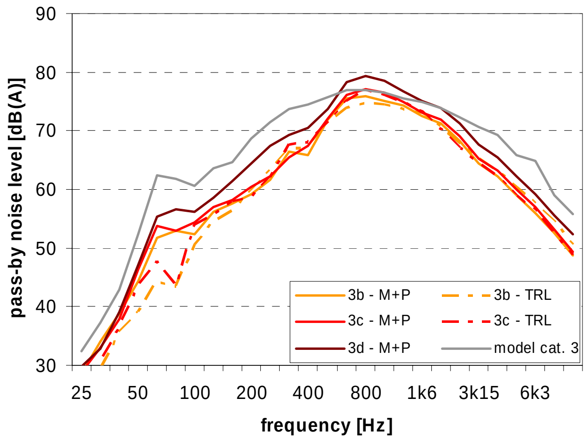


figure 33 – Pass-by SEL levels in 1/3-octave bands for actual measurements of vehicle classes 1, 2 and 3 vs. model calculations

In figure 33, the SEL levels at 70 km/h, measured at 3.0 m height at the roadside, are plotted in 1/3-octave bands, together with the curves calculated with the noise model and transfer functions. The final model result has been A-weighted. The vehicle subclasses *a*, *b* and *c* were given in table I.

The shape of the model curves seems to correspond to the measurement data, showing a main peak at 800 – 2000 Hz for light motor vehicles and around 630 – 1250 Hz for trucks, and a small peak around 63 – 100 Hz caused by the driveline noise. The model curve is somewhat higher than the measurements, outside the main peak, i.e. from 63 to 630 Hz and from 2 kHz upwards. For the heavy duty vehicles this confirms the conclusion that the propulsion noise, which is dominant in these ranges (see figure 27), is somewhat overrated in the current model.

4.4 Other parameters

4.4.1 Vehicle acceleration

In § 2.1.5 the correction for vehicle acceleration / deceleration was presented as $\Delta L = C \cdot a$. Within Harmonoise, the coefficient *C* was determined as being:

- 4.4 dB / m·s^{-2} for category 1 (light motor vehicles);
- 5.6 dB / m·s^{-2} for category 2 and 3 (medium & heavy duty vehicles).

From the on-board measurements of Powered Two-Wheelers, values ranging from 1.8 dB/ms^{-2} for a heavy motorcycle to 4.8 dB/ms^{-2} for a 69 cc moped (with replacement exhaust) were found. The actual value may be different for heavy motorcycles and light mopeds, but calculating a definitive reliable value requires more data.

For the light motor vehicles a value of 4.4 has not been reproduced yet, and it seems somewhat high compared to the acceleration measurements in § 3.5.2. More data to be gathered in upcoming measurements and other datasets should provide a final value. For vehicle categories 2 and 3, a more specific analysis of the propulsion noise measurements and city cycle tests, adding also the outdoor measurements recently performed, will allow a check of the *C* coefficient. However, the uphill / downhill correction of 0.61 dB per % road gradient, as found from figure 11, can be transferred to an acceleration correction by multiplying with the gravity constant *g* of 9.8 m/s^2 (see [6]), which gives a value of 6.0 dB/ms^{-2}.

More measurements will be performed to establish a statistically reliable coefficient for the acceleration, and other data sets (possible from ROTRANOMO) may enhance this. If possible, the correction will be made frequency-dependant, since the effect is expected mainly to occur at lower frequencies.

4.4.2 Regional variations

The investigation of regional variations will mostly take place in the upcoming year of the project. Some figures that were already found are presented here.

Engine fuel type

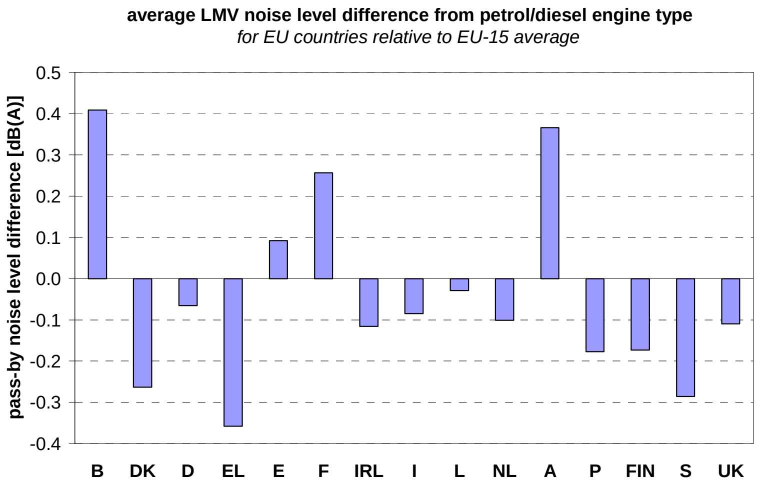


figure 34 – Category 1 passby sound exposure level difference between EU-15 countries, relative to EU average, as a result of deviations in the average % of Diesel vs. petrol engines

In figure 18 the distribution of Diesel / petrol engines for light motor vehicles over EU countries was given, with the amount of Diesel ranging from 1% to 40% for different countries. The increase of pass-by sound exposure level for a Diesel engine relative to a petrol engine was estimated to be 1.7 dB at 40 km/h (see [11]). This would result in an average noise level difference for Category 1 vehicles ranging from -0.4 to +0.4 dB(A) relative to the average European vehicle, as shown in figure 34.

