Integrated assessment of noise reduction measures in the road transport sector

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PROJECT REPORT

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INTEGRATED ASSESSMENT OF NOISE REDUCTION MEASURES IN THE ROAD TRANSPORT SECTOR

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Executive summary

The study described in this report was commissioned by the European Working Group 8 (Road Traffic). This Working Group was formed under the auspices of EU Directorate General - Enterprise.

The main aim of the study was to develop a noise prediction model that would allow comprehensive evaluations of different vehicle and traffic noise control scenarios. It was anticipated that the model, when developed, would be used in association with the development of area-wide noise control strategies. Such strategies are required by the current European Noise Directive (Commission of the European Communities, 2002) in that with regard to roads,

- The first strategic noise maps for major roads carrying greater than six million vehicle passages per year should be completed by June 30, 2007. In subsequent rounds, mapping shall be undertaken for major roads carrying greater than three million passages per year;
- Action plans should be drawn up by July 18, 2008 to manage noise issues and effects, including noise reduction if necessary, for places in the vicinity of major roads carrying greater than six million vehicle passages per year. In subsequent rounds, action plans shall be drawn up for roads carrying greater than three million passages per year.

The Transport Research Laboratory (TRL, UK) in partnership with RWTÜV, Germany were awarded the contract to develop the model.

A primary objective of this work was to ensure that the developed model would be sufficiently versatile to allow accurate forecasts to be made for the different traffic conditions encountered across the member states of the European Union. The model would, therefore, have to take account of area dependant factors such as vehicle fleet compositions, age distribution of vehicles, local road surfaces etc. In addition, it was important to model the traffic stream using a larger number of different vehicle types (layers) than has previously been available from other traffic noise models. This feature was important as it would then facilitate the evaluation of a broad range of traffic based noise control options such as restricting access of vehicles of a specified type.

It was also considered important that, in order that the model should be capable of examining different noise source control options, it should be able to discriminate between the major source groups associated with an operating vehicle. In particular the model would need to discriminate between rolling noise sources and propulsion noise sources. Finally it was considered important that the model should be capable of dealing adequately with future scenarios including the use of new technologies and the effects on noise of vehicle and road surface design improvements.

Prior to setting up the project it was decided that the most appropriate model to use as a basis for the traffic noise prediction model was that developed for the German Environmental Agency (UBA) over the period 1998-2000. This model, *TraNECam*, is essentially a detailed vehicle noise source model where the overall traffic noise levels are determined by summing the various source components for each vehicle type operating in the traffic stream, taking into account traffic speeds and other operational factors and traffic volumes.

The model requires traffic-fleet data to be provided by the user, but performs calculations based around either a single road link or, if calculating for specific drive cycle scenarios, the passage of vehicles over a single route. Although the results from different links could be combined to take account of traffic operations on networks this aspect has not been automated thus far in the formulation of the program. To achieve a fully operational network model some additional programming would be needed to manage the process of inputting traffic data from multiple links. This work was beyond the scope of the present study.

However, it should be noted that work to combine the noise model with a traffic flow simulation model, which would achieve the objective of an automated network model is the main objective of another ongoing project called ROTRANOMO. This project forms part of the current European Commission's 5th Framework Programme. The main advantages in using this type of vehicle source noise model described in this report are that it potentially offers the opportunity to examine a range of vehicle noise control scenarios that can be related to both traffic management and vehicle noise

source-reduction measures. The results from such studies can then be used on a wider scale by national authorities to help develop noise control strategies and action plans. Such a model is also of use to bodies such as industrial associations, since industry is interested in improving knowledge about the contribution of their products to the control of traffic noise levels.

In order for the UBA model to work effectively for examining vehicle noise control scenarios it needed to be made more user friendly and to be expanded to improve its versatility in dealing with the noise control options of interest. In particular, the noise emission factors used in the model that covered the generation of rolling and propulsion noise sources required updating.

The study has therefore been designed so that the work was concentrated on two main areas. Firstly, the development of the programme algorithms so that the model was tailored to the specific objectives of this study and was user friendly and, secondly, to establish improvements that expanded the range of tyre/road noise and propulsion noise sources that can be modelled. It was decided that this second task would require a comprehensive literature review as a precursor to establishing appropriate emission factors in the model.

The technical review of both tyre/road noise and propulsion noise was broadly based and provided detailed information concerning source levels, the main mechanisms governing the generation and, where relevant, the propagation of these sources of noise. It also covered the methods of measurement used to determine source levels and examined the prospects for noise reductions in the future. The role of legislation and likely changes to test procedures etc. were also covered in the technical review.

The main intention in carrying out the review was to provide background and support for the establishment of noise emission factors to be included in the formulation of the revised model. The report therefore provides an updated list of emission factors for both types of sources and also speculates on future emission factors for both source groups that take account of likely technical developments in vehicle and road surface design and the influence of legislative actions.

During the course of the project, the noise model was updated using the new data derived from the literature reviews and the input requirements were simplified. The process of updating the model to take account of new sources was also simplified. An operator manual for the revised model is included in Appendix B of this report. The main changes made to the *TraNECam* model were as follows:

- The dialogue used within the program has been modified so that all command windows and text prompts, are now in the English language.
- The program has been refined to enable the use of different vehicle databases for different regions within the EU. Check routines have been written and installed to ensure the consistency of the databases.
- The number of vehicle types (layers) that can be specified in the model has been extended in order to achieve a greater discrimination between vehicle types. Additional layers have been included for Heavy Duty Vehicles (HDV's) to include vehicles fitted with traction tyres. The program has also been modified so that it is now relatively easy to add new vehicle types (e.g. new technology vehicles)
- The number of road types and traffic categories that can be modelled has been expanded to cover a broader range of different scenarios.
- Improvements have been made with regard to the modelling of propulsion noise sources for all vehicle layers. This helps facilitate the modelling of the effects of improved vehicle design on the propulsion noise functions.
- As a result of the review of both tyre/road noise and propulsion noise sources, the noise emission factors used in the model have been updated. The factors used for these sources are now representative of a broader range of designs than previously and are indicative of the state-of-the-art. In addition to these factors, further tyre and propulsion noise layers have been added in the model. These additional layers were chosen to represent an anticipated staged reduction in source

levels in the future. They were based on the evidence of research and the judgement of the authors.

It was necessary to both 'fine tune' and validate the modified model by comparing predicted values of vehicle noise with actual measurements at real road sites. The differences between measured and predicted results were then used to adjust the emission factors for each vehicle type and operation as appropriate. The results from this 'alignment' and validation exercise resulted in a close agreement between measured and calculated vehicle noise levels for a wide range of vehicle speeds.

Results are presented for sample calculations of traffic noise levels using the revised model. Initially the calculations were limited to individual vehicle layers. These results demonstrate the various stages in the calculation process and illustrate the versatility of the model in being able to address specific questions regarding noise control options.

Finally, results are presented for a range of different scenarios that demonstrate the range of noise source control options that can be examined and the benefits, in terms of traffic noise reductions, indicated by the model. The scenarios modelled have been chosen to reflect possible different traffic situations that might be encountered across the European Union and were selected following discussions with the membership of EU Working Group 8. They include scenarios related to fleet composition changes, the introduction of quieter vehicles, lower noise road surfaces and the benefits of some traffic management measures.

1 Introduction

Noise is often cited as the most important environmental problem associated with road traffic. In the UK over 95% of the population hear noise traffic noise whilst at home and this causes disturbance or annoyance to about a quarter of the population. Similar degrees of exposure and impact are reported in many other European countries. The costs of this exposure and damage to the environment are difficult to determine but have been conservatively estimated to range between 0.2 - 2% of GDP (Commission of the European Communities, 1996).

In 2000, following an earlier review of EU noise policy and the formation of a number Commission working groups on noise impacts, Directorate General - Enterprise formed a working group to look at the specific issue of traffic noise sources. This group, Working Group 8: Road Traffic, has three specific objectives, which can be summarised as follows:

- To identify the occurrences of traffic noise problems and the relative roles of the important noise sources.
- To develop a compilation of information and understanding of the different technical, organisational and economic aspects of road traffic noise and their interactions, which can form the basis for proposals for traffic noise reduction measures.

  This requires studies into the contributions of various vehicle categories (cars, light commercial vehicles, heavy duty vehicles, buses and coaches, motorcycles) to noise exposure in the domestic (urban and rural) and recreational environment. An assessment is also required of the contributions from the different vehicle noise sub-sources (tyre, exhaust, engine, auxiliary equipment, etc.) in the different categories to noise exposure. In addition, there is a requirement to consider the various influencing parameters, for example, road surface, road infrastructure, urban architecture, traffic volume, traffic speed, etc. and the interaction between them with regards to noise emissions.
- The investigation of possible measures related to noise reduction. These include the potential options, the associated costs and their further impacts.

As part of their work, Working Group 8 decided to commission research to update and develop a noise prediction model that would allow comprehensive evaluations of different traffic noise control scenarios. It was anticipated that the model, *TraNECam*, when developed would be used in association with the development of area-wide noise control strategies, although the model itself would not be bound by the requirements of the current European Noise Directive. The Transport Research Laboratory (TRL, UK) in partnership with RWTÜV Fahrzeug GmbH, Germany were awarded the contract to develop the model.

The main objectives of the study are:

- To update the noise prediction model to allow its application across a wider area of the European Union, taking into account area dependant factors such as vehicle fleet compositions and developments in road surface and tyre design, and developments in propulsion noise.
- To consider the application of the model to evaluate the benefits of different scenarios in which alternative noise reduction measures are applied.

This report describes the outcomes of the study.

2 Study design

Prior to setting up the project it had been decided by Working Group 8 that the most appropriate model to use as a basis for the traffic noise prediction model was that developed for the German Environmental Agency (UBA) over the period 1998-2000. This model, *TraNECam*, had been developed initially by RWTUV.

The model is described in the next section but briefly it is essentially a detailed vehicle noise source model. The overall traffic noise levels are determined by summing the various source components for each vehicle type operating in the traffic stream taking into account traffic speeds and other operational factors and traffic volumes.

The main advantages in using this type of model are that it potentially offers the opportunity to examine a range of vehicle noise control scenarios that can be related to vehicle noise source reduction measures. For example, the potential for reducing traffic noise impacts through better tyre and road surface design can be examined as well as a wide range of traffic management options that might affect vehicle mix, speed, and overall traffic volumes.

In order for the model to work effectively, however, for this type of application it needed to be developed from its current condition to make it more comprehensive and versatile. In particular, the model required detailed information on noise emission factors related to road surface and tyre design and to propulsion noise sources. It was considered important, for example, to ensure that the range of road surface types included in the model was comprehensive (i.e. applicable across the European Community) and as up-to-date as possible, but also reflected likely future developments. Similar requirements and objectives were considered to be appropriate for propulsion noise sources.

The study has therefore been designed so that it is focussed in two main areas. Firstly, work was needed to develop the programme algorithms so that the model was tailored to the objectives of this study. This work would be mainly carried out at RWTÜV. Secondly it was necessary to provide a comprehensive overview of the background and development of tyre/road surface design and to review the evolution of propulsion noise sources. This would mainly be the responsibility of TRL.

It was also felt important that in reviewing the current state-of-the-art in vehicle source noise that potential future developments should also be considered. Consequently, to make this as forward looking as possible, it was decided that the study should take account of the development of new technologies and the likely uptake of these technologies over time. Part of this process would involve an overview of future noise policy and legislation and the impact that such measures might have on source levels. In addition consultation with industry representatives, including the European Commission Working Group WG8: Road Traffic, was considered to be important to see whether further insight could be gained on likely future technological developments.

Once the RWTÜV model had been updated and the noise emission factors established different "what if" scenarios could then be examined.

In order to establish the emission factors needed to run the model a number of tasks had to be accomplished. These were:

- To carry out a review of tyre/road noise and propulsion noise sources as a precursor to the establishment of noise emission factors.
- To determine the form that the emission factors should take so that they are compatible as input to the RWTÜV model.
- To establish how many vehicle classification layers are needed for accurate forecasting of traffic noise reductions.
- To undertake a consultation exercise regarding the development of future technologies and the impact of these technologies on future noise emissions.
- To establish the types of "what if" questions that the modelling process should address.

The following sections of this report describe the various components of this study.

- Section 3 describes the basic RWTÜV model, *TraNECam*.
- Section 4 provides a comprehensive review of tyre/road noise sources taking into account, where possible, the views of industry regarding future technological developments. It also examines legislation and policy issues. This review is intended to inform the changes to the model described in Section 6.
- Section 5 provides a similar overview of propulsion noise sources. This overview is also intended to inform the changes described in Section 6.
- Section 6 describes the changes made to the RWTÜV model and the emission factors used.
- Section 7 describes the work done to validate the model, and any changes made as a result
- Section 8 presents some initial calculations for individual vehicle layers using the revised model. It also presents the results of calculations of traffic noise reductions arising from a range of inputted vehicle source control and traffic management options.

3 The RWTÜV vehicle noise emission model, *TraNECam*

This section describes the basic operation of the *TraNECam* model and its current limitations.

3.1 The basic model

Figure 3.1 outlines the procedures for the operation of the model. The double-outlined boxes indicate the various stages where input is required.

Output from the model can be in terms of either the maximum A-weighted level, L_{Amax} or the equivalent continuous level, L_{Aeq} at a receiver position of the user's choice. The L_{Aeq} values are calculated from the L_{Amax} values, by assuming that the noise source is a point source. The model is also capable of generating output using the harmonised indicators required by the European Directive on Environmental Noise, i.e. L_{den} (the day-evening-night equivalent level, as well as its components L_{day}, $L_{evening}$ and L_{night}) and L_{night} (night-time equivalent level).

3.1.1 Modelling of propulsion noise

Based on the experience of previous research projects, the vehicle related noise sources (engine, powertrain, exhaust, intake) are summarised and modelled as function of engine speed and engine load. A further split into different sources is possible in principle but at present there is no data available for the function modelling.

The propulsion noise is described by two normalised engine speed dependent functions, one for low or negative engine load (below 10%) and one for full engine load. The partial load condition is covered by a linear interpolation between both curves.

In order to cover the whole range of vehicles from motorcycles to heavy duty trucks it is necessary to use the normalised values for the engine speed, given by

$$n_{norm} = \frac{n - n_{idle}}{s - n_{idle}}, \qquad (3.1)$$

where n is the actual engine speed, n_{idle} is the idling speed and s is the rated speed.

Both the low engine load function and the full engine load function can be modelled as polynomial functions of up to the 6^{th} degree. To allow the effects of acoustic design on the propulsion noise functions to be modelled, the engine speed range can be separated into 4 smaller ranges and individual functions used for each of these. The user must ensure that the values at the ends of adjacent ranges coincide.

Normally, linear functions can be used. The low load function is then described as

$$L_{eng} = L_{n_{idle}} + \left(L_s - L_{n_{idle}}\right) \times n_{norm}, \qquad (3.2)$$

where L_{eng} is the propulsion noise with low engine load (below 10%), L_{nidle} is the idling noise and L_s is the propulsion noise at the rated speed.

The load influence is modelled as an additive to the low load value and calculated using the equations

$$\begin{aligned} DL_p &= \left(DL_{p,idle} + \left(DL_{p,s} - DL_{p,idle}\right) \times n_{norm}\right) \times \left(P_{norm} - 0.1\right)/0.9 && \text{if } P_{norm} \geq 0.1 \\ DL_p &= 0 && \text{if } P_{norm} < 0.1 \end{aligned} \qquad (3.3)$$

where DL_p is the increase in noise emission due to the engine load P_{norm}, $DL_{p,idle}$ is the increase at idling speed and $DL_{p,s}$ is the increase at rated speed.

This leads to the total propulsion noise, L_{prop}, given by

$$L_{prop} = L_{eng} + DL_p \qquad (3.4)$$

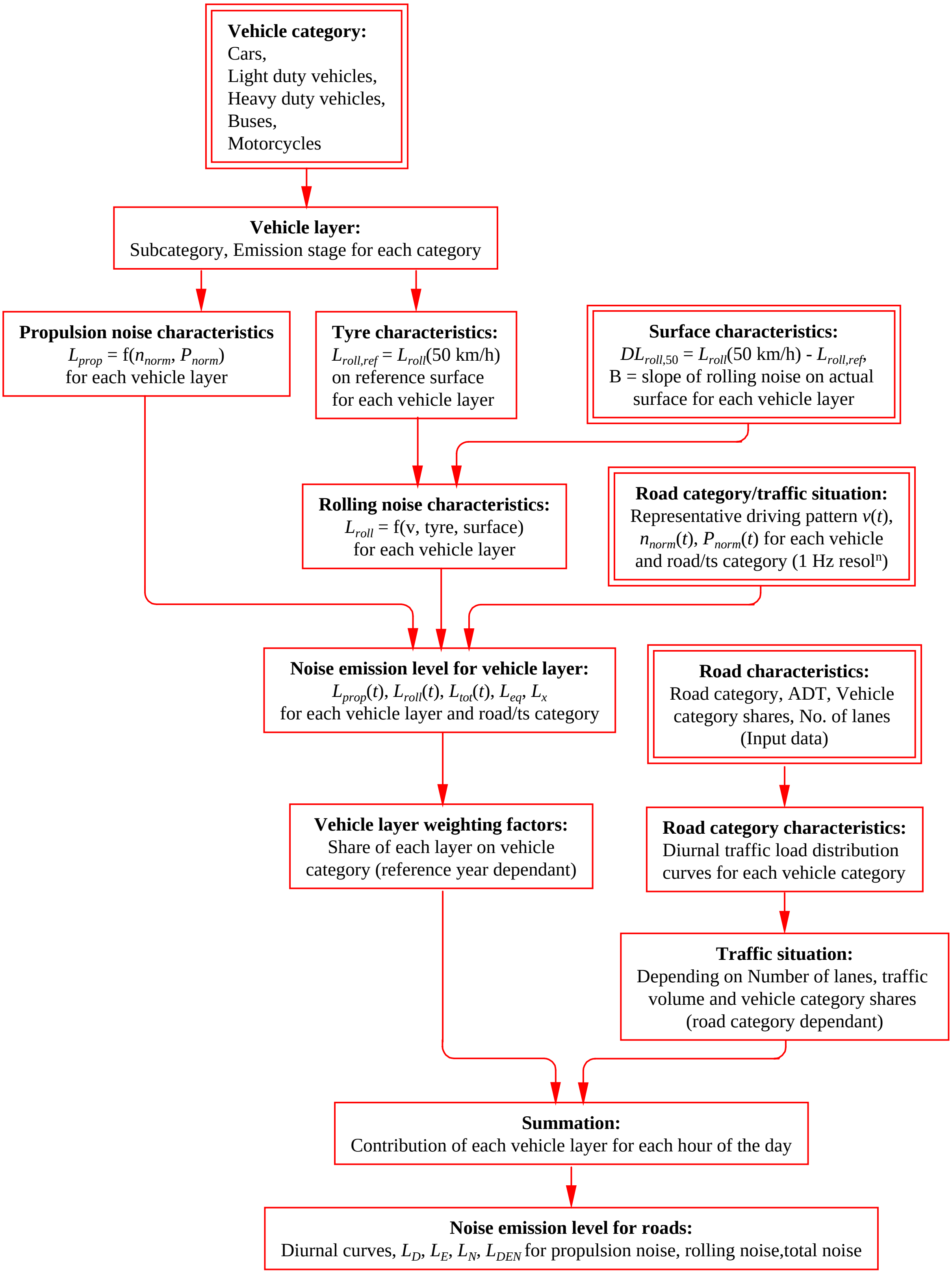

Figure 3.1: The noise emission calculation procedure

where L_{prop} is the propulsion noise level, L_{roll} is the rolling or tyre/road noise level, L_{tot} is the overall noise level, L_{eq} is the equivalent noise level, L_x is the percentile of the noise level distribution, $n_{norm} = (n - n_{idle})/(s - n_{idle})$, n is the actual engine speed, n_{idle} is the idling speed of the engine, s is the rated speed of the engine, v is the vehicle speed and ADT is the average daily traffic volume

Figure 3.2 shows an example of the propulsion noise modelling. This method has been extensively reviewed with vehicle manufacturers and government bodies and found to be appropriate for this purpose.

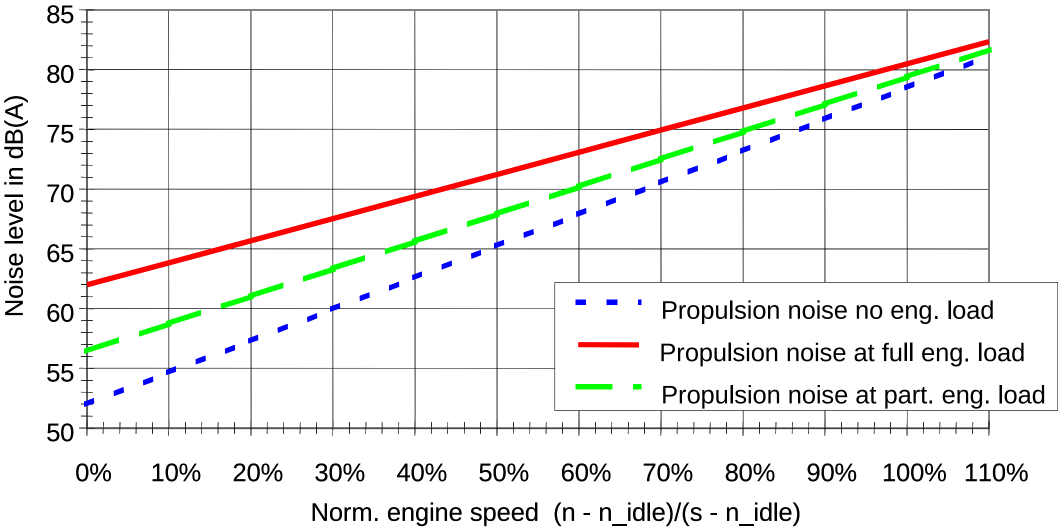

Figure 3.2: Propulsion noise modelling (example for a linear regression)

3.1.2 Modelling of tyre/road noise

The tyre/road, or rolling, noise component L_{roll} is modelled as a function of the tyre, the road surface and the vehicle speed:

$$L_{roll} = L_{r50}(AC\,0/11) + B \times \log(v / 50\ \text{km/h}) + DL_{surface} \qquad (3.5)$$

where L_{r50} (AC 0/11) is the rolling noise at 50 km/h on asphalt concrete with a maximum chipping size of 11mm, B is the slope of the regression curve, v is the vehicle speed and $DL_{surface}$ is the surface specific coefficient. This coefficient provides the additional noise attributed to a particular surface when compared with asphalt concrete (0/11).

Average values within a vehicle layer are used as tyre specific coefficients. The surface specific coefficients are separated for cars and light duty vehicles on one hand and heavy duty vehicles on the other hand and cover the most frequently used road surfaces in Europe as well as new low noise surfaces like drainage asphalt. It will be evaluated depending on whether surface specific slopes have to be used or whether a common slope for all surfaces can be used.

The noise increasing effect of wheel torque is not considered because it is only relevant for type approval conditions.

3.1.3 Total vehicle noise

The overall vehicle noise is calculated as the energetic sum of the propulsion noise and the tyre/road noise components calculated as described above. The determination of the total overall noise level, L_{tot}, is calculated using the equation

$$L_{tot} = 10 \times \log\left(10^{(0.1 \times L_{roll})} + 10^{(0.1 \times L_{prop})}\right) \qquad (3.6)$$

3.1.4 *Vehicle category/subcategory/layer classification*

For this project, we are using the same structure as for the UBA model. Further to discussions within the vehicle noise emission working group and conclusions reached from bilateral discussions, the following vehicle classes were added to the model:

- Since high performance cars (rated power > 140 kW and power-to-mass ratio > 70 kW/t) are subject to a different test method, a higher limit value and often different acoustic design measures, special classes for these vehicles were added.
- For all heavy duty vehicle classes except buses, subclasses with/without traction tyres[1] were added.
- Motorcycle classes had to be integrated into the model. Based on an extended analysis of RWTÜV's own measurement results, it was concluded that two engine capacity classes would be sufficient, up to 150 cm^3 and above 150 cm^3. The first class covers mainly scooters. For each capacity class, an additional class was foreseen for vehicles fitted with replacement/illegal silencers.

The classifications are therefore structured as shown in Table 3.1 (which is continued over the page).

Table 3.1: Vehicle category classification

Vehicle category	Sub-category
Passenger car (M1)	Petrol, < 1400 cm^3
Passenger car (M1)	Petrol, 1400 – 2000 cm^3
Passenger car (M1)	Petrol, > 2000 cm^3
Passenger car (M1)	Diesel ≤ 2000 cm^3
Passenger car (M1)	Diesel, 2000 cm^3
Passenger car (M1)	Petrol, > 2000 cm^3, high performance
Passenger car (M1)	Diesel > 2000 cm^3, high performance
Light duty vehicle (N1)	Petrol
Light duty vehicle (N1)	Diesel
Rigid truck	≤ 7.5 tonnes Gross Vehicle Weight (GVW)
Rigid truck	7.5 – 14 tonnes GVW
Rigid truck	14 – 20 tonnes GVW
Rigid truck	20 – 28 tonnes GVW
Rigid truck	≤ 7.5 tonnes, traction tyres
Rigid truck	7.5 – 14 tonnes, traction tyres
Rigid truck	14 – 20 tonnes, traction tyres
Rigid truck	20 – 28 tonnes, traction tyres

[1] Traction tyres are block-tread pattern tyres used on drive axles to ensure traction during acceleration.

Table 3.1 (continued): Vehicle category classification

Vehicle category	Sub-category
Trailer truck	≤ 32 tonnes GVW
Trailer truck	> 32 tonnes GVW
Trailer truck	≤ 32 tonnes, traction tyres
Trailer truck	> 32 tonnes, traction tyres
Public transport bus	≤ 20 tonnes GVW, standard
Public transport bus	> 20 tonnes GVW, articulated
Motorcycle	≤ 150 cm^3
Motorcycle	≤ 150 cm^3, rep/illegal silencers.
Motorcycle	> 150 cm^3
Motorcycle	> 150 cm^3, rep/illegal silencers

Although the EC legislative limits for heavy duty vehicles are based on the rated power of vehicles, the noise model uses the classifications shown in the table. These are based upon vehicle weight and axle configuration, because these criteria are more relevant to traffic conditions and it is much easier to obtain traffic, stock and mileage data for these.

The emission stages are based on the noise limitation legislation in the EU which is shown in Figure 3.3. This leads to the vehicle layer classes shown in Table 3.2.

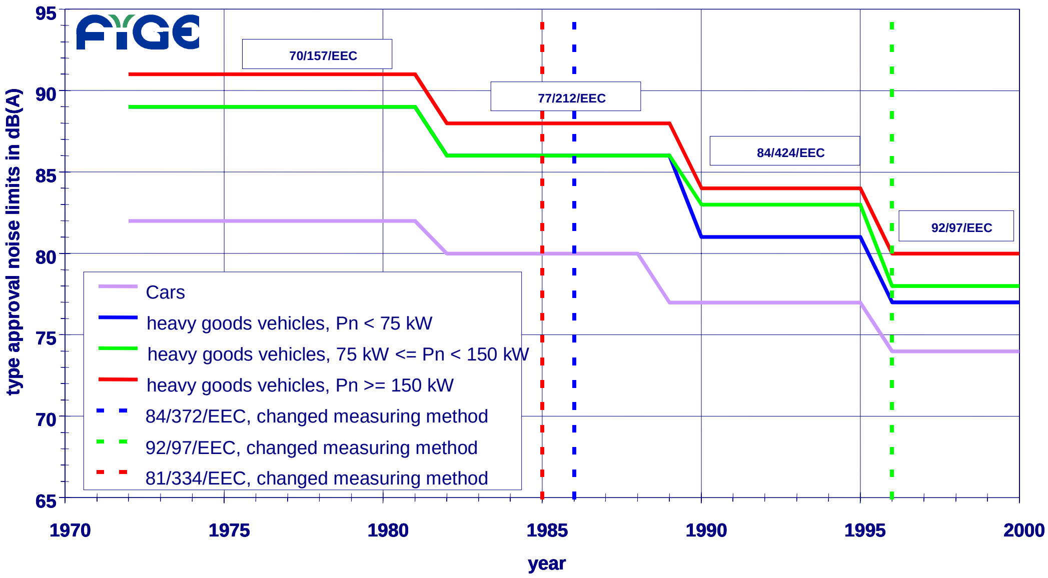

Figure 3.3: Noise limits and measurement method changes in the European Union
(NB. Pn is the maximum power at the rated engine speed)

Table 3.2: Vehicle classifications used within the model

Cars and light duty vehicles		Heavy duty vehicles
Petrol engines	**Diesel engines**	
Up to 1981	Up to 1981	Up to 1982
1982 to 1988	1982 to 1989	1982 to 1984
1989 to 1995	1990 to 1995	1985 to 1989
1996 and later	1996 and later	1990 to 1995
		1996 and later

Further classes will be specified within the project for the calculation of trend scenarios for the future. These may include vehicles with alternative power sources.

In the UBA model, the noise coefficients for the above listed vehicle layers were derived by FIGE/RWTUV Fahrzeug by combining the measurement results of different research projects.

3.1.5 Road category/traffic situation classification

The inclusion of motorcycles within the model made it necessary to restructure the road type/traffic situation classifications used in the original UBA model, because the driving behaviour data for motorcycles could only be separated into urban, rural and motorway operations. On the basis of the analysis of driving behaviour data for cars, heavy duty vehicles and motorcycles, a classification of road categories has been included as shown in Table 3.3.

Driving behaviour databases compiled by RWTÜV Fahrzeug allow representative driving patterns to be assigned to each vehicle class. These driving patterns contain information about vehicle speed, engine speed and engine load on a second by second basis, ensuring that a high time resolution for the emission can be calculated.

3.1.6 Data sources

The model was to be developed during the course of the project with supplementary data obtained from recent studies. The following data sources have been used to support the UBA model:

- Results of field measurements in Germany on different road categories/traffic situations (statistical pass-by levels) from 1978, 1983, 1986, 1992,
- Statistics of the type approval noise levels of the UBA,
- Results of field measurements (statistical pass-by levels) on different surfaces,
- Results of investigations in improving the method of noise measurement for powered vehicles (driving behaviour data for cars and light duty vehicles),
- Results of driving behaviour measurements of heavy duty vehicles (results of the UBA research project *"Influence of the transient operating mode of commercial vehicles and its consideration in emission measurement according to ECE R49"*),
- Vehicle layer shares for different road categories and reference years and average vehicle category shares for different road categories from *TREMOD* and *MOBILEV* (both UBA exhaust emission calculation models),
- Driving patterns from the research programme for updating the exhaust emission factors in Austria, Germany and Switzerland.

Table 3.3: Road type/traffic situation classification

Road type/traffic situation	v_ave_cars	v_ave_mot	v_ave_HDV (km/h)	Standstill (%)
Motorway, without speed limit, traffic density (TD) < 1400 veh/h per lane	130.0	140.0	85.9	0.0
Motorway, speed limit 120 km/h, TD < 1400 veh/h per lane	120.0	130.0	85.9	0.0
Motorway, speed limit 100 km/h, TD < 1400 veh/h per lane	110.0	120.0	85.9	0.0
Motorway, speed limit 80 km/h, TD < 1500 veh/h per lane	95.0	105.0	81.7	0.0
Motorway, speed limit 60 km/h, TD < 1500 veh/h per lane	80.0	90.0	75.1	0.0
Rural, speed limit 100 km/h, straight, TD < 1400 veh/h per lane	83.2	88.1	69.1	1.4
Rural, speed limit 80/90 km/h, TD < 1300 veh/h per lane	76.8	81.8	72.3	2.1
Rural, speed limit 70 km/h, TD < 1100 veh/h per lane	61.8	66.6	55.7	2.9
Main streets, speed limit 60/70 km/h, small interactions, TD 300-800 veh/h per lane	58.2	63.2	53.2	0.6
Main streets, speed limit 60/70 km/h, medium interactions, TD 800-1200 veh/h per lane	48.2	53.1	42.5	2.8
Main streets, speed limit 60/70 km/h, strong interactions, TD 1200-1500 veh/h per lane	37.8	42.4	33.1	10.7
Main streets, speed limit 50 km/h, right of way, without interactions, TD < 300 veh/h per lane	58.2	63.2	53.2	0.6
Main streets, speed limit 50 km/h, right of way, small interactions, TD 300-750 veh/h per lane	46.4	51.3	43.0	3.1
Main streets, speed limit 50 km/h, right of way, medium interactions, TD 750-1100 veh/h per lane	39.2	43.9	34.5	9.4
Main streets, speed limit 50 km/h, right of way, strong interactions, TD 1100-1350 veh/h per lane	32.0	36.5	28.2	15.7
Main streets, speed limit 50 km/h, with traffic lights, small interactions, TD 300-700 veh/h per lane	39.2	43.9	34.5	9.4
Main streets, speed limit 50 km/h, with traffic lights, medium interactions, TD 700-1000 veh/h per lane	28.0	32.2	23.3	22.3
Main streets, speed limit 50 km/h, with traffic lights, strong interactions, TD 1000-1200 veh/h per lane	23.9	27.9	19.7	29.0
Urban city centre, strong interactions, TD 1000-1200 veh/h per lane	19.9	23.6	16.7	35.6
Residential streets, speed limit 50 km/h	38.7	43.5	34.0	6.1
Residential streets, speed limit 30 km/h	28.9	33.7	24.4	8.9
Urban, Stop+Go, TD > 1200 veh/h per lane	6.3	9.2	6.2	22.1

With regards to the driving behaviour data for cars and light duty vehicles, the data includes:

- 11 vehicles (9 cars, 2 light duty vehicles),
- 3 driving styles per vehicle,
- up to 36 road type/traffic situation cases per vehicle.

Similarly, the driving behaviour data for heavy duty vehicles includes:

- 22 trucks (5.6 – 40 tonnes Gross Vehicle Weight, 63 – 365 kW rated power).
- 7 public transport buses,
- 1 coach.

3.2 Limitations of the model

Currently, the model is limited to overall A-weighted noise levels. Although in principle it is possible to extend the model to 1/3rd-octave band levels, the database which is currently implemented does not provide appropriate and reliable data for this extension.

The model performs calculations based around either a single road link or, if calculating for specific drive cycle scenarios, the passage of vehicles over a single route. Consequently although the results from different links could be combined to take into account of simple wider scenarios, the model as developed for this project is not intended for modelling road networks. The combining of the model with a traffic flow simulation model, to improve its meaningfulness with regard to real life behaviour, is the main objective of another ongoing project, ROTRANOMO, within the European Commission’s 5th Framework Programme .

The model is an expert system that requires experience and traffic fleet-data if it is to be fully applied. However, even in the absence of such traffic data, the model can be used to evaluate the influence of parameter variation by changing certain starting conditions. Hence the model could still be of benefit to national authorities for the development of noise control strategies and action plans, in accordance with the EU Directive on Environmental Noise. It is also relevant for use by bodies such as industrial associations, since industry is interested in improving knowledge about the contribution of their products to the control of traffic noise levels.

4 Tyre and road surface noise – a review of technical and legislative issues

Of the sources that contribute to road traffic noise, the noise generated by the interaction of the tyres with the road surface has become the dominant noise source for vehicles travelling at speeds in excess of approximately 50-60km/h on dry roads. The dominance of tyre/road noise over other sources has been brought about partly by the gradual reduction of noise from other sources (engine, exhaust etc.) and partly from the fact that over the past 20 years or so, changes in tyre design have tended to increase tyre noise.

The generation and propagation of tyre/road noise is, however, complex and as a result there has been a great deal of research activity aimed at improving the understanding the processes involved. The ultimate aim is to achieve control of these sources of noise and to determine ways of reducing them. A major part of the problem stems from the fact that the design of tyres and road surfaces has to satisfy other important objectives that are often in conflict with reducing noise. For example, both tyres and surfaces have to meet stringent requirements regarding skidding resistance and both have to provide a high degree of durability and be affordable.

As part of this process of understanding tyre/road noise, a great deal has been accomplished in terms of measurement methods. Improved measurement techniques have application both for the use in research when attempting to gain insight into the relative importance of different tyre/road noise sources as well having application for more pragmatic purposes of approving or certifying surface types for use in highway constructions. Legislation has also evolved and is now playing its part in controlling tyre noise by encouraging the innovation of quieter tyres and road surfaces.

This section provides a review of both the technical and legislative issues associated with tyre/road noise and outlines the progress made in developing quieter designs. This review is intended to serve as background and a precursor to establishing comprehensive noise emission factors that are provided in section 6 of this report.

4.1 The generation and propagation of tyre/road noise

4.1.1 Generation mechanisms

The design of the tyre and the road surface both play a part in the generation of tyre noise. However, design changes to either the surface or tyre can only be made provided there is a full understanding of the wider issues. These include a good understanding of the relationships between noise generation and other important performance factors such as safety and economy. This, in turn, requires knowledge of the mechanisms of tyre noise generation and an understanding of the relative importance of the different sources of tyre noise.

Tyre/road noise is considered to result from a combination of physical processes that are categorised by convention into three distinct mechanisms. These are:

(i) **impacts and shocks** resulting from contact between the tyre tread and the road surface

(ii) **aerodynamic processes** between, and within, the tyre tread and road surface

(iii) **adhesion and micro-movement effects** of tread rubber on the road surface

The main mechanisms described above are illustrated in Figure 4.1 which shows the different noise generation effects associated with the rotation of the tyre.

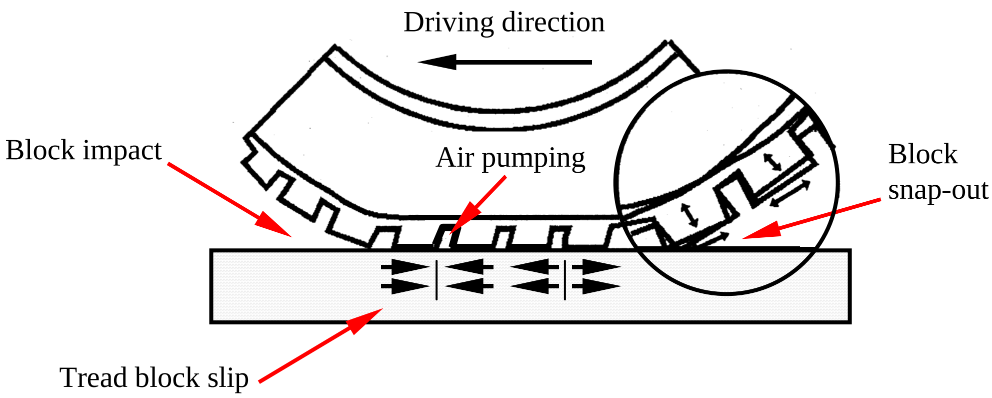

Figure 4.1: Representation of tyre/road noise generation mechanisms

(i) Impacts and shocks

This mechanism essentially consists of the excitation of the tyre tread elements as they come into contact with the road surface, the vibrational response of the tyre carcass, and the subsequent radiation of sound by an area of the vibrating tyre (Plotkin *et al*, 1980).

Vibrations are generated in vehicle tyres by the impacts and deflections that occur as the tread blocks enter and leave contact with the road surface, and as a result of movement of the tread elements in contact with the road base. A tread block entering the contact patch impacts the road surface, generating vibrations which are driven radially into the tyre. The tension exerted on the tread block then decreases and increases depending on the frictional forces between the tyre and road whilst the block is passing through the contact patch. As the trailing edge of the block leaves the contact patch, it is released from this tension and rapidly returns to its undeflected radius. The rapid movement occurring during this process, known as block "snap out", excites both radial and tangential vibration modes in the tyre structure (Bergmann, 1980).

Noise that is generated by the tyre as a result of vibrations caused by tyre impacts and "snap out" effects tends to occur towards the lower end of the frequency range (below 1000 Hz) attributed to tyre noise. This is because the tyre acts as a low pass band filter, effectively attenuating the radiation of noise at higher frequencies.

(ii) Aerodynamic sources

Noise is generated by several mechanisms related to the movement of air in the cavities of the tread pattern. These occur principally in the region of the contact patch. Of these processes the most commonly cited is referred to as "air pumping".

The original air-pumping theory was described by Hayden (1971). The process involves the sudden outflow of air trapped in the grooves of the tread pattern or road surface texture when the tyre comes into contact with the road surface. The air pressure modulations caused by these processes have been shown theoretically to cause significant levels of tyre/road noise, particularly when the surface is non-porous and relatively smooth (Hamet *et al*, 1990). The provision of air paths in the road surface layer (i.e. porous and semi-porous surfaces) can help to dissipate air trapped in the tread grooves and therefore largely prevent air-pumping occurring.

Sandberg (1987) and Cena and Travaglio (1995) have discussed the possibility of noise generation being affected by air resonance in the cavities of the tread pattern. The phenomenon occurs when the dimensions of the cavities are small in comparison to the wavelengths of sound and is analogous to the resonance of a mechanical system.

In general, noise generated by aerodynamic mechanisms tends to be important in the range of frequencies between 1000 and 2000 Hz.

(iii) Adhesion mechanisms

A further noise generation mechanism is caused by tyre vibrations induced by the frictional forces created in the contact patch between the tyre and road surface. When the tyre flattens in the contact patch, the continually changing radial deflection produces tangential forces between the tyre and road. These forces are resisted by friction and tyre stiffness, and any residual forces are dissipated by slip of the tread material over the road surface.

Forces comprised of hysteresis and adhesion components control friction between the tread and the surface. The adhesion component has its origins at a molecular level and is governed to a large extent by the small-scale roughness characteristics, or microtexture of the road surface. During relative sliding between the tyre and the road base, the adhesion bonds that have been formed between the tyre and road surface begin to rupture and break apart so that contact is effectively lost and the tyre element is then free to slip across the road surface. Contact may be regained as these residual forces are dissipated. The hysteresis force is due to a bulk phenomenon that also acts at the sliding surface. The hysteresis component of tyre/road surface friction is largely controlled by the surface macrotexture, which comprises texture wavelengths corresponding to the size of the aggregate used in the surface material.

Clearly, the slippage of tread elements alone cannot give rise to tangential vibrational excitation of the tyre. It is rather the combination of the slip of the tread elements as adhesion is lost in the contact patch and a build up of the hysteresis frictional force as deformation of the tread occurs, which gives rise to a “slip/stick” process in the contact patch. This process provides the vibration excitation of the tyre. Tyre vibration, and hence noise, generated by this mechanism has been related to the slip velocity of the tread elements (Nelson and Underwood, 1984). The highest velocities tend to be found to the rear of the contact patch and may contribute to block “snap out” effects as the tread elements are released from the contact patch and return rapidly to the undeflected radius of the tyre.

4.1.2 Propagation mechanisms

The road surface can play an important part in affecting how sound generated by the tyre propagates to the roadside. This mechanism involves the complex interference between sound reflected from the surface and sound directly radiated to the receiver position. The process is demonstrated in Figure 4.2. The figure shows a simple geometrical representation of a source (tyre) and receiver located above a reflective and an absorptive road surface. It should be noted that when the surface is porous then additional propagation occurs in the surface itself. The diagram clearly shows that the sound pressure arriving at the receptor depends upon the combination of the direct and reflected sound waves which, in turn, depends upon the phase and amplitude of the component waves. When the phase of the two main components differs then destructive interference can occur and the resulting sound level is reduced.