Vehicle age

As can be seen from figure 20 and figure 21, the average vehicle age for light motor vehicles does not vary more than 2 years over the countries that data are currently available for. For heavy motor vehicles, this is about 4 years. From [11], the effect on noise levels was estimated to be 0.4 dB per 10 years age increase for light motor vehicles, which would mean the effect is negligible. For dual-axle trucks (category 2), the effect was 1 dB per 10 year age difference, which would mean an effect of 0.4 dB (peak-to-peak) for this vehicle category. For trucks, therefore, this effect will be investigated further.

Illegal RESS on Two-Wheelers

From § 3.6.4 it was made clear that the percentage of illegal exhaust systems on two-wheelers varies from 10% to 60% for the countries mentioned. The average noise increase of the RESS is not yet known, but would be around 12 dB(A) according to [7]. This would imply a regional variation of the average (propulsion) noise level of 5 dB(A) for heavy two-wheelers, and even more for mopeds.

5 Conclusions and future plans

The results of Chapter 3 and Chapter 4 show that some important issues for our final model are still to be solved. The comparison of our model results with actual measurement data still shows significant differences, mainly on the propulsion noise part, and some of our coefficients and parameters, such as the influence of vehicle acceleration and the coefficients of two-wheelers in general, are not yet established with statistical reliability or confidence.

There are, however, significant amounts of data left to be analysed, and a limited amount of new measurements is also scheduled within the remainder of this project. In Table VII an overview of our work remaining is given for each noise component and for each vehicle category.

Table VII – Overview of lacks in the data required for determination of the sound power level of road vehicles

<table>
<tr><th>Vehicle category</th><th>Light motor vehicles</th><th>Medium duty vehicles</th><th>Heavy duty vehicles</th><th>Powered two wheelers</th></tr>
<tr><td>Rolling noise</td><td>Extensive data available

- construct consistent set
- extensive pass-by data expected from SP</td><td>Scarce data available: TRL has some overall levels; maybe type approval values can be of use

combine information from passenger car tyres and HDV tyres with that of SPB data</td><td>data available at M+P for 15 types of truck tyres
extensive pass-by data available

- analyse data into A_R and B_R coefficients for representative tyre combination
- extensive pass-by data expected from SP</td><td>Not relevant</td></tr>
<tr><td>Road surface effects</td><td>Substantial information available for a limited set of surfaces

gather all currently available data; supply guidelines (SILVIA) for assessment of other surfaces</td><td>Limited data available

combine information for passenger car tyres and truck tyres</td><td>Substantial information available for a limited set of surfaces

gather available data and supply guidelines</td><td>Not relevant</td></tr>
<tr><td>Regional effects</td><td>extensive data available on width effect

SP will measure SPB, incl. studded winter tyres. ETRTO may have statistical data.

- search for statistics
- relate vehicle weight to tyre width</td><td>Local regulations affect the composition of the LDV fleet.

search for statistics</td><td>Local winter conditions might affect the tyre mounting.

search for statistics</td><td>Not relevant</td></tr>
<tr><td>Temperature effects</td><td>See TC 42/ WG 27
look at SILVIA conclusions</td><td>Minor effect assumed (see WG 27)</td><td>No effect assumed (see WG 27)</td><td>Not relevant</td></tr>
<tr><td rowspan="2">Propulsion noise</td><td rowspan="2">TUG has data on appr. 10 different cars, for various speed ranges and gear selection, for their VENOM model

- analyse into A_P and B_P coefficients
- request ROTRANOMO for additional information
- new on-board measurements for specific questions</td><td>Scarce data available</td><td>Volvo has done laboratory and test track measurements on a few new vehicles</td><td rowspan="2">Detailed but narrow information from M+P testing. JRC data also includes scooters/mopeds.

- Gather current data and analyse
- contact ROTRANOMO
- new measurements in Southern Europe
- contact IMMA for noise data</td></tr>
<tr><td colspan="2">propulsion noise coefficients of light duty vehicles may be equal to Heavy Duty Vehicles

- TUG may perform new measurements, if vehicle/test track/driver are available at Volvo
- contact ROTRANOMO for additional information
- perform pass-by measurements at low speeds
- limited on-board measurements for specific questions
- analyse TRL pull-away data</td></tr>
<tr><td rowspan="2">Effect of acceleration/ deceleration</td><td rowspan="2">Limited data available from M+P pass-by measurements Detailed data available for limited number of vehicles in VENOM model of TUG

- M+P data set will be extended
- possibly JRC/Autostrade measurements of stop-and-go traffic at toll station</td><td>Only limited data available from M+P pass-by measurements and TRL pull-away tests</td><td>Data available from Volvo indoor and outdoor tests, TRL pull-away tests and M+P pass-by measurements</td><td rowspan="2">Only limited data available from on-board measurements

More measurements needed, either in-traffic or test track measurements with specific vehicles</td></tr>
<tr><td colspan="2">*- M+P data set will be extended*
- possibly JRC/Autostrade measurements of stop-and-go traffic at toll station</td></tr>
<tr><td>Regional effects</td><td>PMR-effect and engine type effect

- search for statistics first
- pass-by measurements w. number plate recognition may be necessary</td><td>PMR effect and possibly vehicle age

no noise data available

search for statistics</td><td>PMR effect

limited data available

search for statistics</td><td>IRESS effect

- search for statistics
- contact ICEM/IMMA for noise data</td></tr>
</table>

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