Generally, for tyre noise propagating over reflecting surfaces, this destructive interference effect occurs at relatively high frequencies (typically over 8 kHz). However, for propagation over porous surfaces the additional phase shifts that occur as a result of propagation in the surface layer give rise to destructive interference effects at much lower frequencies (i.e. typically at about 800 Hz - 1 kHz). These are the frequencies where most of the acoustic energy generated by vehicle tyres is located. The beneficial effects caused by these phase interactions coupled with the lack of air pumping are the primary reasons why porous road surfaces have been shown to be associated with significantly lower tyre noise levels than non-porous road surfaces.

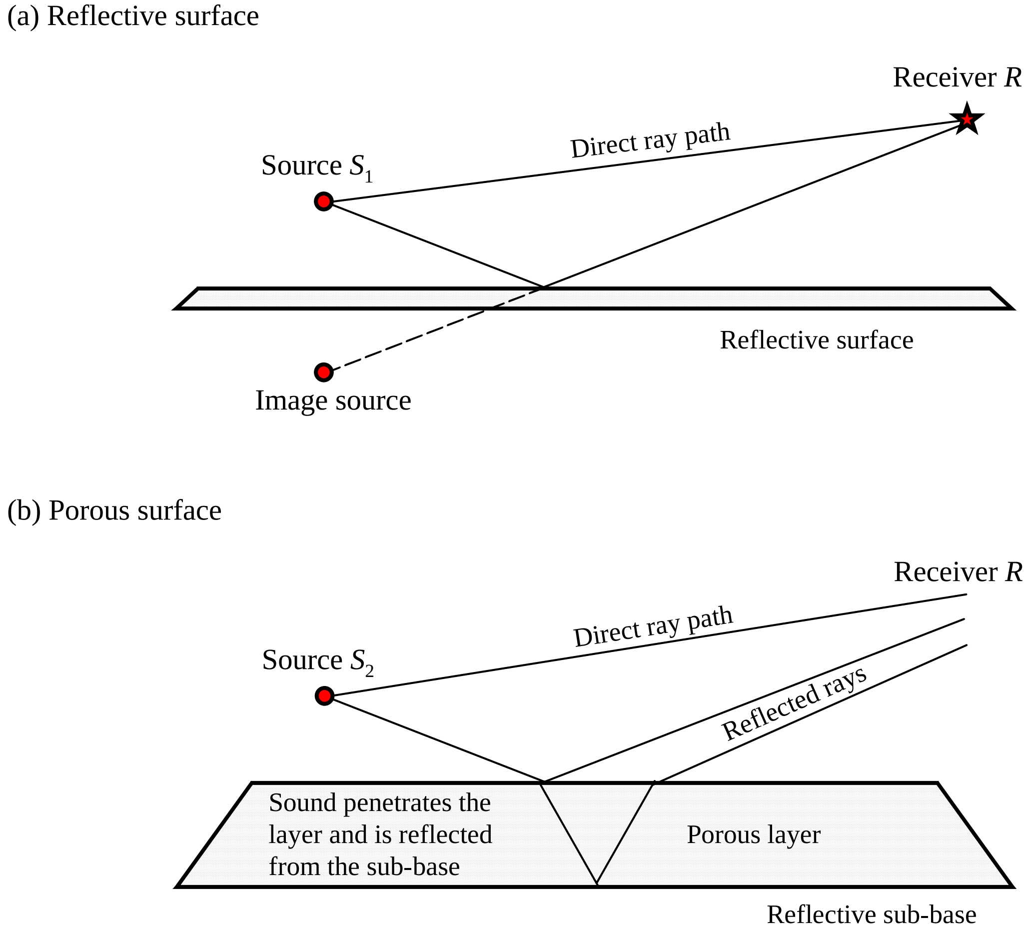

Figure 4.2: Geometry for a source and receiver in the vicinity of a ground plane

Although not strictly a noise propagation mechanism, a further phenomenon is worthy of note. Noise generated at or near the contact patch can be exaggerated due to the shape of the region between the tyre and road surface immediately to the rear (or front) of the contact patch. In this region multiple reflections between the tyre and road surface occur which focus the sound. The process is referred to as the “horn effect” (Nilsson *et al*, 1980). Laboratory studies by Schaaf and Ronnenberger (1982) investigated the influence of the horn effect by measuring the noise levels from an omni-directional impulsive noise source placed close to the rear of the contact patch of a stationary tyre. The measurements were then repeated with the tyre removed and the differences between noise levels across the spectral range determined. The largest amplifications were reported to occur in the region of 2000 Hz. Amplification of the noise levels measured at this frequency and to the rear of the contact patch, where the influence was found to be greatest, was found to be 22 dB(A). It was found that substantial amplification occurred at frequencies from 1000 Hz up to approximately 10 kHz. It follows that porous road surfaces help to reduce the amplifications produced by the horn effect as reflections from the road surface are reduced.

4.2 The measurement of tyre/road noise

The methods used to measure the noise influence of the road surface differ substantially from the methods designed primarily to determine tyre noise. For this reason they are treated separately in the following text.

4.2.1 Road surface noise

The standard method for assessing the acoustic performance of road surfaces is that described in the ISO standard Statistical Pass-By (SPB) Method (International Organisation for Standardisation, 1997). The technique was originally developed at TRL in the 1970s (Franklin *et al*, 1979). The SPB technique is based upon measurements that are taken from a number of vehicles that are operating within the normal traffic stream. Essentially, the method relies on normalising all relevant parameters that could affect noise levels apart from the influence of the road surface.

During an SPB measurement, individual vehicles are selected from the traffic stream travelling in the nearside lane of the carriageway and the maximum (A-weighted) noise levels measured simultaneously with their speed as they travel past a microphone located at a standard position at the side of the road. All vehicles are classified into different groups - normally “light” or “heavy”. For each vehicle group a linear regression of noise against the logarithm of the vehicle speed is carried out and from the regression lines obtained for each vehicle group, the noise levels at a specified speed are determined. This noise level is then used to categorise the surface.

Since the SPB method captures the individual noise generated by passing vehicles, the results obtained can be related directly to traffic noise levels. In addition, when combined with a traffic noise propagation model the SPB noise levels could provide a means of determining traffic noise levels at any point in a community located near to the road section of interest. However, for the purpose of this study, SPB noise levels provide the source information needed to establish emission factors for use in the source model described in section 3. The development of emission factors is developed further in section 6 of this report.

Despite the obvious advantages of the SPB method in establishing road surface noise influence, it is a method that clearly only applies to a specific section of road. In addition, the standard requires fairly stringent site criteria to be met for a valid measurement. For example, the road surface must be homogeneous, straight level and in good order and there should be no acoustically reflective objects/surfaces in the near vicinity of the measurement point. Clearly these restrictions can pose considerable limitations in practice on the locations at which measurements can be taken.

In order to overcome some of these limitations and to supplement the SPB method a further procedure, known as the Close-Proximity method (CPX), has been developed into a draft ISO standard (International Organisation for Standardisation, 2000a). Essentially the method involves noise level measurements using microphones located close to a dedicated test tyre(s) mounted on a vehicle or trailer. The most significant benefits in using this method are that measurements can be taken at arbitrary locations and continuously along long sections of road. The disadvantages are that the measurements are only relevant to a single (or small number) of test tyres and therefore cannot simply be considered to be representative of the traffic stream. Attempts to correlate SPB and CPX measurements are ongoing so that in the future it may be possible to accurately relate the two types of measurements.

A further problem affecting the SPB technique is the location of roadside safety fences and noise barriers. These devices can interfere with the placement of the measurement microphone and contravene the standard site requirements as they potentially cause sound energy to be reflected back to the measurement microphone. This can, of course, restrict the locations where noise levels can be measured which, in turn, limit the ability of highway authorities to assess the acoustic performance of road surfaces at arbitrary locations. To overcome these problems work has been undertaken to develop a method that is independent of site reflections (Kollamthodi *et al*, 2000). Essentially, the method is the same as the standard SPB measurement but it incorporates an acoustically reflective board located directly behind the measurement microphone. The presence of the board means that the unpredictable acoustical effects from roadside features are effectively removed from the measurement and are replaced by a reflective surface whose influence is both consistent and predictable. The microphone position is also located closer to the road than in the standard measurement procedure. This also broadens the potential range of valid measurement sites.

Currently the SPB method is being modified as part of an EC-funded project, SilVia (see section 4.5.3). Options being considered within this project are an extension of the number of vehicle categories used in the regression analysis - It is known that the accuracy of SPB measurements is often dependent on the split between twin-axle commercial vehicles and multi-axle vehicles. An adjustment to the vehicle classification in this manner would also help to align the procedure with that used in the UK for the certification (i.e., 'type-approval') of road surfaces (see section 4.5.1). Further potential modifications include the use of additional microphone positions. It should be noted that the ISO standard on SPB measurements is scheduled for review in 2003. The draft CPX standard is also scheduled for conversion to a full standard. However the timetable for this has been disrupted following the discontinued manufacture of one of the four tyres required by the draft standard. This is Tyre D, the winter tyre, which is currently included to represent the coarser tread patterns used for tyres on heavy goods vehicles.

4.2.2 Acoustic absorption

Porous road surface exhibit important acoustical absorption properties that can affect both the generation and propagation of vehicle noise (See also section 4.1). A particular feature of porous road surfaces is that their acoustical absorption properties vary over time particularly as the surface becomes clogged with detritus. This can directly affect the acoustical performance of these surfaces.

Traditionally, measurements of the acoustic absorption of road surfaces can be taken on samples of the road surface using an impedance tube (International Organisation for Standardisation, 1998). The impedance tube method generally requires the extraction of test cores from a road surface. This can lead to problems with potential damage to the surface and, of course, the extraction process generally requires some form of traffic control- often a lane or carriageway closure. Furthermore, large quantities of water are used to lubricate the cutting tool when cutting and extracting the core and this can wash away some of the detritus lodged in the sample so that the core is then not representative of the road surface from which it was extracted.

To overcome the extraction problems, an extension of the impedance tube method has been developed (von Meier *et al*, 1994) that allows the impedance tube to be used in-situ and does not require a core to be extracted. A draft ISO standard is in development that uses this procedure (International Organisation for Standardisation, 2000b).

The use of a non-destructive technique based upon time domain Maximum Length Sequence (MLS)-based measurements has been demonstrated to be effective in determining the acoustic absorption spectra of surfaces under static conditions (Garai *et al*, 1998). An ISO standard has recently been published (International Organisation for Standardisation, 2002a) covering the procedure. The technique has also been demonstrated to offer the potential for measurement under dynamic conditions at low speeds within the traffic stream (Morgan and Watts, 2002). This technique will be further developed under the auspices of the SilVia project (see section 4.5.3) with the long-term intention being to develop an ISO standard for the technique. Other in-situ techniques based on acoustical interference have also been developed (Attenborough and Howarth, 1992; Nelson, 1993).

4.2.3 Tyre noise

The measurement methods used to determine tyre noise levels range from relatively simple techniques designed to determine overall levels of tyre noise from passing vehicles to very sophisticated techniques designed primarily to gain a greater understanding of the various sources of tyre noise and to establish their relative importance. The main measurement methods can be summarised as:

- Controlled pass-by (CPB) and close proximity (CPX) methods
- Laboratory drum method
- Microphone array techniques

(i) CPB and CPX techniques

Perhaps the simplest technique developed for the assessment of tyre noise is the 'Controlled Pass-By' (CPB) method. This method is normally used for comparing the noise from different tyres on standard testing surfaces and is the basis of the procedure that has been selected for use with the European tyre noise type approval Directive (Commission of the European Communities, 2001).

The CPB procedure involves the measurement of the maximum noise emitted from a single test vehicle as it is driven at steady speed past a measurement microphone. A variant of this technique, known as the coast-by or coast-down method, also requires the engine to be switched off during testing in order that the noise contribution from the tyres is not significantly affected by other noise sources on the vehicle.

The CPX method, described previously in section 4.2.1 is also an example of a relatively simple method but does require the use of specially designed trailers or vehicles. Examples of some of the trailer systems that have been developed for CPX measurements are shown in Figure 4.3.

Figure 4.3: Examples of CPX noise measurement vehicles from Austria (left) and Germany (right)

An example of a vehicle based system for the measurement of tyre noise using the CPX method is shown in Figure 4.4. This vehicle (TRITON) was developed by TRL and is based on a 10 tonne truck. The test tyre is located in a specially developed semi-anechoic chamber. The tyre and chamber can be lowered onto the road surface during testing. The main advantages of this vehicle mounted system is that it can be used on public roads in the UK at normal operating speeds up to 112 km/h and on test tracks to speeds up to 130 km/h.

Figure 4.4: TRL “TRITON” CPX vehicle

(ii) Laboratory drum measurements

The drum method is essentially a laboratory-based technique whereby a test tyre is mounted so that it rolls over a rotating drum. The drum is usually coated with an artificial road surface texture. As in the trailer method, measurements are carried out in close proximity to the tyre/surface interface. This is necessary to ensure that any noise generated by the drum mounts and bearings does not contaminate noise from the tyre. The method is suitable for situations that require a high degree of reproducibility and precision but where a lack of realistic operation can be accepted.

It is difficult to achieve realistic performance with this technique because of the curvature of the drum surface. On a curved surface, the tyre contact patch length is shorter than on a flat road. To combat this effect, some researchers lower the tyre inflation pressure or increase the load on the tyre. Unfortunately, this affects other noise generating mechanisms and consequently the drum method is not generally considered suitable as a means of assessing tyre noise on real road surfaces. Despite these problems some tyre manufacturers and researchers, such as at BAST in Germany, use the drum method during the development of prototype tyres and road surfaces.

(iii) Microphone array techniques

To further the understanding of the mechanisms responsible for tyre/road noise generation it is important to be able to identify the location, acoustic power and directivity of individual sources of noise on a tyre. It is preferable to be able to do this under realistic operating conditions, i.e. at high speeds on typical road surfaces. Hybrid experimental/predictive techniques have been developed which use the results of measurements in close proximity to the vehicle tyre to localise individual sources, determine their strengths and predict far-field noise levels. These include techniques known as acoustic holography and transfer path analysis. They require the use of arrays of microphones located around the tyre. As such they are not regarded as routine measurement techniques as they require sophisticated and expensive instrumentation and require specialist knowledge of some advanced signal processing and analysis techniques. An example of the set up used for a technique known as Airborne Sound Quantification (ASQ) is shown in Figure 4.5. The figure shows an array of 32 microphones located in close proximity to a truck tyre. The tyre is mounted on a specially designed trailer and can be loaded to simulate normal running conditions. This method and others have been reviewed by TRL for quantifying tyre noise sources under realistic operating conditions (Morgan *et al*, 2003).

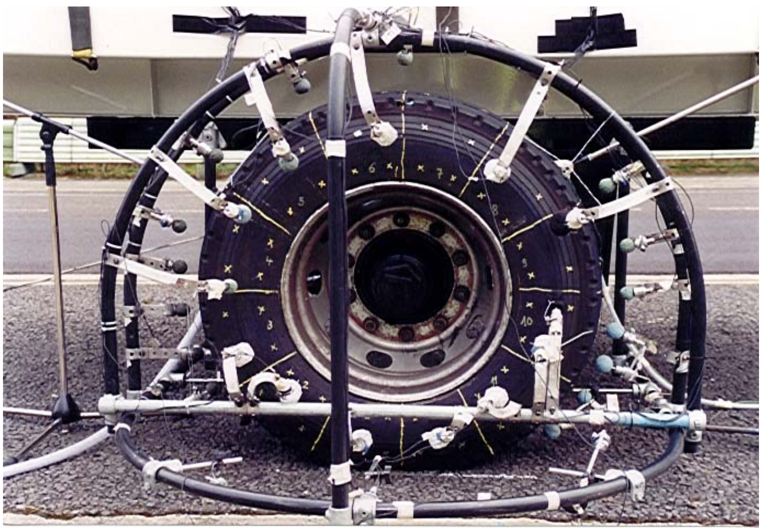

Figure 4.5: Microphone array used for ASQ measurements

4.3 Developing quieter surfaces

A great deal of research work has been invested in developing road surfaces that reduce tyre noise generation and propagation. For convenience low noise surfaces can be grouped according to whether they are porous or non-porous.

A useful overview of recent work carried out on low noise road surfaces has been written by Bérengier and Licitra (2003). A further more in-depth review has been made by Sandberg and Ejsmont (2002).

4.3.1 Non-porous road surfaces

It has been known for many years that the roughness or texture applied to a road surface strongly influences both its skidding resistance in wet conditions and the level of traffic noise, particularly at high speed. (NB. The role of texture in affecting tyre noise generation mechanisms has been reviewed earlier in this document).

Early research established that there could be a conflict between measures of average road surface texture depth and noise levels. Roads with deeper textures, which offered higher standards of skidding performance, tended to produce higher noise levels (Franklin *et al*, 1979). It was thought, therefore, that there was an intractable conflict between the requirements for safe road surfaces and noise generation.

More recently the research has on non-porous road surfaces has focussed on discovering the precise relationships between noise generation and individual texture wavelengths (Hewitt *et al* (1997), Phillips et al (2001)). The results established the importance of texture wavelengths in the megatexture range (i.e. 50 -500mm) with regard to the generation of high levels of tyre noise. This was an important finding since these wavelengths are known to have only a relatively minor role in affecting skid resistance. Skidding resistance is mainly affected by surface textures in the macrotexture range (0.5 - 50mm) and microtexture (<0.5mm). Macrotexture is particularly important in dissipating the energy of braking for high-speed operations whilst microtexture is a region of the texture spectrum important for ensuring good grip at low speeds.

This result clearly pointed to the need to remove megatexture amplitudes as far as possible from road surfaces as this would help to reduce noise levels without seriously affecting skidding performance and hence safety. As a result of this and other research a new range of quieter (non-porous) surfaces are gradually being introduced across Europe. For example, traditional surfaces such as Hot Rolled Asphalt (HRA, used extensively in the UK) and concrete surfaces are slowly being replaced, either as part of routine maintenance or programmed replacement, with surfaces designed to generate lower levels of tyre road noise. Some examples of lower noise surfaces are described below:

- **Thin surfacings**

  Thin surfacings are frequently used for low-cost repairs or surface replacements. They are, however, increasingly being specified for new road surfaces. The term is a generic description for three distinct classes of surface:

  - Very thin surfacing: thickness 20 – 25 mm
  - Ultra thin surfacing: thickness 12- 18 mm
  - Micro surfacing: thickness 8 – 12 mm

  These surfaces can be constructed with relatively have low texture amplitudes in the megatexture region and posses a property known as negative texture. Essentially negative texture refers to the fact that the surface texture is formed primarily by the presence of holes in the surface layer rather than from stones protruding above the surface layer. This later type of texture occurs frequently when stones are rolled into the surface following laying the asphalt mix. (e.g. HRA) The presence of negative texture helps to provide air drainage channels between the tyre and surface and therefore helps to reduce the occurrence of air pumping noise.

Most thin surfacings are proprietary, i.e. they are designed, marketed and produced exclusively by companies. Examples of thin surfacings used in the UK are Safepave and UL-M. Trials of these surfaces have shown them to be acceptable for use on UK high-speed roads and have since been approved by the Highways Agency as being suitable for use on motorways. A further proprietary thin surface is Colsoft which incorporates crumb rubber aggregate reclaimed from waste tyres in an asphalt overlay. The surface was developed in France in 1994.

- **Exposed aggregate concrete**

  Historically, road surfaces constructed in concrete have tended to be textured transversely across the carriageway by brushing the surface just after laying and before the concrete has set. Although this form of texturing forms a durable and safe surface it has been shown to produce higher noise levels than bituminous surfaces. The reason for the high levels of noise can be attributed to the texture pattern which encourages higher levels of tread block tyre excitation than occurs typically on bituminous surfaces which have a randomised surface texture pattern.

  In order to remedy the high levels of noise produced by concrete roads, an alternative form of texturing concrete roads has been developed that produces a texture pattern similar to bituminous surfaces. The technique consists of laying a concrete slab in either one or two layers and then spraying the finished surface with a cement retarder. The retarder slows down the curing process of the surface layer of concrete while the lower layers are allowed to set and harden. Once this has occurred the concrete is brushed or washed with a pressure hose to remove the mortar at the surface of the slab. This exposes the aggregate and produces the randomised texture required.

  Recent studies of the performance of Exposed Aggregate Concrete Surfaces (EACS) has established both acoustic and durability performance in comparison with other conventional surfaces over a period of exposure to trafficking (Chandler *et. al*, 2003). A comparison of noise generated on the EACS with adjacent hot rolled asphalt (HRA) showed the EACS sites, constructed with a 10 – 6 mm maximum aggregate size produced, on average, about 1.7 dB(A) less noise for light vehicles and 1.3 dB(A) less noise for heavy vehicles. The study also included the results of measurements taken on Savepave with both a 10 mm and 14 mm maximum stone size aggregate (SP10 and SP14), and on Stone Mastic Asphalt (SMA). It was found that initially the noise levels were either close to or lower than those measured on the EAC surfaces. However, the levels for the SP10 and SP14 surfaces tended to increase more rapidly with time than EACS.

4.3.2 Porous road surfaces

As mentioned earlier porous road surfaces offer unique properties of potentially reducing both the generation and propagation of tyre noise. There are, however, many variants of this type of surface some of which are reviewed below:

- **Porous asphalt (PA)**

  This is generally considered to be the quietest of high-speed road surfacings. It was developed by TRL in the late 1950s for use on airport runways and trialed for use on public roads in the 1960s. Originally PA was developed to reduce surface water and spray on high-speed roads during periods of heavy rainfall. Following the road trials it was found that this type of surface also offered acoustic benefits. Although Porous Asphalt is an approved road surfacing in the UK, it is not generally used on very busy motorways where there is a high proportion of heavy commercial vehicles because of the risk of early failure. The specification for PA requires the use of large sized and good quality crushed rock (20 mm maximum aggregate size). This produces a high quality surfacing but is more expensive than other forms of bituminous surface.

In practice, the acoustical benefits of PA are reduced over time due to clogging of the pores within the surface by detritus resulting from the passage of traffic (Nicholls, 1997). The drainage performance of the surface is also reduced. However, due to the large stone size used in the specification of PA, the surface does tend to remain porous over a relatively long period when compared with other porous road specifications that use smaller aggregates.

It is fair to say that at the present time porous surfaces are not commonly used in the UK but are found more frequently in mainland Europe although the specifications are usually different from that used in constructing PA.

- **Double Layer Porous Surface (Twinlay)**

  The clogging problems which result when using some porous surfaces has led to the development of double layer porous materials, i.e. two porous layers superimposed, each having a different grading. The upper layer uses a smaller aggregate than the lower layer. The concept is that the fine grain of the upper layer acts as a filter for dust and deposits that are removed by means of the cleaning effect caused by constant vehicle passages. The coarse grain layer on the bottom is protected from clogging so that rainwater can drain away and the acoustic properties are retained. This type of double layer material was first used in Germany and the Netherlands in. Tests have been reported by Bendtsen *et al* (2001, 2002).

- **Poroelastic surfaces**

  An alternative to double layer PA is the poroelastic road surface. This consists of rubber granules or fibres bound together with a bitumen or polyurethane binder. The lack of fine graded material in such a surface makes it highly porous whilst the high rubber content makes the surface elastic. The elasticity of the surface helps to reduce “vibrational-excited” tyre/road noise.

  Examples of these surfaces have been tested with limited success in Norway (Arnevik, 2000), and also in work carried out in Japan (Ohnishi, 2000) and Sweden (Sandberg *et al*, 2000). These surfaces have been found to reduce traffic noise by between 5 –15 dB(A) compared to dense asphalt surfaces, although problems were encountered particularly regarding the durability of the surfaces. New sections of poroelastic surface are currently undergoing test trials in Sweden.

- **Stone Mastic Asphalt (SMA)**

  SMA was originally developed in Germany and is now widely available throughout Europe. It is not really a porous surface but is included in this section as the aggregate grading is similar to that of porous asphalt. The main difference being that the binder content is much higher than for a truly porous surface and as a result the porosity is much lower. SMA is sometimes regarded as a thin surfacing and has similar acoustic properties to the thin surfaces reviewed earlier. It normally does exhibit some porosity but the main noise reduction features are associated with the negative texture, which helps to reduce air-pumping noise and the low amplitudes of megatexture, which helps to reduce tyre tread impact noise.

  Following trials at TRL a SMA mixture with a maximum aggregate size of 14 mm was recommended to provide adequate texture for use on high-speed roads. This type of surfacing is now being used on a wide range of roads partly as a means of controlling noise levels.

4.3.3 Other developments of low noise surfaces

A research project, HILJA, was started in Finland in 2001 to find suitable products to be used in quiet asphalt surfaces and to develop better methods to measure noise. Seven test roads were paved between 2001/02, four on national highways and three on municipal roads in Helsinki and Espoo. A large number of test stretches were laid on these roads, including porous asphalt and SMA. The results of this project are expected at the end of 2003.In 2001

Traditionally, developments in surface technology have been primarily concerned with improving durability, life span, safety performance and factors such as noise generation. However it is becoming increasingly important to minimise disruption caused by maintenance works and consequently an additional factor which is now taken into account is the speed and ease with which surfaces can be laid or replaced. This tends to mitigate against the acoustic advantages of porous road surfaces since when these surfaces need replacing the whole of the layer has to be removed before a replacement can be laid. This adds greatly to the time required for the construction and hence adds to the disruption caused.

As part of the Dutch “Roads To The Future” scheme, full-scale trials have been conducted on a number of prototype road surfaces that have been designed to minimise the disruption caused by this form of construction work. Six innovative designs of road surface (and one noise barrier design) were selected for testing, and promised to achieve a noise reduction of between 5-12 dB(A). Two of the surfaces were selected for study under the Noise Pilot project (Ministerie van Verkeer en Waterstaat, 2001) - *Silent Transport* and *Tapis Tolerance*. The former was optimised to reduce noise from heavy goods vehicles while the latter comprised 3 layers, the bottom being an absorptive layer comprised of honeycomb profiles and mineral wool. The remaining four surfaces were selected for study under the Modular Road Surface Pilot Study: *The Very Silent Sound Module*, *Modieslab*, *The Way of no Resound* (this included Helmholtz resonators within the surface), and *The Adhesive Road*. The concept behind a modular surface is that the surface consists of different layers, potentially prefabricated, with each layer having an individual purpose, e.g. noise reduction, water permeability, etc. The measurement programme was concluded in September 2000 and the results indicated the surfaces to produce noise reductions of between 5-8 dB(A) for light vehicles travelling at 100 km/h in comparison to the Dutch dense asphalt concrete reference surface (Hofman and Mank, 2003).

Work has been carried out by DWW into the development of modular road surfaces. In this instance the prefabricated road surface, an asphalt surface, was rolled onto a drum and then unrolled on site directly onto the prefabricated slabs forming the base course as shown in Figure 4.6 and Figure 4.7.

In the Netherlands, the Ministry of Transport and Environment Affairs have begin an extensive research and development programme, the “Noise Innovation Program” (IPG) (Vos, 2002). In its first phase this programme will investigate the potential noise reduction offered by road surfaces, tyres and vehicles and enhanced noise barriers, as well as the development of technologies and products for general application in the road surface and vehicle fields. Two of the main research areas are the road surface and the tyre/vehicle system. The road surface project includes the wide application of twin-layer porous asphalt pavements, improvements in the acoustical and structural performance of porous/non-porous surfaces, and the development of the next generation of silent roads. Further details are given in the paper by Hofman and Mank (2003).

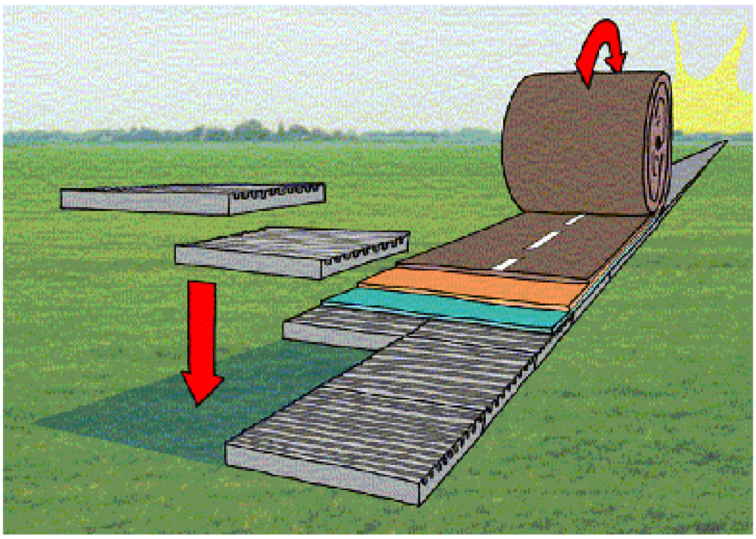

Figure 4.6: Example of a prefabricated modular road surface
(Pictures courtesy of DWW)

Figure 4.7: Example of a prefabricated, modular road surface
(Pictures courtesy of DWW)

4.4 Developing quieter tyres

Over the last 30 years, tyre noise levels have tended to increase due mainly to changes that have occurred in tyre design. In particular, tyre dimensions have changed. For example, car tyres have become progressively wider over time - in the past 15 years the increase has been about 2 mm per year.

It is generally accepted that tyre/road noise levels tend to increase with increasing tyre section width. The mechanism can be simply related to block tread impacts. As the section width increases, a greater number of tread blocks can be accommodated across the width of the tyre. This results in a greater number of tread blocks impacting against the road surface as the tyre rotates, which leads to an increase in noise.

TRL carried out a comprehensive study of tyre/road noise for the UK Department of Environment, Transport and the Regions (DETR) (Phillips *et al*, 2001). Overall, twenty-nine passenger tyres, four van tyres and eleven truck tyres were studied running over seven different road surfaces that were typical of roads in the UK and Europe. The selection of tyres and surfaces included those that were specifically designed to result in low levels of tyre noise. The study included an examination of tyre noise and section width. The results indicated that for car tyres, the noise levels increase by between 0.2 and 0.4 dB(A) for each 10 mm increase in section width depending on the road surface, whilst for truck tyres the increase was approximately 0.1 dB(A) per 10 mm width increase. The increase for truck tyres was found to be independent of the type of road surface.

The aspect ratio of the tyre is also a facet of the tyre dimensions that can have an influence on noise generation. The aspect ratio is the ratio, expressed as a percentage, of the height of the sidewall of a tyre to the section width. A decrease in aspect ratio is usually associated with increased tyre sidewall stiffness. Stiffer tyres tend to generate more noise due to the lower levels of damping inherent in their structure.

The TRL study also showed the potential for reducing road/tyre noise simply by matching tyres and road surfaces so that the design features of each interact symbiotically to reduce noise. It was shown, for example, that for car tyres, the difference in noise between the quietest and noisiest tyre/road surface combination was 9 dB(A). The corresponding difference for van tyres was also 9 dB(A) and for truck tyres was 7dB(A). These numbers alone indicate that there are substantial opportunities for reducing overall levels of traffic noise and hence the noise impact on communities. However, it will, of course take a considerable time for the design changes needed to take place. While tyres may be replaced on vehicles every 2 -3 years on average, roads typically last 10 - 15 years before they need to be resurfaced. A further point is that the current type-approval test for vehicle tyres requires measurements to be taken on the ISO 10844 surface ,which is a smooth asphalt surface, which was specifically designed to reduce as much as possible the contribution of tyre noise to the overall levels of vehicle noise. The tyre industry has therefore worked to optimise its tyres based on tread pattern designs appropriate for this surface which, therefore, may not be fully realised on other surface types.

The importance of speed in relation to noise generation by tyres was also highlighted in the TRL study. It was shown, for example, that noise from air pumping was generally more dynamically related to speed than tread block noise generation. This, of course, points to the advantages offered by tyre/surface combinations that tend to produce lower levels of air pumping noise particularly for high-speed road applications.

The demand for lower noise has resulted in a substantial change in tread pattern design in recent years. Previously, low profile tyres tended to be characterised by open block patterns to assure swift water dispersal. This type of pattern, however, is not only noisier, it wears quicker too. Now, largely due to legislation and improvements in compound technology, we are seeing a move to quieter rib type patterns broken up by narrow cross grooves with the blocks located closer together. With more rubber on the ground, this means not only better dry grip but improved mileage performance, no loss in wet grip and, of course, potentially lower noise.

The TRL study also briefly examined the influence of tyre tread pattern design on noise levels and illustrated the practical acoustical advantages in employing tyres with directional tread pattern designs over tyres with no directional features.

4.4.1 Future developments and concepts

For heavy-duty vehicles noise reductions could be achieved by employing some from of shielding around the tyre and/or using absorbent material in the region of the wheel arch. Studies at TRL using a mathematical modelling technique have attempted to establish the performance of different designs of shields and enclosures (Morgan and Watts, 2003). The study was restricted to a single frequency, due to the complexity of the calculation method, but it indicated that substantial reductions were possible using appropriate designs of shields. Such measures would probably not be possible for car tyres as the body design for most car models already provides a degree of shielding. It is also claimed that some additional reduction in tyre noise could be achieved if the air cavity inside the tyre could be replaced with a closed cell foam material. Reductions of 2-3 dB(A) are claimed. Further possibilities for the development of composite wheels (whereby the hub, rim and tread are formed from a single section) are discussed by Sandberg and Ejsmont (2002), including open composite wheels where the tread and the centre hub are connected by a series of “spokes”. However no results from the trials of such wheels are available.

Over the coming decade, the tyre industry anticipates that there will be a steady improvement in the use of alternative raw materials rather than any major breakthroughs, with such improvements being balanced with maintaining safety performance and product durability.

It is interesting that the tyre manufacturers expect a 3dB(A) reduction in tyre/road noise in real traffic if all after-market tyres were to meet the noise standards of the original tyres fitted to the vehicle by the manufacturers (i.e. OEM tyres). It is claimed that currently some after market tyres have up to 6dB(A) higher noise emission values than type approval tyres.

Generally tyre manufacturers are concerned that further reductions in tyre noise will be difficult due to the constraints imposed by the vehicle manufacturers regarding wear and handling. Furthermore, noise is not considered by the industry to be the most important parameter relating to tyre design, the following ranking being considered to be the most appropriate.

1. Safety and handling aspects.
2. Environmental aspects (including tyre/road noise emission, vibration and harshness).

3. Economical aspects (Rolling resistance and tyre wear).

4.5 Legislation and policy drivers affecting tyre/road noise

Across the European Community there is now in place a range of legislative and policy related procedures that are intended to have an impact on current and future levels of tyre/road noise. They range from limiting noise levels of new tyre and road surface products through the application of closely regulated type approval procedures, to the implementation of monitoring and replacement policies aimed at closer control of noise levels over time. Both types of regulatory instrument are reviewed in this section. Also included in this section is a summary of projects financed by the EU that could have a bearing on future noise policies and procedures.

4.5.1 Type approval

Tyres:

A directive for tyre noise type approval, 2001/43/EC was introduced in the EU in 2001 (Commission of the European Communities, 2001). The new directive specifies test procedure and limit values for all new tyres entering service. The limit values have been set initially to reflect current practice and to encourage innovation, but progressive tightening of the limit values is proposed in future years provided that future noise level reductions can be achieved without reducing safety performance or other desirable factors.

The current limit values in the Directive have also been set to ensure that the safety performance of existing tyres is not compromised. However, this means that tyres older than current generation models have been demonstrated to meet the current limit values.

Road surfaces:

There is no type approval procedure for road surfaces that applies across the European Community. However, some countries are beginning to operate schemes that effectively act as type approval procedures for road surfaces and there is a growing interest generally across Europe in establishing suitable standard procedures.

In the United Kingdom, the Highways Agency Products Approval (HAPAS) was developed primarily with the aim of assessing the fitness for purpose of different road surface products. New road surfaces now have to comply with the requirements of HAPAS in order to achieve certification for use in road constructions and maintenance programs. It was developed by a number of bodies involved in the management of roads that included the Highways Agency and the British Board of Agrément, which is responsible for the certification process (British Board of Agrément, 2001). In 1998 the scheme was extended to cover the type approval of proprietary thin surfacing materials, and it was decided at the time to include an optional noise test. The test procedure developed by TRL for this type approval largely follows the ISO Statistical Pass-by (SPB) method (International Organisation for Standardisation, 1997) (see Section 4.2.1), but uses three classes of vehicle instead of the two classes normally used.

A similar scheme, known as the C-Road scheme was introduced in the Netherlands in the late 1990s (van Blokland and Kjuipers, 2001) to act as both a type approval scheme, based around the ISO SPB method, and for ensuring conformity of production, using CPX measurements.

The SilVia project (see Section 4.5.3) is working to develop a classification procedure for low noise road surfaces which will include checks to ensure conformity of production. The classification will attempt to introduce some type of overall lifetime criteria for the surface as well as criteria to be satisfied within a relatively short time span of the surface being laid.

4.5.2 Other legislatory and policy instruments

Surface replacement policies:

Some countries have adopted policies that ensure that when roads are replaced or resurfaced lower noise surface materials are used. For example, in the United Kingdom, the Government's 10 year investment plan for transport (Department of the Environment, Transport and the Regions, 2000a) is aimed at implementing transport policy which will, amongst other objectives, help to reduce the impact of traffic noise from trunk roads. The plan requires that over its duration, 60% of the trunk road network in England will be resurfaced with lower noise road surfaces, including the replacement of all sections surfaced with concrete. This equates to resurfacing some 2500 miles of trunk roads, with the concrete surfaces constituting about 250 miles of the network. The Highways Agency is committed, as a matter of course, to using quieter surfaces whenever a road needs resurfacing as part of its usual maintenance programme and it is anticipated that 55% of all blacktop roads will have been resurfaced by March 2011.

Also in the UK, The Mayor of London's draft London Ambient Noise Strategy (Greater London Authority, 2002) sets out a proposal for London's roads to *"… use noise reducing surfaces, where practicable and cost effective, and where they meet safety and other criteria"*.

In the Netherlands, the "Roads To The Future" scheme (Wegen naar de Toekomst, 2000), an innovation programme run by the Ministry of Transport, Public Works and Water Management, is predominantly aimed at seeking smart solutions for mobility and infrastructure. It provides incentives for solutions to accessibility problems in consultation and co-operation with external partners, such as interest groups, technical experts and road users. It is also a legal requirement in the Netherlands that roads carrying traffic above a certain volume be surfaced/resurfaced with porous asphalt. This treatment process commenced in 1987.

Noise modelling;

Work by the French in the late 1990's to update the vehicle noise emission values used in the French road traffic noise prediction models resulted in a determination of three different surface classes (Dulau *et al*, 2000).

- Low noise R1 – thin asphalt concrete 0/6, 0.10, porous asphalt 0/10
- Intermediate class R2 – cold applied macadam, bituminous concrete 0/10, 0/14
- Noisy class R3 – cement concrete, surface dressing and thin bituminous concrete 0/1

Similarly in the UK the standard traffic noise prediction model provides corrections for low noise porous surfaces. Clearly by including different emission factors in the prediction model top take account of the effects of different surfaces on traffic noise it highlights the economic and social benefits of lower noise surfaces which, in turn, helps encourage their wider use in new constructions.

Environmental labelling:

An alternative to type approval would be to use the concept of noise labelling. In such an instance, surfaces are tested using an officially recognised test method, but prescribed limits for the performance of the surface are not set. Such an approach has a background in legislation but does not enforce limit values.

Tyres that meet certain noise criteria (often in tandem with other environmental criteria) may be marked with am environmental label, which would certify the product is environmentally friendly, at least in relation to other products. It is feasible that the use of such labelling might influence consumers in their purchases. The following lists examples of environmental labelling systems for tyre/road noise that are in operating currently in Europe.

- *German Blue Angel:* Managed by RAL (the German Institute for Quality Assurance and Certification) and developed with the support of the German Federal Environmental Agency (UBA). Criteria for awarding of the label have been specified for low noise and fuel-saving automobile tyres (RAL_UZ89) and retreaded tyres (RAL_UZ 1)
- *The Nordic Swan*: This is the official Nordic eco-label and was introduced by the Nordic Council of Ministers. Tyres for light as well as heavy vehicles are products for which the label can be obtained, and retreaded tyres are also eligible.

An EU eco-label is also in existence, but this is not yet been extended to cover vehicle tyres or the vehicles themselves.

4.5.3 European research projects

The following is a summary of ongoing European projects that may impact upon the application of quieter tyres and/or road surfaces in the longer term:

- **SilVia** *(Sustainable road surfaces for traffic noise control)*

  This project is aimed at providing decision-makers with a tool that will allow them to rationally plan traffic noise control measures. To this end, the objective is to fill three major knowledge and technical gaps, namely by

  (i) setting up classification and conformity-of-production procedures of road pavements with respect to their influence on traffic noise,

  (ii) investigating and improving the functional and structural durability of low-noise pavement construction and maintenance techniques, based on existing data and laboratory and field testing, and

  (iii) developing a full life-cycle cost/benefit analysis procedure for traffic noise abatement measures.

  The main final product will be a European Guidance Manual on the Utilisation of Low-Noise Road Surfacings" integrating low-noise surfaces with other traffic noise control measures including vehicle and tyre noise regulation, traffic management and road and building noise protection equipment.

- **CALM** *(Community noise research strategy plan)*

  The objective of the CALM network is to establish and co-ordinate a community noise research strategy plan to define the steps to be taken towards reducing noise emission within the EU from air traffic, road and rail transport, marine technologies and outdoor equipment.

- **ROTRANOMO** *(Development of a microscopic road traffic noise model for the assessment of noise reduction measures)*

  The main objective of the project is to build up a subtly differentiated road traffic noise calculation model that can be used for the development of effective and economic noise reduction action plans. It is intended for use in developing assessments of various noise reduction strategies within the frame of the environmental protection policy in the EU or its member states. The model must include all relevant influencing parameters, be sensitive for all kinds of reduction measure scenarios, and be applicable to future prospects estimations. It will be capable of considering technical improvements leading to noise emission reduction of vehicles, tyres and road surfaces, traffic management related measures, driving behaviour influencing measures, reduction of the transmission of sound (e.g. improvement of noise barriers), environmental planning, structural changes, cost effects of noise reduction.

- **RATIN** *(Road and tyre interaction noise)*

  The objective of the project is to provide tools and guidelines for the reduction of exterior vehicle noise due to the interaction between tyre and road. The results of the project will assist in preparing the tyre and car industries for future challenges. The main potential for reducing tyre/road noise is in the simultaneous optimisation of tyre and road properties. It is therefore proposed that RATIN will develop a complete and physically consistent model for the prediction of exterior and interior tyre/road noise over the audible frequency range, i.e. at least up to 3 kHz.

5 Vehicle propulsion noise – a review of legislative and technical issues

The overall noise level generated by an operating vehicle is comprised of a large number of separate sources. However, for convenience they can be divided into sources that relate to the engine and its ancillaries and sources that relate to the movement of the vehicle over the road surface. The latter group of sources includes tyre/road noise and aerodynamic sources but, as has been stated earlier, for normal road vehicle operation it is largely dominated by the tyre/road noise. Propulsion noise sources are largely controlled by the speed of the engine.

Propulsion noise sources are numerous but primarily include noise originating from the combustion of the fuel in the cylinders as well as noise emanating from the various moving parts of the engine and gearbox. Combustion noise is generated through vibration of the engine block and sump as well as through the flow of gases into the engine and at the exhaust. Mechanical noise can arise from movement of the pistons, crankshaft, timing chain, gears, cooling fan, fuel injectors, etc.

Although the control of these sources requires a great deal of ingenuity and technical know how, there have been remarkable reductions in the maximum noise generated by the propulsion noise from all vehicle types over the past 20 years. This has arisen as a result of major investment in research with the result that noise control is no longer considered to be an issue to be dealt with by retrofit or iterative processes, it is now a fundamental ingredient of all new vehicle design.

In keeping with the major advances made in power unit design, vehicle noise type approval limits have been progressively reduced in Europe.

This section reviews the legislation and test procedures developed for vehicle propulsion noise and briefly examines the prospects for further noise reductions in propulsion noise. Again the intention is that this information will serve as background and a precursor to the establishment of noise emission factors for vehicle propulsion noise that are provided in section 6 of this report.

5.1 Test procedures for the assessment of vehicle noise

5.1.1 Current test procedures

Vehicle type approval is presently carried out according to the procedures specified in either EC Directive 92/97/EC (Council of the European Communities, 1992) or UN-ECE Regulation No.51 (Noise emissions from category M and N vehicles). The former is mandatory within all EC Member States, the latter is optional but it is this standard that is recognised outside of the European Community. The procedure adopted in the ECE regulation and EU Directive is based upon the technical standard International Standard ISO 362 (International Organisation for Standardisation, 1964).

The test procedure involves driving an unladen vehicle over a specially designed test surface laid in an open area. The site requirements are specified in the Directive. During the test the vehicle is rapidly accelerated from a low initial speed and in a low gear. The intention is for the vehicle to generate the maximum noise it is capable of under normal driving conditions in-service. During the test the maximum noise level in dB(A) is measured at a standard distance from the accelerating vehicle. The process is repeated and the noise measured on both sides of the vehicle. The results are averaged and rounded to determine the test level.

5.1.2 Revisions and future developments of test procedures

Although the type approval test procedure has been part of vehicle type approval in the EU for over 25 years, the method has been criticised on the grounds that it is not sufficiently representative of normal driving conditions. It is argued that a full throttle acceleration condition only occurs relatively rarely in practice and therefore the results obtained using this form of test will not reflect the annoyance typically felt in the community. Furthermore, despite the dramatic reductions achieved in propulsion noise from vehicles, traffic noise levels in the UK and Europe have not fallen significantly. Vehicle manufacturers have repeatedly claimed that further reductions in the permissible noise levels are not possible due to the contribution to the whole vehicle noise level by the noise generated at the tyre/road interface.

It is clear that if future vehicle noise test procedures are to be effective, they will need to ensure a greater degree of correspondence between test results and noise generation in practice. In other words, test procedures will need to offer a better degree of discrimination between noisy and relatively quiet vehicles for conditions representative of noise intrusion in community settings. This may require vehicles to be tested under a variety of operating conditions representative of normal driving. Future testing will also need to ensure that appropriate examination of both propulsion and rolling noise components are considered and with the emergence of alternative fuelled and hybrid powered vehicles, any future test procedure should also be appropriate for new and emerging vehicle technologies.

Recently, it has been decided to amend the test procedure in order to address these concerns. ISO WORKING GROUP TC 43/SC1/WG42 is carrying out the revision of ISO 362. Concurrently UN-ECE Regulation 51 is being updated by Working Group WP29/GRB. The proposals currently being considered by the Working Group involve testing vehicles undergoing both a steady speed cruise-by operation and a low speed acceleration that is more representative of actual driving than the high torque acceleration condition specified in the current standard. In addition, in the proposed method, vans and trucks will be operated carrying a representative load rather than unladen as in the current test. Again this change to the standard is intended to create a more realistic test. The Working Group is also considering introducing a mode of operation that is more representative of urban driving. This could take the form of a low speed acceleration condition typically encountered at traffic lights. Research at TRL is also currently investigating different forms of test procedure including a low speed 'urban' drive test.

In the revision of Regulation 51 (Noise emissions from category M and N vehicles) being carried out by WP29/GRB, no consideration is being given to the levels of noise generated by stationary vehicles or those travelling at low speeds. Although the current regulations include a stationary vehicle test, there is no requirement to comply with any maximum limiting values. The UK Department for Transport (DfT) is looking towards the development of a low-cost test procedure for use with stationary vehicles which will be capable of distinguishing between quiet/new technology vehicles (gas- or hybrid-powered) and noisy (conventionally fuelled) vehicles. It is also required that any new test also be representative of vehicles undertaking slow-speed manoeuvres such as those undertaken when carrying out goods deliveries. As mentioned above TRL is currently carrying out research to determine appropriate test methods including test procedures on stationary vehicles. It is expected that the results of this work will be used to help inform WP29 and the revision of Reg 51.

5.2 Developments in propulsion noise

Clearly changes to the type approval test procedure and changes to the limit values for different vehicle categories will take some time to be implemented. However, eventually the new limit values imposed will be set at levels designed to encourage the innovation and development of quieter vehicles. It is useful therefore to examine the prospects for further noise level reductions of the power train.

A review of propulsion noise sources has recently been carried out by RWTUV as part of a research project, “Ermittlung des weiteren Lämminderungspotentials bei Kraftfahrzeugen” commissioned by the German Environmental Agency (UBA). Consultation with the vehicle manufacturers in Germany and Japan revealed that information on propulsion noise sources was limited to type approval drive-by conditions.

It was found that for state-of-the-art cars the drive train contribution is currently of minor importance (typically greater than 10 dB below the total sound power). The main contributions come from the engine, the intake, exhaust and the tyres. The contribution of intake and exhaust noise varies between

6-10 dB below the total sound power (depending upon the vehicle concept and the engine speed). For sports cars the contribution might be higher (4-5 dB below the total sound power). The precise rank order depends upon the vehicle type, transmission characteristics and the gear selected. For heavy duty vehicles the engine is the dominant source under the current type approval conditions, where the manufacturer can choose the tyres used for the test. The contributions of other sources are typically up to 8 dB(A) below the engine noise. Heavy duty vehicles with high rated power values (above 320 kW) are already equipped with some form of engine encapsulation that can result in a 3dB(A) reduction in engine noise. Encapsulation is needed in order to reach the current 80 dB(A) limit.

A review of vehicle manufacturers in different countries has also included an assessment of future noise levels for the main sources of propulsion noise. The findings can be summarised as follows:

- *Engine* – The variance of today’s production engines for cars is 7dB(A) over the whole speed range. The upper half consists of engines that are still on the market but no longer state-of-the-art engines. That means that there is a reduction potential of 3dB(A) for vehicles that are equipped with these engines.
- *Gas flow noise* – A further reduction of intake and exhaust noise can in general be achieved using greater silencer volumes and double-walled silencers. The problem is to reserve the necessary storage capacity for the silencers and to accommodate the increase in weight.
- *Mechanical noise* – For cars, the contribution of gearbox and drive train to the overall noise emission is insignificant. For heavy-duty vehicles the situation is different, especially since the requirements for robustness and durability are much higher than for cars. Possible reduction measures are advanced encapsulations and the de-coupling of the engine and gearbox.
- *Whole vehicle noise reduction* - Daf Trucks have a ‘silent’ concept truck. In the low noise operation mode the truck could meet a noise target as low as 65 dB(A) compared with the 78dB(A) required by current legislation for this type of vehicle. This low threshold value is achieved by a special engine management programme that limits the engine speed values significantly when operating in noise sensitive areas. The new truck is based on a DAF CF75 tractor and is designed for night-time urban delivery work. The significance of the design is that it clearly demonstrates that diesel trucks can meet the very lowest noise levels and can then be used for operations in noise sensitive areas and at night.

  There is some interest in the use of alternative fuelled vehicles, (e.g. LPG, CNG etc.) and the use of electric powered vehicles and hybrids. These technologies are not particularly new but they are still at an early developmental stage when compared with the huge investments already made to develop modern diesel and petrol powered vehicles. The uptake of new technologies into the vehicle fleet is small at present due mainly to the lack of re-fuelling infrastructure, cost and reliability issues. However, new technology vehicles are likely to have significantly quieter power plants than their predecessors, particularly where an alternative to the internal combustion engine is used. Electric vehicles, for example, are known to have very quiet power plants due to the fact that there is no combustion process involved and the mechanical noise is much reduced due to the smaller number of moving parts.

It should be noted that the generation of tyre/road noise is, however, independent on the type of power plant used and it is reasonable to assume it will limit the noise reductions that are achievable due to the use of these new technologies.

5.3 Legislation and policy drivers for vehicle noise

Clearly, vehicle noise type approval is potentially the most important item of legislation controlling current and future levels of noise emission from vehicles. The improvements that are being examined for amending the test procedure should help to make this an even more effective tool for the future. During the last decades, the noise limits for motor vehicles were reduced by 8-11 dB(A). Several studies in Europe show, however, that the measures applied by the manufacturers to achieve this reduction affected the emissions in real world operation to a much smaller degree. Amongst the reasons for this, the most important are that

- the reduction in noise limit was partly compensated for by changes in the measurement method,
- the type test operating conditions were too oriented towards worst case scenarios,
- the tyre/road noise is not included in a representative way.

An amendment of the tyre approval measurement method, aiming at more efficiency for real world emissions, is currently under discussion.

Furthermore, it should be noted that type approval does not cover all vehicle noise sources and only covers new vehicle types and not in-service vehicles. Noise from a vehicle throughout its operational life may not necessarily be linked to the original type approval test limit. The state of repair of a vehicle and the standard of replacement components (e.g. exhaust systems) are important factors. Consequently there is considerable scope for further noise control legislation/policy to include currently unregulated sources and to include noise from in-service vehicles.

Unregulated sources:

- In the UK it was recognised that a common cause of complaint of noise from road vehicles was that attributed to body noise or body rattle. As a result TRL, in association with the commercial vehicle industry, has produced a “Guide to good practice on the control of vehicle body noise”. This guide, issued in 2000, is helping both vehicle manufacturers and operators minimise the occurrence of both vehicle body and suspension noise (Department of the Environment, Transport and the Regions, 2000b). TRL has also developed a possible test method for vehicle body and suspension noise.
- TRL is currently examining the possibility of introducing a test procedure for vehicle ancillary noise such as hydraulic lifting equipment and refrigeration units. Although these sources of noise are rarely of significance for a moving vehicle, they can be important during the delivery of goods, particularly if this occurs in a noise sensitive area at night.

In service testing:

- The need for in-service testing has been supported previously by the European Commission who have proposed that in-service testing for noise is introduced more widely throughout the EU. The recent EC Green paper strongly recommends a regime of enforcement along similar lines to that adopted in parts of Australia and in some parts of Europe.
- TRL has conducted a comprehensive study of in-service test methods for the Department. This study showed that there are difficulties in developing a stationary, in-service noise test for vehicles that could be easily carried out, was repeatable, suitable for all vehicles and was representative of the actual noise produced by vehicles in use. Particular difficulties were encountered with petrol-powered cars and vehicles with ungoverned engines. The greatest scope was found to exist for the in-service testing of motorcycles for which the test method could be relatively simple. Current research is re-examining possible test procedures for future application in certifying 'quiet' commercial vehicles for operations in noise sensitive areas.

Traffic management:

A wide range of traffic management and calming methods are currently being used in cities and towns across Europe primarily to ease congestion and to reduce accident risk. However, increasingly these methods are also being employed to reduce noise impact. Schemes can be very site specific, such as, the use of speed control humps and cushions, or can be area wide. They can be associated with fiscal measures such as charging.

- The London Night and Weekend Lorry Control Scheme, often referred to as the "London Lorry Ban" is an example of an area wide traffic control scheme. It was introduced in 1986 to remove through-London freight and minimise the use of unsuitable roads. The Association of London Government on behalf of the London Boroughs presently administers the scheme. A review of the scheme has been proposed within the Mayor of London's Transport Strategy. It recommends an examination of the operation and administration aspects, taking into account the possibility of both congestion charging and the introduction of low emission zones, and a review of the environmental criteria used given the improvements in environmental performance that have taken place since the introduction of the scheme. It is acknowledged that if the ban were lifted the potential air quality, energy and congestion benefits are only achievable provided that there are no unacceptable night-time noise impacts. Consideration will be given to the possibilities of new forms of enforcement, e.g. in-service night noise testing.
- Recently, a system of charging for entry into the centre of London has been introduced. Initial results indicate that congestion has been greatly reduced although there is little available at present to determine the noise changes. Work is currently underway at TRL to investigate some aspects of the noise changes that have occurred from congestion charging policy.
- The UK Government is supporting a series of pilot projects to test a series of noise-reduction measures which have been agreed with the haulage and retail industries. A six month pilot scheme is shortly to begin in Leeds which will involve lifting night-time curfews on heavy vehicles at six supermarkets. The lorries involved are to be fitted with devices for cutting out the engine when the vehicle is parked, as well as having silencers fitted to the brakes. Reversing alarms on the vehicles will be switched off and cab radios will be automatically switched off when the cab doors are opened. Noise barriers and canopies are to be installed in the loading bays at the participating supermarkets.

5.3.1 Current European projects which may impact upon propulsion noise

The following is a summary of on-going European projects that may have an impact on propulsion noise.

- **VISPER** *(Vehicle integral simulation for pass-by noise reduction – an innovative step towards low noise traffic emissions)*

  The reduction of pass-by noise from road vehicles is dependant upon experimental work which is considered in the later stages of the vehicle development process, since no reliable prediction tool is currently available. The objective of the project is the development of hybrid engineering tools (both for simulation and testing), i.e. a methodology and prediction system, to assess the possibilities for future low noise vehicles. To demonstrate the validity of the developed prediction methodology, a 3 dB(A) target for noise reduction has been defined for two demonstrator vehicles modifying the power train and exhaust/ intake systems.

6 Modifications to improve and extend the RWTÜV model

The modifications to the RWTÜV model required for this project fall into three general categories:

- Basic modifications which improve the ease of application of the model across a wide user base, e.g. the use of a common language or technical expressions within the program dialog, and which are not specifically applicable to any given source emission type;
- Improvements that widen the range of tyre/road surface scenarios that can be modelled. This has been informed, where appropriate, by the review presented in Section 4;
- Improvements that widen the range of vehicle categories or propulsion types that can be considered. This has been informed, where appropriate, by the review presented in Section 5, and by discussions with the membership of the European Working Group on Road Traffic Noise.

This section gives details of these modifications, together with information relating to their impact upon the performance of the model.

6.1 Basic modifications

The following basic modifications have been made to the program:

- The dialog tools and control elements within the program have been modified so that the program dialog, i.e. all command windows and text prompts, are in English.
- The program was refined to enable the use of different databases for different regions. This was achieved by creating additional tables and program forms to allow the user to choose the appropriate basic data. All tables with basic data such as vehicle layer characteristics and weighting factors have therefore been duplicated and made accessible to the user. Dummy data was used in some cases to establish the correct formatting of the tables. Check routines have been written and installed to ensure the consistency of the databases.

  In principle, the number of regions that can be defined by the user is now unrestricted. It was proposed that as soon as appropriate data was available, any dummy tables would be replaced with real data.
- In order to facilitate the evaluation of the relative benefits of different noise control options, the vehicle layer branch was extended to calculate the in-use noise emission from vehicles for different scenarios. This means that for each vehicle layer, different emission data for propulsion noise as well as for tyre/road noise can be defined and the influence on the overall levels of in-use emission can then be calculated.
- With regard to propulsion noise, both the low engine load function and the full engine load function can now be modelled as polynomial functions of up to the 6^{th} degree. In order to allow the effects of acoustic design on the propulsion noise functions to be modelled, the engine speed range can be separated into 4 smaller ranges and individual functions used for each of these. The user must ensure that the values at the ends of adjacent ranges coincide. The low load function has been derived from stationary measurements at 7.5 m (1.2 m height) on both sides of the vehicle by operating the engine from idling speed to rated speed and back to idling again. The full load curve has been derived by pass-by measurements at full load.
- Further to discussions within the vehicle noise emission working group (WG8) and conclusions reached from bilateral discussions, the following vehicle classes were added to the model:

  (i) Since high performance cars (rated power > 140 kW and power-to-mass ratio > 70 kW/t) are subject to a different test method, a higher limit value and often *acoustic* design measures, special classes for these vehicles were added.

(ii) For all heavy duty vehicle classes except buses, subclasses with and without traction tyres[2] were included.

(iii) Motorcycle classes have been integrated into the model. Based on an extended analysis of RWTÜV's own measurement results, it was concluded that two engine capacity classes would be sufficient to provide accurate modelling forecasts (i.e. $\leq$150 cc's and >150 cc's). The first class covers mainly scooters. For each capacity class, an additional class was included for vehicles fitted with low cost replacement (illegal) silencers.

- The inclusion of motorcycles within the model made it necessary to restructure the road type/traffic situation classifications used in the original UBA model, because the driving behaviour data for motorcycles could only be separated into urban, rural and motorway operations. On the basis of the analysis of driving behaviour data for cars, heavy duty vehicles and motorcycles, a classification of road categories has been included as already shown in Table 3.3.

Since the databases for cars, heavy duty vehicles and motorcycles could not be directly combined to establish characteristic emission values for each vehicle category and a common set of road type/traffic situation classes, the following approach was chosen to solve that problem.

The different road type/traffic situation classes shown in Table 3.3 were derived from the car driving behaviour database and *form* the basis of the modelling. The vehicle speed distributions for the cars were then modified to be representative for the other vehicle categories. The modifications were made in such a way that the differences in standstill and average speed are in line with real world driving.

The vehicle speed-frequency distribution for each of the road type/traffic speed classes were calculated in steps of 5 km/h from standstill to maximum speed, and expressed as percentages, so that these percentages could be used as a weighting factor for the calculation of average values. In a second step the noise behaviour of each vehicle layer, in terms of average L_{max}, was calculated for all second-by-second datasets in the in-use driving behaviour data, as well as the L_{Aeq} for each speed class.

The average noise values for each road type/traffic situation was then calculated by multiplying the average noise intensity values for each vehicle speed class by the frequency of this class for the road type/traffic situation class under consideration. The results were then combined logarithmically to give an average L_{Amax} at a distance of 7.5 m from the road and a height of 1.2 m, together with an L_{Aeq} value representing the hourly contribution of a single vehicle in the selected vehicle layer at a distance of 25 m and a height of 4 m. The receiver position selected for the L_{Aeq} calculations is at the distance used in the German national noise impact calculation scheme.

6.2 Noise emission factors for tyre and road surface noise

The influence of tyre/road noise L_{roll} is taken into account in the model using equation 3.5 which, for convenience, is reproduced below:

$$L_{roll} = L_{r50}\left(AC\,0/11\right) + B \times \log\left(v/50\ \text{km/h}\right) + DL_{surface} \qquad (6.1)$$

L_{r50} (AC 0/11) is the rolling noise at 50 km/h on asphalt concrete 0/11, B is the surface specific slope of the regression curve, v is the vehicle speed and $DL_{surface}$ is the surface specific coefficient.

It is important to note at this point that, while equation 6.1 provides a means of accounting for the large ranges of tyres and road surfaces in current use, the equation implies that the rank ordering of tyre noise on different surfaces is identical at a given speed. In practice, this is not necessarily the case as the various mechanisms governing the generation and propagation of tyre noise may be different for different tyre/surface combinations and that this also may be dependent on speed (Phillips et al, 2001). As has been shown earlier in this report, on some surfaces the main noise generation mechanisms relate to the impacts of tread blocks with the road surface macrotexture whilst

[2] Traction tyres are block-tread pattern tyres used on drive axles to ensure traction during acceleration.

on other surfaces air pumping noise and acoustic absorption mechanisms can be important. A further point is that the current type-approval test for vehicle tyres requires measurements to be taken on the ISO 10844 surface, which is a smooth asphalt surface, which was specifically designed to reduce as much as possible the contribution of tyre noise to the overall levels of vehicle noise. The tyre industry has therefore worked to optimise its tyres based on tread pattern designs appropriate for this surface which, therefore, may not be fully realised on other surface types.

Despite this apparent limitation in the formulation of the model, it is considered that given the current tyre/road surface noise data, the method of approach does provide the user with a reasonably accurate means of forecasting noise levels for different traffic mixes and road surface conditions. Theoretically some errors could occur where the traffic stream is comprised of an unusual mix of vehicles fitted with tyres whose noise characteristics depart markedly from the average. Clearly future refinements of the model could address the issue of accounting for specific tyre/surface noise generation issues.

6.2.1 $DL_{surface}$ values

The values of $DL_{surface}$ values for the surfaces included within the model are shown in Table 6.1. Separate coefficients are provided for heavy-duty vehicles (HDV) and light duty vehicles (LDV) and cars (M1).

It is anticipated that further surfaces may be included in the future. For example, additional data may be available on completion of the Europe-wide database that is being collated as part of the SilVia project (see section 4.5.3). This would potentially allow chipping size data to be taken into account on a wider range of surfaces.

Table 6.1: Road surface types and corresponding $DL_{surface}$ values

Road surface type	Identifier	$DL_{surface}$ in dB(A)	
		LDV and M1	**HDV**
Asphalt concrete 0/11	AC 0/11	0.0	0.0
Stone mastic asphalt 0/11	SMA 0/11	0.0	-0.3
Hot rolled asphalt	HRA	2.0	1.0
Surface Dressing 0/11	SD	1.5	0.5
Gussasphalt	GA	1.9	-0.3
Grip-surface	GR	1.3	0.4
Asphalt concrete 0/16	AC 0/16	2.0	0.0
Drainage asphalt 0/11, less than 3 years old	DA 0/11 k3	-3.1	-3.7
Drainage asphalt 0/11, 3-5 years old	DA 0/11 3-5	-2.0	-2.0
Drainage asphalt 0/11, more than 5 years old	DA 0/11 g5	0.0	0.0
Drainage asphalt 0/8, less than 3 years old	DA 0/8 k3	-5.8	-3.7
Drainage asphalt 0/8, 3-5 years old	DA 0/8 3-5	-3.8	-2.0
Drainage asphalt 0/8, more than 5 years old	DA 0/8 g5	-0.4	0.0
Drainage asphalt 0/16, less than 3 years old	DA 0/16 k3	-2.0	-3.0
Drainage asphalt 0/16, 3-5 years old	DA 0/16 3-5	-1.0	-1.5

Table 6.1: Road surface types and corresponding $DL_{surface}$ values (continued…)

Road surface type	Identifier	$DL_{surface}$ in dB(A)	
		LDV and M1	HDV
Drainage asphalt 0/16, more than 5 years old	DA 0/16 g5	0.0	0.0
Drainage asphalt twin layer, less than 3 years old	DA twin k3	-6.0	-4.5
Drainage asphalt twin layer, 3-5 years old	DA twin 3-5	-4.0	-3.0
Drainage asphalt twin layer, more than 5 years old	DA twin g5	-2.0	-1.5
Exposed aggregate	EA	1.3	0.4
Burlap treated cement concrete	CC burlap	1.0	1.2
Cement concrete, longitudinally brushed	CCB lo	1.3	1.7
Cement concrete, transversely brushed	CCB tr	3.7	2.1
Even pavement stones	PS even	3.0	2.0
Uneven pavement stones	PS uneven	6.0	4.0

6.2.2 Slope coefficients, B

It is known that the relationship between vehicle speed and noise is dependent on the type of road surface. Generally noisier tyre/surfaces are associated with higher values of the speed/noise slope coefficient. This fact is reflected in equation 3.5 above by the inclusion of the slope coefficient, B. However, unfortunately at present there is not enough reliable information available to add individual figures for the slope coefficient for each surface. Therefore currently the slope values included in the model are those associated to the tyre characteristics for each identified vehicle type and are assumed to be the same for all surface types. However, the model does contain dummy values for individual surfaces so that as this information becomes available it can be easily added to the model. The values of the slope coefficient, B, currently used in the model are included in table 6.2.

6.2.3 Tyre specific coefficients, L_{r50} (AC 0/11)

The tyre specific rolling noise characteristics used in the revised model are also shown in Table 6.2. As mentioned earlier these characteristics represent the rolling noise level at a speed of 50 km/h for vehicles running on asphalt concrete, L_{r50} (AC 0/11).

The values given in the table are relevant for current generation tyres. In case of heavy duty vehicles the influence of traction tyres is assumed to result in an increase in L_{r50} *(AC 0/11)* by 1.7 dB(A) for rigid trucks and 0.8 dB(A) for trailer trucks.

For older vehicles, higher values at 50 km/h are assumed for heavy duty vehicles and a slightly lower values are assumed for cars.

It is acknowledged that retreaded tyres are not subject to the same limit values as new tyres set out by the EU tyre noise type approval directive. The use of such tyres is not uncommon, for example, in Sweden retreated tyres constitute around 25 % of the car tyre market and 50 % of the truck tyre market (Sandberg, 2001). However, studies by RWTÜV have demonstrated that the tyre/road noise emission levels from such retreaded tyres are not significantly different from those for standard tyres, and as such, they have not been included within the model.

Table 6.2: Tyre specific rolling noise characteristics

Vehicle layer	Emission stage	L_{r50} (AC 0/11) dB(A)	*B*
Car, petrol, < 1.4 l	From 1996 onwards	69.4	33
Car, petrol, 1.4 – 2 l	From 1996 onwards	70.0	33
Car, petrol, > 2 l	From 1996 onwards	70.5	33
Car, petrol, > 2 l, high perf.	From 1996 onwards	71.0	33
Car, diesel, < 2 l	From 1996 onwards	70.0	33
Car, diesel, > 2 l	From 1996 onwards	70.5	33
Car, diesel, > 2 l, high perf.	From 1996 onwards	71.0	33
Light duty vehicle, petrol	From 1996 onwards	69.0	34
Light duty vehicle, diesel	From 1996 onwards	69.0	34
Rigid truck, < 7.5 t	From 1996 onwards	72.0	34
Rigid truck, < 7.5 t, traction	From 1996 onwards	73.7	35
Rigid truck, 7.5 – 14 t	From 1996 onwards	72.5	34
Rigid truck, 7.5 – 14 t, traction	From 1996 onwards	74.2	35
Rigid truck, 14 – 20 t	From 1996 onwards	73.5	34
Rigid truck, 14 – 20 t, traction	From 1996 onwards	75.2	35
Rigid truck, 20 – 28 t	From 1996 onwards	74.5	34
Rigid truck, 20 – 28 t, traction	From 1996 onwards	76.2	35
Trailer truck, ≤ 32 t	From 1996 onwards	76.5	34
Trailer truck, ≤ 32 t, traction	From 1996 onwards	77.3	35
Trailer truck, > 32 t	From 1996 onwards	77.0	34
Trailer truck, > 32 t, traction	From 1996 onwards	77.8	35
Public transport bus, ≤ 20 t	From 1996 onwards	72.5	34
Public transport bus, > 20 t	From 1996 onwards	74.5	34

As part of this study, representatives from the tyre industry were consulted with the objective of estimating future noise levels tyres. Unfortunately very little usable information was obtained from this line of research. Understandably any projections of future levels would be very tentative and dependent on other factors that are outside the control of the industry. In addition the tyre industry operates in a very competitive market and there is a natural reluctance to disclose this type of information.

However, despite the lack of evidence form the industry, three additional future tyre noise layers have been added in the model which are referred to as *roll, stage 1, 2 and 3*. These assume a reduction of tyre road noise of 1.5 dB(A), 3 dB(A) and 4.5 dB(A) for all vehicle layers compared to the today's tyres and were chosen based on the evidence of research and expert judgement of the authors.

6.3 Noise emission factors for propulsion noise

The calculation scheme was modified to allow the modelling of resonances in the propulsion noise curves. These modifications allow the comparison of the influence of noise reduction measures on type approval measurement results and in-use emissions under various driving conditions, and therefore the assessment of the effectiveness of such measures.

The modelling of propulsion noise was changed from linear functions of engine speed to polynomial approximation of up to 6^{th} degree. This necessity was indicated by measurement results from an on-going RWTÜV project.

The program has also been extended to allow calculations for motorcycles. In-use driving behaviour data for motorcycles has been added to the database, covering all road categories (urban, rural and motorway) for different vehicle types (engine capacity and rated power). Since the test runs were carried out with a series of different drivers, the influence of driving style on the in-use emission can also be assessed. Based on an extended analysis of RWTÜV's own measurement results, it was concluded that two engine capacity classes would be sufficient, up to 150 cm^3 and above 150 cm^3. The first class covers mainly scooters. For each capacity class, an additional class was foreseen for vehicles fitted with illegal silencers.

The propulsion noise is modelled by linear functions of normalised engine speed in all cases at the present time. The values were derived on the basis of a combination of measurement results and expert views. The coefficients are shown in Table 6.3 to Table 6.9.

It should be noted that, with the exception of motorcycles, the vehicle layers defined in the model cover the time period from the introduction of vehicle noise type-approval limits in the EU. The reductions assumed over this period are higher for heavy-duty vehicles than for cars and light duty vehicles. This has been demonstrated by field measurement results taken by RWTÜV in different years since 1978 and is also mentioned in an I-INCE report by Sandberg. Motorcycle layers start with today's vehicles, but these values are also applicable for older vehicles in these categories.

Two future stages have been added to represent, future generation, propulsion noise values and are referred to as *prop stage 1 and 2*. These assume the following:

- *Prop, stage 1* - For cars and light duty vehicles, a 1 dB reduction for low load and 2 dB reduction for full load are assumed. For heavy duty vehicles, a 1.5-2 dB reduction for idling speed and a 2.5 dB reduction for rated speed are assumed.
- *Prop, stage 2* - For cars and light duty vehicles, a 2 dB reduction for low load and 4 dB reduction for full load are assumed. For heavy duty vehicles, a 3 dB reduction for idling speed and a 5 dB reduction for rated speed are assumed.

Table 6.3: Propulsion noise coefficients for heavy-duty vehicles (up to 1981)

Vehicle layer	Registration year	Low load		Full load	
		k_1	k_0	w_1	w_0
Rigid truck, < 7.5 t	Up to 1981	19.3	68.0	7.0	84.0
Rigid truck, < 7.5 t, traction	Up to 1981	19.3	68.0	7.0	84.0
Rigid truck, 7.5 – 14 t	Up to 1981	19.3	71.0	7.0	86.0
Rigid truck, 7.5 – 14 t, traction	Up to 1981	19.3	71.0	7.0	86.0
Rigid truck, 14 – 20 t	Up to 1981	19.9	71.0	6.65	87.0
Rigid truck, 14 – 20 t, traction	Up to 1981	19.9	71.0	6.65	87.0
Rigid truck, 20 – 28 t	Up to 1981	19.9	71.0	6.65	87.0
Rigid truck, 20 – 28 t, traction	Up to 1981	19.9	71.0	6.65	87.0
Trailer truck, ≤ 32 t	Up to 1981	19.9	73.0	6.65	89.0
Trailer truck, ≤ 32 t, traction	Up to 1981	19.9	73.0	6.65	89.0
Trailer truck, > 32 t	Up to 1981	19.9	73.0	6.65	89.0
Trailer truck, > 32 t, traction	Up to 1981	19.9	73.0	6.65	89.0
Public transport bus, ≤ 20 t	Up to 1981	19.9	69.8	6.65	85.3
Public transport bus, > 20 t	Up to 1981	19.9	69.8	6.65	85.3

Table 6.4: Propulsion noise coefficients for cars/light duty vehicles (up to 1981), heavy duty vehicles (1982-1984)

Vehicle layer	Registration year	Low load		Full load	
		k_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	Up to 1981	30.0	51.0	20.0	62.0
Car, petrol, 1.4 – 2 l	Up to 1981	31.0	52.0	20.0	64.0
Car, petrol, > 2 l	Up to 1981	32.0	52.0	20.0	65.0
Car, petrol, > 2 l, high perf.	Up to 1981	32.0	54.0	28.0	64.0
Car, diesel, < 2 l	Up to 1981	31.0	53.0	21.0	64.0
Car, diesel, > 2 l	Up to 1981	31.0	53.0	21.0	64.0
Car, diesel, > 2 l, high perf.	Up to 1981	32.0	54.0	28.0	64.0
Light duty vehicle, petrol	Up to 1981	18.3	59.0	4.6	73.5
Light duty vehicle, diesel	Up to 1981	18.3	62.0	7.3	73.0
Rigid truck, < 7.5 t	1982 to 1984	18.3	68.0	6.0	83.0
Rigid truck, < 7.5 t, traction	1982 to 1984	18.3	68.0	6.0	83.0
Rigid truck, 7.5 – 14 t	1982 to 1984	18.3	71.0	6.0	85.0
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	18.3	71.0	6.0	85.0
Rigid truck, 14 – 20 t	1982 to 1984	18.9	71.0	5.7	86.0
Rigid truck, 14 – 20 t, traction	1982 to 1984	18.9	71.0	5.7	86.0
Rigid truck, 20 – 28 t	1982 to 1984	18.9	71.0	5.7	86.0
Rigid truck, 20 – 28 t, traction	1982 to 1984	18.9	71.0	5.7	86.0
Trailer truck, ≤ 32 t	1982 to 1984	18.9	73.0	5.7	88.0
Trailer truck, ≤32 t, traction	1982 to 1984	18.9	73.0	5.7	88.0
Trailer truck, > 32 t	1982 to 1984	18.9	73.0	5.7	88.0
Trailer truck, > 32 t, traction	1982 to 1984	18.9	73.0	5.7	88.0
Public transport bus, ≤ 20 t	1982 to 1984	18.9	69.8	5.7	84.3
Public transport bus, > 20 t	1982 to 1984	18.9	69.8	5.7	84.3

Table 6.5: Propulsion noise coefficients for cars/light duty vehicles (1982-1988), heavy duty vehicles (1985-1989)

Vehicle layer	Registration year	Low load		Full load	
		k_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	1982 to 1988	29.8	50.5	21.0	60.0
Car, petrol, 1.4 – 2 l	1982 to 1988	31.0	51.5	21.0	62.0
Car, petrol, > 2 l	1982 to 1988	31.8	51.5	21.0	63.0
Car, petrol, > 2 l, high perf.	1982 to 1988	32.0	53.5	30.0	62.0
Car, diesel, < 2 l	1982 to 1988	31.0	52.5	22.0	62.0
Car, diesel, > 2 l	1982 to 1988	31.0	52.5	22.0	62.0
Car, diesel, > 2 l, high perf.	1982 to 1988	32.0	53.5	30.0	62.0
Light duty vehicle, petrol	1982 to 1988	18.1	58.7	7.1	70.5
Light duty vehicle, diesel	1982 to 1988	18.1	61.7	8.8	71.0
Rigid truck, < 7.5 t	1985 to 1989	16.3	67.0	60.0	80.0
Rigid truck, < 7.5 t, traction	1985 to 1989	16.3	67.0	6.0	80.0
Rigid truck, 7.5 – 14 t	1985 to 1989	16.3	70.0	6.0	82.0
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	16.3	70.0	6.0	82.0
Rigid truck, 14 – 20 t	1985 to 1989	16.9	70.0	5.7	83.0
Rigid truck, 14 – 20 t, traction	1985 to 1989	16.9	70.0	5.7	83.0
Rigid truck, 20 – 28 t	1985 to 1989	16.9	70.0	5.7	83.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	16.9	70.0	5.7	83.0
Trailer truck, ≤ 32 t	1985 to 1989	16.9	72.0	5.7	85.0
Trailer truck, ≤ 32 t, traction	1985 to 1989	16.9	72.0	5.7	85.0
Trailer truck, > 32 t	1985 to 1989	16.9	72.0	5.7	85.0
Trailer truck, > 32 t, traction	1985 to 1989	16.9	72.0	5.7	85.0
Public transport bus, ≤ 20 t	1985 to 1989	16.9	68.8	5.7	81.3
Public transport bus, > 20 t	1985 to 1989	16.9	68.8	5.7	81.3

Table 6.6: Propulsion noise coefficients for cars/light duty vehicles (1989-1995), heavy duty vehicles (1990-1995)

Vehicle layer	Registration year	Low load		Full load	
		k_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	1989 to 1995	29.7	50.0	22.4	58.0
Car, petrol, 1.4 – 2 l	1989 to 1995	30.5	51.0	22.4	60.0
Car, petrol, > 2 l	1989 to 1995	31.7	51.0	22.4	61.0
Car, petrol, > 2 l, high perf.	1989 to 1995	31.5	53.0	32.5	60.0
Car, diesel, < 2 l	1989 to 1995	30.5	52.0	23.4	60.0
Car, diesel, > 2 l	1989 to 1995	30.5	52.0	23.4	60.0
Car, diesel, > 2 l, high perf.	1989 to 1995	31.5	53.0	32.5	60.0
Light duty vehicle, petrol	1989 to 1995	18.0	58.3	9.1	67.5
Light duty vehicle, diesel	1989 to 1995	17.7	61.0	9.8	69.0
Rigid truck, < 7.5 t	1990 to 1995	14.3	66.0	6.0	77.0
Rigid truck, < 7.5 t, traction	1990 to 1995	14.3	66.0	6.0	77.0
Rigid truck, 7.5 – 14 t	1990 to 1995	14.3	69.0	6.0	79.0
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	14.3	69.0	6.0	79.0
Rigid truck, 14 – 20 t	1990 to 1995	14.9	69.0	5.7	80.0
Rigid truck, 14 – 20 t, traction	1990 to 1995	14.9	69.0	5.7	80.0
Rigid truck, 20 – 28 t	1990 to 1995	14.9	69.0	5.7	80.0
Rigid truck, 20 – 28 t, traction	1990 to 1995	14.9	69.0	5.7	80.0
Trailer truck, ≤ 32 t	1990 to 1995	14.9	71.0	5.7	82.0
Trailer truck, ≤ 32 t, traction	1990 to 1995	14.9	71.0	5.7	82.0
Trailer truck, > 32 t	1990 to 1995	14.9	71.0	5.7	82.0
Trailer truck, > 32 t, traction	1990 to 1995	14.9	71.0	5.7	82.0
Public transport bus, ≤ 20 t	1990 to 1995	14.9	67.8	5.7	78.3
Public transport bus, > 20 t	1990 to 1995	14.9	67.8	5.7	78.3

Table 6.7: Propulsion noise coefficients for cars/light duty vehicles (1996-present), heavy duty vehicles (1996-present) and motorcycles (present)

Vehicle layer	Registration year	Low load		Full load	
		K_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	From 1996	29.0	49.0	22.6	56.0
Car, petrol, 1.4 – 2 l	From 1996	30.0	50.0	22.6	58.0
Car, petrol, > 2 l	From 1996	31.0	50.0	22.6	59.0
Car, petrol, > 2 l, high perf.	From 1996	31.0	52.0	35.0	58.0
Car, diesel, < 2 l	From 1996	30.0	51.0	23.5	58.0
Car, diesel, > 2 l	From 1996	30.0	51.0	23.5	58.0
Car, diesel, > 2 l, high perf.	From 1996	31.0	52.0	35.0	58.0
Light duty vehicle, petrol	From 1996	17.3	58.0	11.1	64.5
Light duty vehicle, diesel	From 1996	17.3	60.0	10.8	67.0
Rigid truck, < 7.5 t	From 1996	12.3	65.0	4.0	75.0
Rigid truck, < 7.5 t, traction	From 1996	12.3	65.0	4.0	75.0
Rigid truck, 7.5 – 14 t	From 1996	12.3	68.0	4.0	77.0
Rigid truck, 7.5 – 14 t, traction	From 1996	12.3	68.0	4.0	77.0
Rigid truck, 14 – 20 t	From 1996	12.9	68.0	3.7	78.0
Rigid truck, 14 – 20 t, traction	From 1996	12.9	68.0	3.7	78.0
Rigid truck, 20 – 28 t	From 1996	12.9	68.0	3.7	78.0
Rigid truck, 20 – 28 t, traction	From 1996	12.9	68.0	3.7	78.0
Trailer truck, ≤ 32 t	From 1996	12.9	70.0	3.7	80.0
Trailer truck, ≤ 32 t, traction	From 1996	12.9	70.0	3.7	80.0
Trailer truck, > 32 t	From 1996	12.9	70.0	3.7	80.0
Trailer truck, > 32 t, traction	From 1996	12.9	70.0	3.7	80.0
Public transport bus, ≤ 20 t	From 1996	12.9	66.8	3.7	76.3
Public transport bus, > 20 t	From 1996	12.9	66.8	3.7	76.3
Motorcycle, ≤ 150cm^3	Stage 0	26.8	53.8	22.7	58.7
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	23.8	61.0	18.7	68.0
Motorcycle, > 150 cm^3	Stage 0	30.6	63.7	23.1	74.0
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	26.6	69.7	18.1	84.0

Table 6.8: Propulsion noise coefficients for cars/light duty vehicles, heavy duty vehicles and motorcycles (all future layer level 1)

Vehicle layer	Registration year	Low load		Full load	
		K_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	Prop, Stage 1	28.5	48.0	23.0	54.0
Car, petrol, 1.4 – 2 l	Prop, Stage 1	30.0	49.0	23.5	56.0
Car, petrol, > 2 l	Prop, Stage 1	30.5	49.0	23.0	57.0
Car, petrol, > 2 l, high perf.	Prop, Stage 1	31.0	51.0	35.0	56.0
Car, diesel, < 2 l	Prop, Stage 1	30.0	50.0	24.5	56.0
Car, diesel, > 2 l	Prop, Stage 1	30.0	50.0	24.5	56.0
Car, diesel, > 2 l, high perf.	Prop, Stage 1	31.0	51.0	35.0	56.0
Light duty vehicle, petrol	Prop, Stage 1	16.8	57.0	12.6	61.5
Light duty vehicle, diesel	Prop, Stage 1	16.8	59.0	10.8	65.5
Rigid truck, < 7.5 t	Prop, Stage 1	11.8	63.0	3.0	73.5
Rigid truck, < 7.5 t, traction	Prop, Stage 1	11.8	63.0	3.0	73.5
Rigid truck, 7.5 – 14 t	Prop, Stage 1	11.8	66.0	3.0	75.5
Rigid truck, 7.5 – 14 t, traction	Prop, Stage 1	11.8	66.0	3.0	75.5
Rigid truck, 14 – 20 t	Prop, Stage 1	12.4	66.0	2.7	76.5
Rigid truck, 14 – 20 t, traction	Prop, Stage 1	12.4	66.0	2.7	76.5
Rigid truck, 20 – 28 t	Prop, Stage 1	12.4	66.0	2.7	76.5
Rigid truck, 20 – 28 t, traction	Prop, Stage 1	12.4	66.0	2.7	76.5
Trailer truck, ≤ 32 t	Prop, Stage 1	12.4	68.0	2.7	78.5
Trailer truck, ≤ 32 t, traction	Prop, Stage 1	12.4	68.0	2.7	78.5
Trailer truck, > 32 t	Prop, Stage 1	12.4	68.0	2.7	78.5
Trailer truck, > 32 t, traction	Prop, Stage 1	12.4	68.0	2.7	78.5
Public transport bus, ≤ 20 t	Prop, Stage 1	12.4	64.8	2.7	74.8
Public transport bus, > 20 t	Prop, Stage 1	12.4	64.8	2.7	74.8
Motorcycle, ≤ 150cm^3	Stage 1	26.6	52.3	24.7	54.7
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 1	23.6	59.5	20.7	64.0
Motorcycle, > 150 cm^3	Stage 1	30.1	62.2	25.1	70.0
Motorcycle, > 150 cm^3, illegal silencers	Stage 1	26.1	68.2	20.1	80.0

Table 6.9: Propulsion noise coefficients for cars/light duty vehicles, heavy duty vehicles and motorcycles (all future layer level 2)

Vehicle layer	Registration year	Low load		Full load	
		K_1	k_0	w_1	w_0
Car, petrol, < 1.4 l	Prop, Stage 2	28.0	47.0	23.5	52.0
Car, petrol, 1.4 – 2 l	Prop, Stage 2	30.0	48.0	24.5	54.0
Car, petrol, > 2 l	Prop, Stage 2	30.0	48.0	23.5	55.0
Car, petrol, > 2 l, high perf.	Prop, Stage 2	31.0	50.0	35.0	54.0
Car, diesel, < 2 l	Prop, Stage 2	30.0	49.0	25.5	54.0
Car, diesel, > 2 l	Prop, Stage 2	30.0	49.0	25.5	54.0
Car, diesel, > 2 l, high perf.	Prop, Stage 2	31.0	50.0	35.0	54.0
Light duty vehicle, petrol	Prop, Stage 2	16.3	56.0	14.1	58.5
Light duty vehicle, diesel	Prop, Stage 2	16.3	58.0	10.8	64.0
Rigid truck, < 7.5 t	Prop, Stage 2	10.3	62.0	2.0	72.0
Rigid truck, < 7.5 t, traction	Prop, Stage 2	10.3	62.0	2.0	72.0
Rigid truck, 7.5 – 14 t	Prop, Stage 2	10.3	65.0	2.0	74.0
Rigid truck, 7.5 – 14 t, traction	Prop, Stage 2	10.3	65.0	2.0	74.0
Rigid truck, 14 – 20 t	Prop, Stage 2	10.9	65.0	1.7	75.0
Rigid truck, 14 – 20 t, traction	Prop, Stage 2	10.9	65.0	1.7	75.0
Rigid truck, 20 – 28 t	Prop, Stage 2	10.9	65.0	1.7	75.0
Rigid truck, 20 – 28 t, traction	Prop, Stage 2	10.9	65.0	1.7	75.0
Trailer truck, ≤ 32 t	Prop, Stage 2	10.9	67.0	1.7	77.0
Trailer truck, ≤ 32 t, traction	Prop, Stage 2	10.9	67.0	1.7	77.0
Trailer truck, > 32 t	Prop, Stage 2	10.9	67.0	1.7	77.0
Trailer truck, > 32 t, traction	Prop, Stage 2	10.9	67.0	1.7	77.0
Public transport bus, ≤ 20 t	Prop, Stage 2	10.9	63.8	1.7	73.3
Public transport bus, > 20 t	Prop, Stage 2	10.9	63.8	1.7	73.3
Motorcycle, ≤ 150cm^3	Stage 2	26.6	50.8	25.7	52.7
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 2	23.6	58.0	21.7	62.0
Motorcycle, > 150 cm^3	Stage 2	30.6	60.7	26.1	68.0
Motorcycle, > 150 cm^3, illegal silencers	Stage 2	26.6	66.7	21.1	78.0

7 Aligning the model calculations with measured values

It was necessary to both 'fine tune' and validate the model by comparing predicted values of vehicle noise with actual measurements at real road sites. Any differences could then be interpreted and adjustment made to the emission factors for each vehicle type and operation as appropriate. The following approach was used:

Noise emission values were calculated using the model for each vehicle layer (1996 onwards) for a range of vehicle speeds. The full range of vehicle speeds were examined by taking speeds in intervals of 5km/h (i.e. 0, 5, 10km/h etc., until the maximum speed assumed for the vehicle layer is achieved). The average L_{max} values were therefore determined for each layer as a function of vehicle speed. These calculated relationships were then compared with corresponding measured results obtained from random vehicle samples measured at various road sites in Germany during 2001. The measured data was taken initially as part of a separate project carried out for the German Environmental Agency (UBA). It should be noted that the results of this other project are not published at time of writing.

The different vehicle layers were identified in the measurements using information taken from the vehicle registration plates. This gave information about the vehicles engine capacity, rated power, gross mass and year when the vehicle was initially registered for road use. This detailed information on each vehicle enabled the vehicle layers used in the model to be matched with the vehicles observed in the traffic stream. Further adjustments were made to the measured data so that they were each normalised to the same road surface conditions which was taken to be a dense asphalt with 11mm maximum chipping size.

As might be expected some differences between measured and predicted results were found in the initial comparison. For example it was found that the noise levels calculated for the car layers were systematically lower than the average L_{max} values obtained from the measured values. The differences between the values were attributed to an underestimation of the tyre noise coefficient used in the model. It should be noted that the predicted results were obtained assuming the road surface was similar to the standard ISO surface. This surface tends to produce relatively low levels of tyre noise when compared with other surface types. The tyre noise coefficients were adjusted to bring the modelled estimations in line with the emissions measured for the real traffic.

Figure 7.1 and Figure 7.2 show the final results using the adjusted coefficients for the petrol car and diesel car layers respectively.

It was also noted that the calculated noise levels of some heavy duty vehicle layers were lower than the equivalent levels measured in real traffic particularly in the low vehicle speed region. In this case, the differences were attributed to the fact that the propulsion noise coefficients employed in the model were estimated on the basis of type approval measurement results. Type approval test conditions are designed so that the vehicle generates its maximum noise emission during the test. In practice such conditions are relatively rare even during operations at low speed. As a result of the comparison results the propulsion coefficients have been modified slightly to achieve a greater correspondence between measured and calculated results over the whole of the speed range. Figure 7.3 and Figure 7.4 compare the measured results with calculated values using the modified coefficients for rigid-based and trailer-based trucks respectively.

Figure 7.5 and Figure 7.6 show the corresponding comparison for the motorcycle layers.

The modifications for the “from 1996 on” layers compared to the initial validation are summarised in Table 7.1 and Table 7.2.

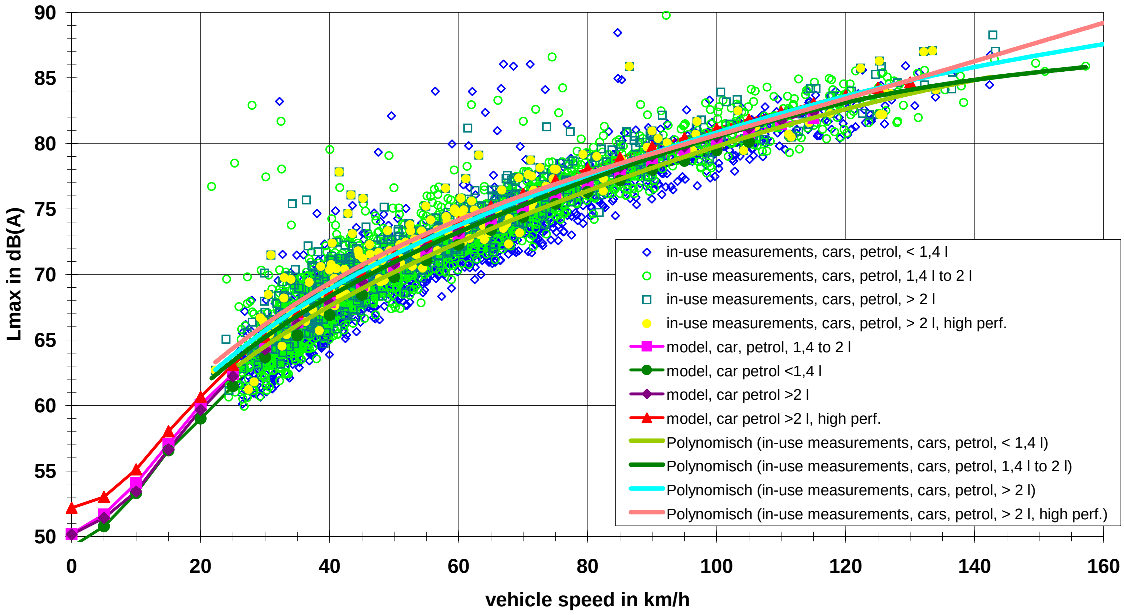

Figure 7.1: Comparison of modelled and measured average overall noise emissions for petrol car layers

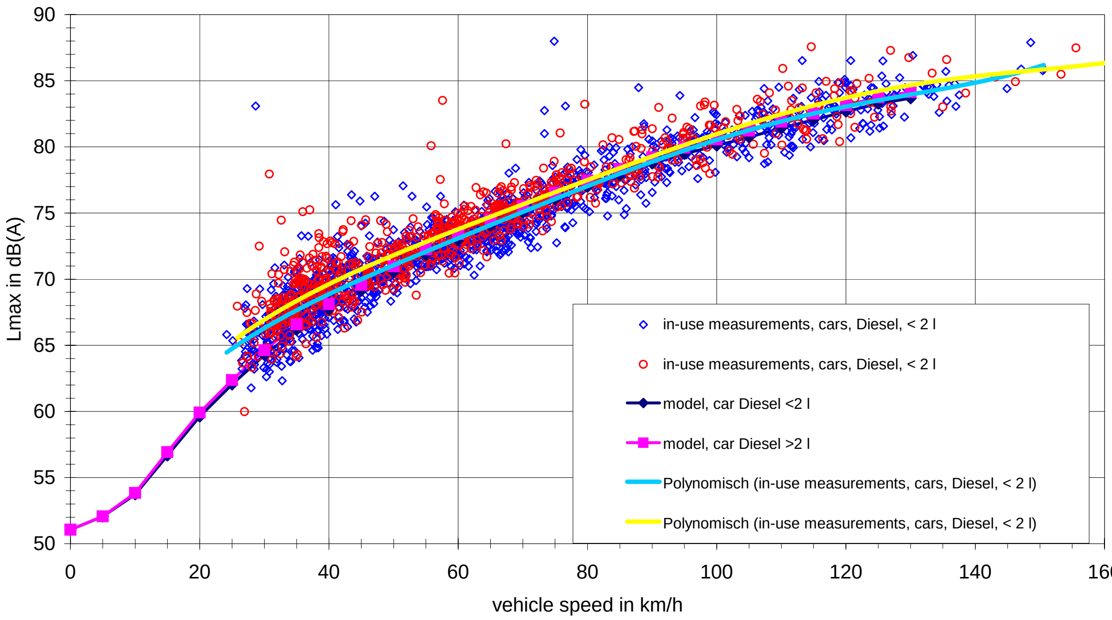

Figure 7.2: Comparison of modelled and measured average overall noise emissions for diesel car layers

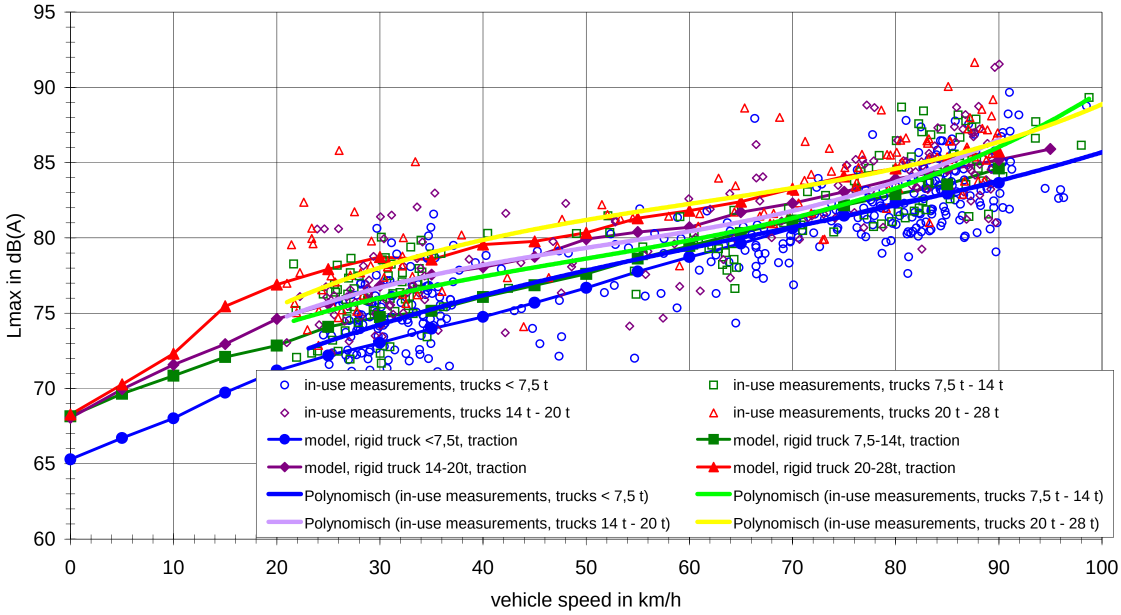

Figure 7.3: Comparison of modelled and measured average overall noise emissions for rigid truck layers

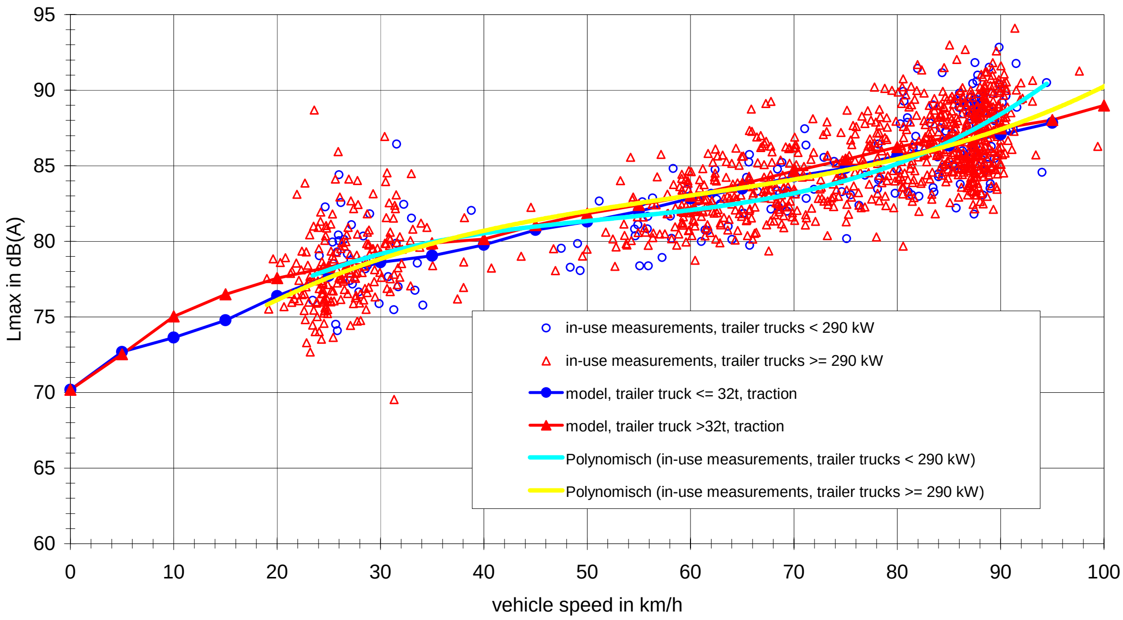

Figure 7.4: Comparison of modelled and measured average overall noise emissions for trailer truck layers

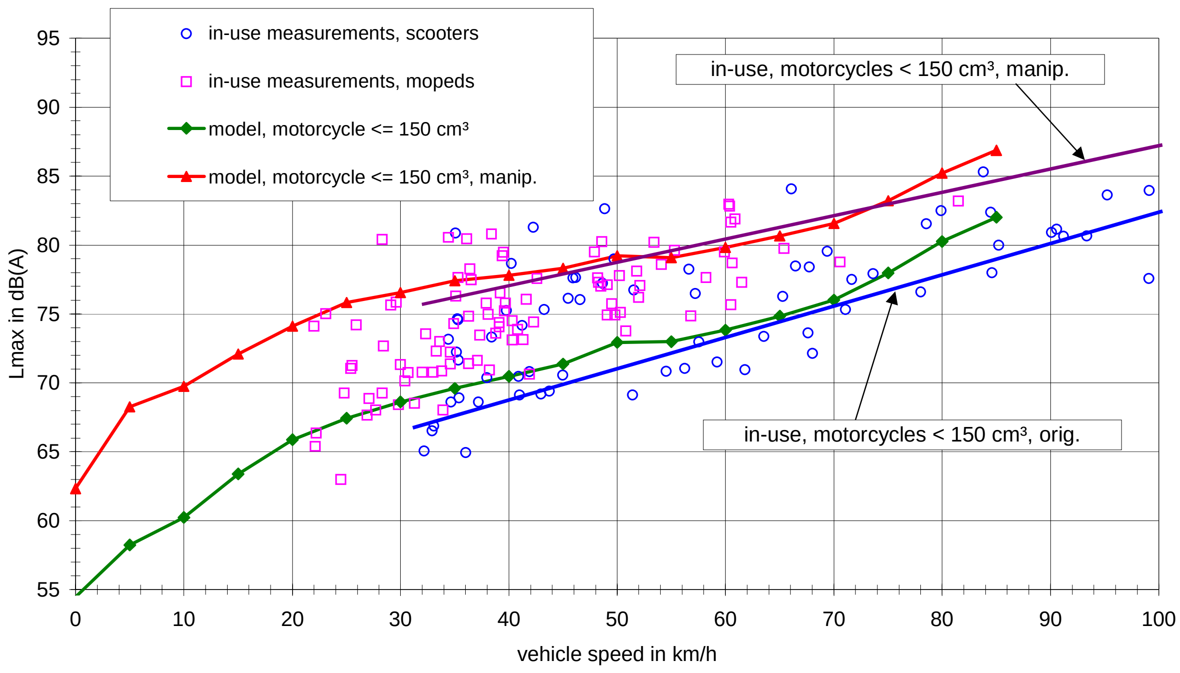

Figure 7.5: Comparison of modelled and measured average overall noise emissions for motorcycles < 150 cm³

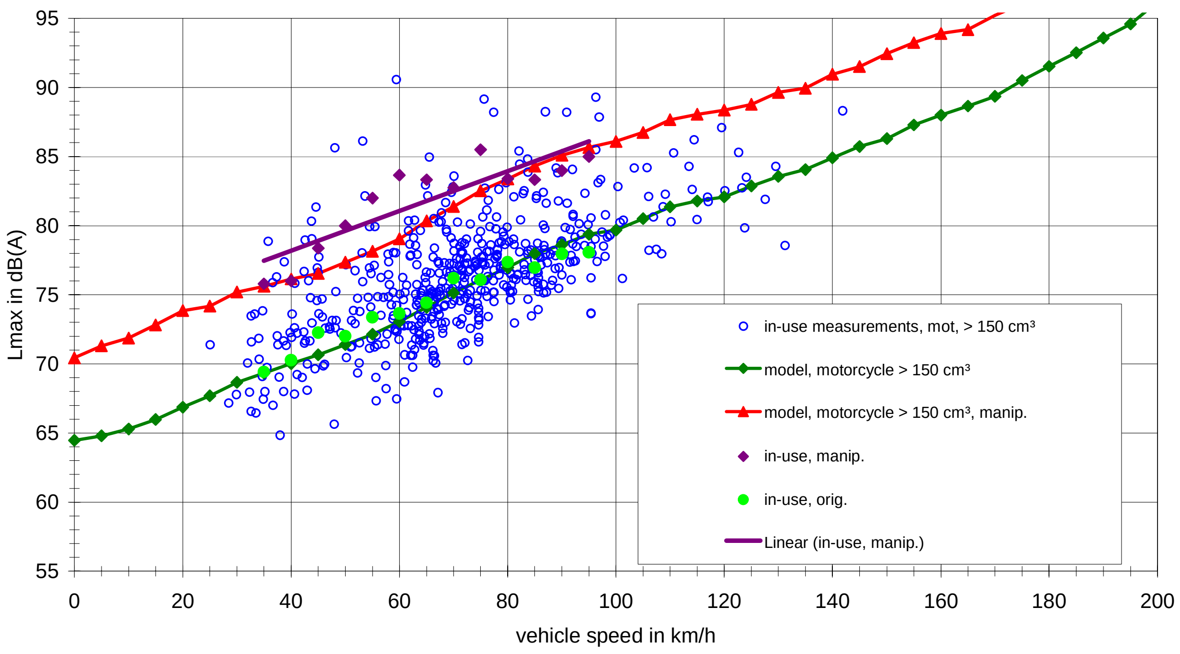

Figure 7.6: Comparison of modelled and measured average overall noise emissions for motorcycles >= 150 cm³

Table 7.1: Modification of tyre noise characteristics compared to initial validation

Vehicle layer	Emission stage	Modifications compared to initial validation	
		Delta_L $_{r50}$ **(AC 0/11) dB(A)**	***Delta_B***
Car, petrol, < 1.4 l	From 1996 onwards	2.0	1.0
Car, petrol, 1.4 – 2 l	From 1996 onwards	2.6	1.0
Car, petrol, > 2 l	From 1996 onwards	3.1	1.0
Car, petrol, > 2 l, high perf.	From 1996 onwards	3.1	1.0
Car, diesel, < 2 l	From 1996 onwards	2.6	1.0
Car, diesel, > 2 l	From 1996 onwards	3.1	1.0
Car, diesel, > 2 l, high perf.	From 1996 onwards	3.1	1.0
Light duty vehicle, petrol	From 1996 onwards	0.0	0.0
Light duty vehicle, diesel	From 1996 onwards	0.0	0.0
Rigid truck, < 7.5 t	From 1996 onwards	1.5	-1.0
Rigid truck, < 7.5 t, traction	From 1996 onwards	1.5	-1.0
Rigid truck, 7.5 – 14 t	From 1996 onwards	1.0	-1.0
Rigid truck, 7.5 – 14 t, traction	From 1996 onwards	1.0	-1.0
Rigid truck, 14 – 20 t	From 1996 onwards	1.0	-1.0
Rigid truck, 14 – 20 t, traction	From 1996 onwards	1.0	-1.0
Rigid truck, 20 – 28 t	From 1996 onwards	0.0	-1.0
Rigid truck, 20 – 28 t, traction	From 1996 onwards	0.0	-1.0
Trailer truck, ≤ 32 t	From 1996 onwards	1.0	-1.0
Trailer truck, ≤ 32 t, traction	From 1996 onwards	1.0	-0.5
Trailer truck, > 32 t	From 1996 onwards	0.5	-1.0
Trailer truck, > 32 t, traction	From 1996 onwards	0.5	-0.5
Public transport bus, ≤ 20 t	From 1996 onwards	0.0	-1.0
Public transport bus, > 20 t	From 1996 onwards	0.0	-1.0

Table 7.2: Modification of propulsion noise characteristics compared to initial validation

Vehicle layer	Registration year	Modifications compared to initial validation			
		Low load		Full load	
		Delta_K $_1$	***Delta_k*** $_0$	***Delta_w*** $_1$	***Delta_w*** $_0$
Car, petrol, < 1.4 l	From 1996	0.0	0.0	0.0	0.0
Car, petrol, 1.4 – 2 l	From 1996	0.0	0.0	0.0	0.0
Car, petrol, > 2 l	From 1996	0.0	0.0	0.0	0.0
Car, petrol, > 2 l, high perf.	From 1996	0.0	0.0	0.0	0.0
Car, diesel, < 2 l	From 1996	0.0	0.0	0.0	0.0
Car, diesel, > 2 l	From 1996	0.0	0.0	0.0	0.0
Car, diesel, > 2 l, high perf.	From 1996	0.0	0.0	0.0	0.0
Light duty vehicle, petrol	From 1996	0.0	2.4	0.3	1.1
Light duty vehicle, diesel	From 1996	0.0	4.4	0.0	3.6
Rigid truck, < 7.5 t	From 1996	0.0	1.8	0.0	0.7
Rigid truck, < 7.5 t, traction	From 1996	0.0	1.8	0.0	0.7
Rigid truck, 7.5 – 14 t	From 1996	0.0	4.8	0.0	2.7
Rigid truck, 7.5 – 14 t, traction	From 1996	0.0	4.8	0.0	2.7
Rigid truck, 14 – 20 t	From 1996	0.0	1.2	-0.1	1.7
Rigid truck, 14 – 20 t, traction	From 1996	0.0	1.2	-0.1	1.7
Rigid truck, 20 – 28 t	From 1996	0.0	1.2	-0.1	1.7
Rigid truck, 20 – 28 t, traction	From 1996	0.0	1.2	-0.1	1.7
Trailer truck, ≤ 32 t	From 1996	0.0	3.2	-0.1	3.7
Trailer truck, ≤ 32 t, traction	From 1996	0.0	3.2	-0.1	3.7
Trailer truck, > 32 t	From 1996	0.0	3.2	-0.1	3.7
Trailer truck, > 32 t, traction	From 1996	0.0	3.2	-0.1	3.7
Public transport bus, ≤ 20 t	From 1996	0.0	0.0	-0.1	0.0
Public transport bus, > 20 t	From 1996	0.0	0.0	-0.1	0.0
Motorcycle, ≤ 150 cm^3	Stage 0	0.0	0.0	0.0	0.0
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	0.0	3.2	0.0	3.3
Motorcycle, > 150 cm^3	Stage 0	0.0	5.0	0.0	4.2
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	0.0	5.0	0.0	4.2

8 Application of the model

This section describes some example calculations obtained using the revised model. The calculations are intended to demonstrate the range of noise control strategies that can be examined and to provide useful indications of the benefits achieved. The section begins with some calculations made for single vehicle types and then continues with calculations based on traffic streams. The single vehicle calculations help to demonstrate the various stages in the calculation process and provide useful indicators for a range of vehicle source control options. The traffic stream calculations provide direct estimates of reductions in traffic noise for a range of vehicle source control measures.

8.1 Single vehicle calculations

The results of calculations given in this section are presented as hourly L_{Aeq} values for each different vehicle layer at a reference propagation distance of 25 m and for a receiver height of 4 m. As indicated above the results are intended to demonstrate the various stages in the calculation process that was described in section 3 of this report as well as illustrating the versatility of the model in being able to address specific questions regarding noise control options. The section concludes with some example calculations of how the model can be used to determine the noise changes resulting from different source control options. It should be noted at this stage the calculations have been limited to individual vehicle layers and not combined into representative traffic flows. Traffic flows are, of course, site specific and traffic mixes, age etc., will be regionally dependent within the EU. Regional differences are taken into account when using the model by inputting appropriate weighting factors depending on the fleet composition.

8.1.1 Noise levels for different vehicle layers and road category/traffic situations

Figure 8.1 shows the values of L_{Aeq} for different vehicle types (layers) operating in a residential street where the speed limit is 30 km/h. The posted values represent the hourly contribution of one vehicle of each vehicle layer represented.

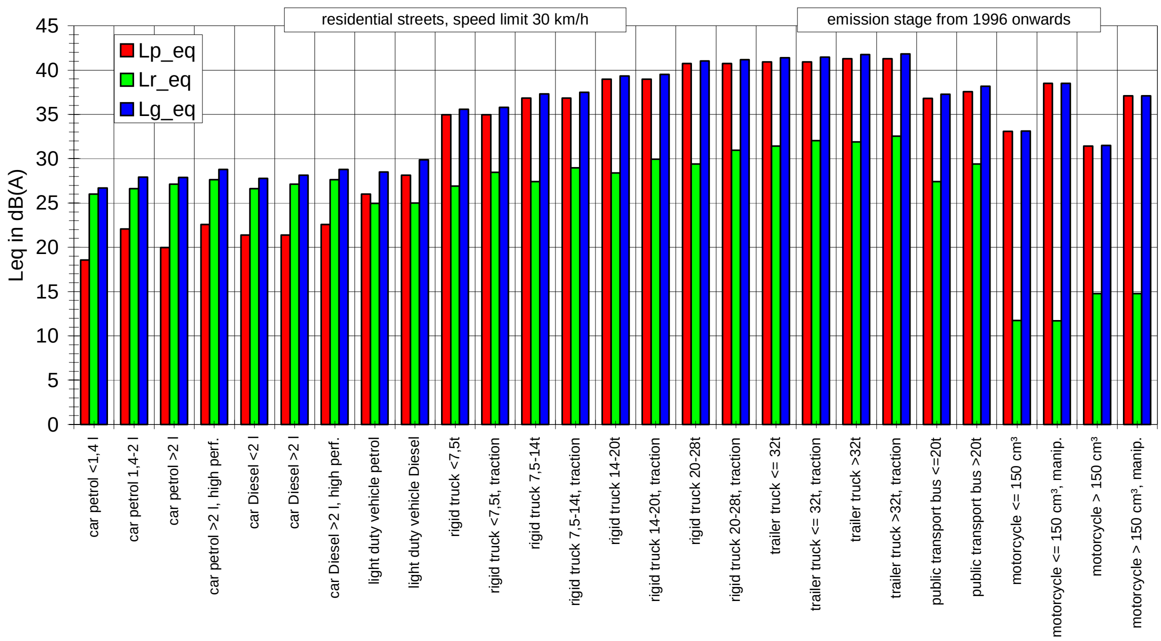

Figure 8.1: $LA_{eq,1hr}$ for a single vehicle by category/subcategory, operating in a residential street with a speed limit of 30 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

In each case the individual L_{Aeq} values for propulsion noise (L_{peg}), rolling noise (L_{reg}), and total (combined) noise (L_{geg}) are given. It is assumed in this calculation that the vehicle was first registered after 1996 and that the noise limits in operation at that time apply.

It can be seen in Figure 8.1 how the relative importance of propulsion and rolling noise sources changes for the different vehicle types. As expected, for the HDVs propulsion noise dominates over rolling noise in this type of street environment whereas for cars and LDVs the two source types are more evenly matched. Similar figures for vehicles operating in other road category/traffic situations are given in Appendix A.

8.1.2 Combining the layers to form traffic stream noise levels

In order to determine hourly values of L_{Aeq} for real traffic situations, it is necessary to combine the individual contributions from each vehicle type comprising the traffic stream weighted according to the actual flow volumes on the road section of interest. Table 8.1 shows how part of this calculation is performed in the model.

The table provides information on the contribution to the overall L_{Aeq} level relative to a petrol-powered car with an engine capacity in the range 1.4 - 2.0 litres. Data is provided for each vehicle layer and for each road category/traffic situation included in the model that represent current generation vehicles i.e. vehicles first registered since 1996. In the actual model additional vehicle layers have been included to represent future generation vehicles. These cases have been discussed earlier in the report.

Having established the overall noise levels of each vehicle layer and the contribution of each vehicle layer to the single vehicle L_{Aeq} level the model then computes the overall traffic L_{Aeq} levels by summing the flow volumes of each vehicle layer. The summation takes into account the distribution of flows across different lanes of the road and the diurnal traffic load distributions that are input by the user.

8.1.3 Effects of source control measures on traffic noise levels –reduction of total vehicle noise

In order to demonstrate the types of noise control issues that can be examined using the model a series of source control options have been examined. The control options examined include the imbedded reductions in noise from both rolling and propulsion noise sources that were described earlier in the report.

Table 8.2 shows the results of calculations carried out using the model for three different road category/traffic situations that collectively cover a broad range of situations occurring in practice. The noise level reductions have been calculated relative to current generation vehicles first registered after 1996. These results are presented in terms of absolute levels of L_{Aeq}.

The source reduction scenarios are those imbedded in the model and described earlier in the report. R1, R2 and R3 refer to the three levels of rolling noise reduction and P1 and P2 refer to the future projections for reductions in propulsion noise from current generation vehicle types. In addition, three options are also included where both rolling and propulsion noise sources were operating.

The data in the tables can be used to provide estimates of noise reductions for a wide range of traffic situations. For example, the results demonstrate that for relatively low speed operations in residential streets, greater reductions in overall traffic noise levels will be achieved by reducing propulsion noise whereas at higher speeds in rural areas, reducing rolling noise provides the greater benefits.

Overall, given the anticipated potential to reduce source noise levels that has been imbedded in the model, it is predicted that traffic noise levels could be reduced by typically 3-4 dB(A) for a broad range of road types and vehicle operations depending on the mix of traffic.

Table 8.1: Contribution to L_{Aeq} relative to medium size cars

Vehicle layer	Registration year	Residential streets, speed limit 30 km/h	Residential streets, speed limit 50 km/h	City centre	Main streets, speed limit 50 km/h, traffic lights	Main streets, speed limit 50 km/h, dense traffic	Main streets, speed limit 50 km/h, congested	Main streets, speed limit 50 km/h, right of way	Main streets speed limit > 50 km/h,	Rural, speed limit 70 km/h	Rural, speed limit 100 km/h	Urban motorway, speed limit 100 km/h
Car, petrol, < 1.4 l	From 1996	75%	80%	76%	80%	79%	80%	81%	77%	78%	67%	66%
Car, petrol, 1.4 – 2 l	From 1996	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Car, petrol, > 2 l	From 1996	99%	105%	101%	108%	104%	105%	107%	109%	109%	110%	111%
Car, diesel, < 2 l	From 1996	122%	127%	124%	129%	126%	127%	128%	131%	131%	136%	135%
Car, diesel, > 2 l	From 1996	96%	99%	97%	100%	99%	99%	100%	102%	102%	107%	106%
Car, petrol, > 2 l, high perf.	From 1996	106%	109%	107%	111%	109%	109%	110%	113%	113%	119%	118%
Car, diesel, > 2 l, high perf.	From 1996	122%	127%	124%	129%	126%	127%	128%	131%	131%	136%	135%
Light duty vehicle, petrol	From 1996	115%	94%	120%	89%	102%	100%	89%	84%	84%	83%	82%
Light duty vehicle, diesel	From 1996	156%	116%	163%	104%	129%	125%	105%	93%	92%	88%	87%
Rigid truck, < 7.5 t	From 1996	582%	369%	588%	293%	428%	405%	317%	230%	230%	172%	162%
Rigid truck, 7.5 – 14 t	From 1996	616%	415%	625%	348%	472%	452%	366%	290%	291%	229%	219%
Rigid truck, 14 – 20 t	From 1996	871%	514%	898%	387%	618%	580%	424%	287%	285%	212%	200%
Rigid truck, 20 – 28 t	From 1996	909%	566%	939%	450%	668%	634%	481%	355%	354%	277%	265%
Rigid truck, < 7.5 t, traction	From 1996	1387%	824%	1357%	580%	976%	894%	678%	405%	401%	280%	259%
Rigid truck, 7.5 – 14 t, traction	From 1996	1442%	893%	1414%	661%	1043%	963%	751%	494%	490%	368%	347%
Rigid truck, 14 – 20 t, traction	From 1996	2056%	1091%	1943%	732%	1326%	1189%	851%	479%	474%	306%	274%
Rigid truck, 20 – 28 t, traction	From 1996	2117%	1176%	2010%	831%	1407%	1275%	942%	585%	582%	405%	373%

Table 8.1 (Continued): Contribution to L_{Aeq} relative to medium size cars

Vehicle layer	Registration year	Residential streets, speed limit 30 km/h	Residential streets, speed limit 50 km/h	City centre	Main streets, speed limit 50 km/h, traffic lights	Main streets, speed limit 50 km/h, dense traffic	Main streets, speed limit 50 km/h, congested	Main streets, speed limit 50 km/h, right of way	Main streets speed limit > 50 km/h,	Rural, speed limit 70 km/h	Rural, speed limit 100 km/h	Urban motorway, speed limit 100 km/h
Car, petrol, 1.4 – 2 l	From 1996	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Trailer truck, ≤ 32 t	From 1996	2222%	1315%	2222%	946%	1570%	1450%	1078%	652%	647%	447%	411%
Trailer truck, > 32 t	From 1996	2258%	1373%	2264%	1019%	1623%	1510%	1142%	728%	724%	521%	484%
Trailer truck, ≤ 32 t, traction	From 1996	2416%	1398%	2382%	1010%	1671%	1539%	1141%	700%	697%	488%	448%
Trailer truck, > 32 t, traction	From 1996	2456%	1461%	2428%	1092%	1728%	1603%	1211%	785%	783%	571%	531%
Public transport bus, ≤ 20 t	From 1996	864%	508%	866%	363%	607%	562%	418%	244%	244%	145%	129%
Public transport bus, > 20 t	From 1996	1065%	630%	1061%	480%	746%	697%	525%	345%	345%	219%	205%
Motorcycle, ≤ 150cm3	Stage 0	332%	222%	306%	198%	249%	226%	185%	201%	199%	246%	243%
Motorcycle, ≤ 150 cm3, illegal silencers	Stage 0	1140%	745%	1060%	648%	842%	769%	627%	626%	620%	707%	692%
Motorcycle, > 150 cm3	Stage 0	228%	168%	241%	157%	187%	184%	154%	148%	148%	152%	150%
Motorcycle, > 150 cm3, illegal silencers	Stage 0	828%	588%	882%	540%	665%	653%	536%	495%	496%	483%	468%

Table 8.2: Calculated reductions in total noise levels, L_{geq} dB(A), for selected future scenarios

Road type/traffic situation	Vehicle category/subcategory	Future Scenarios							
		R1	R2	R3	P1	P2	R1/ P1	R2/ P2	R3/ P2
Residential Street speed limit 30 km/h	Car Petrol 1.4-2l	1.1	2.0	2.8	0.3	0.5	1.4	2.8	3.8
	Car Petrol > 2l, high perf	1.1	2.1	2.9	0.3	0.4	1.4	2.9	3.9
	Light Duty Vehicle, Diesel	0.4	0.8	1.0	0.8	1.5	1.3	2.7	3.1
	Rigid Truck, < 7.5t	0.2	0.3	0.4	1.7	3.1	2.0	3.7	3.9
	Rigid Truck, 14-20t, traction	0.2	0.3	0.3	1.8	3.3	2.0	3.9	4.1
	Rigid Truck, 20-28t, traction	0.1	0.2	0.3	2.1	3.9	2.3	4.4	4.6
	Trailer Truck, > 32t, traction	0.2	0.3	0.3	1.9	3.4	2.1	4.1	4.2
Main Street, speed limit 50 km/h, traffic lights	Car Petrol 1.4-2l	1.3	2.6	3.8	0.1	0.2	1.5	2.9	4.2
	Car Petrol > 2l, high perf	1.3	2.5	3.6	0.1	0.2	1.5	3.0	4.2
	Light Duty Vehicle, Diesel	0.9	1.7	2.4	0.4	0.7	1.4	2.8	3.7
	Rigid Truck, < 7.5t	0.5	0.9	1.2	1.2	2.1	1.9	3.6	4.2
	Rigid Truck, 14-20t, traction	0.5	0.9	1.2	1.3	2.2	1.9	3.7	4.3
	Rigid Truck, 20-28t, traction	0.5	0.8	1.1	1.4	2.4	2.0	4.0	4.5
	Trailer Truck, > 32t, traction	0.6	1.0	1.3	1.2	2.0	1.9	3.7	4.3
Rural, speed limit 70 km/h	Car Petrol 1.4-2l	1.4	2.7	4.0	0.1	0.1	1.5	3.0	4.3
	Car Petrol > 2l, high perf	1.3	2.6	3.8	0.1	0.2	1.5	3.0	4.3
	Light Duty Vehicle, Diesel	1.1	2.1	3.0	0.3	0.5	1.4	2.9	4.0
	Rigid Truck, < 7.5t	0.7	1.2	1.7	1.0	1.6	1.8	3.6	4.4
	Rigid Truck, 14-20t, traction	0.7	1.3	1.8	0.9	1.5	1.8	3.6	4.4
	Rigid Truck, 20-28t, traction	0.7	1.4	1.9	0.9	1.6	1.9	3.7	4.5
	Trailer Truck, > 32t, traction	0.8	1.4	2.0	0.8	1.4	1.8	3.5	4.4
Rural, speed limit 100 km/h	Car Petrol 1.4-2l	1.4	2.8	4.2	0.0	0.1	1.5	3.0	4.4
	Car Petrol > 2l, high perf	1.4	2.8	4.1	0.1	0.1	1.5	3.0	4.4
	Light Duty Vehicle, Diesel	0.2	2.4	3.4	0.2	0.3	1.5	2.9	4.2
	Rigid Truck, < 7.5t	0.8	1.5	2.0	0.8	1.3	1.8	3.5	4.5
	Rigid Truck, 14-20t, traction	0.9	1.8	2.5	0.6	1.0	1.7	3.4	4.5
	Rigid Truck, 20-28t, traction	1.0	1.8	2.6	0.6	1.0	1.7	3.4	4.5
	Trailer Truck, > 32t, traction	1.0	1.9	2.7	0.5	0.9	1.7	3.3	4.4

8.2 Traffic stream calculations

The model is potentially capable of calculating traffic stream noise levels for a very broad range of situations that might occur in practice. It is impractical therefore to include all possible scenarios that could be examined. Consequently, in order to demonstrate the potential of the model, a few case study scenarios have been selected for detailed analysis. The case studies described in the following section were selected following discussions with the membership of EU Working Group 8.

The method adopted for each case study has been to compare model predictions for each noise control option considered against a baseline situation where the traffic flow, speed and composition is assumed. Typical traffic flows have been assumed for each type of road category investigated.

8.2.1 Model scenarios for baseline calculations

Seven road types were chosen for the baseline calculations; 4 urban streets, 2 rural roads and 1 motorway. The traffic data assumed for these road types is summarised in Table 8.3. The chosen values of traffic volume and percentages of vehicle categories are representative for the Western Europe region. In addition to the assumed traffic parameters listed in the table it was also assumed the road, in each baseline scenario, was surfaced with a stone mastic asphalt (0/11).

Table 8.3: Traffic data for baseline calculations

No.	Road category	No. of lanes	Av. Daily traffic	% Cars	% LDV	% HDV	% M/cycles	% Scooters
1	Residential streets, speed limit 30 km/h	2	2000	94.0	3.0	1.0	1.0	1.0
2	Residential streets, speed limit 50 km/h	2	2000	94.0	3.0	1.0	1.0	1.0
3	Urban, main streets, speed limit 50 km/h, traffic lights	4	40,000	88.5	4.5	5.0	1.0	1.0
4	Urban, main streets, speed limit 60/70 km/h	4	40,000	88.5	4.5	5.0	1.0	1.0
5	Rural, speed limit 70 km/h	2	15,000	87.0	4.5	5.0	3.5	0.0
6	Rural, speed limit 100 km/h	2	15,000	87.0	4.5	5.0	3.5	0.0
7	Motorway, speed limit 120 km/h	4	40,000	81.5	4.5	13.0	1.0	0.0

The model has been used with these traffic inputs and road surface inputs to determine noise levels L_{Aeq} , averaged over different time periods, and L_{den}. The results have been calculated using diurnal traffic flow curves which are stored by default within the model. These curves are based upon measurements carried out by RWTÜV for the German Federal Government. These results are shown in Table 8.4. In each case the calculations were made assuming the receptor was located at a distance of 25 m from the edge of the road and a height of 4 m. This receptor position was also used in all other cases considered. The influence of traffic volume can clearly be seen.

Table 8.4: Noise emission results for the baseline scenarios

No.	Road category	Averaging Period	L_{Aeq} dB(A)		
			Propulsion	**Rolling**	**Overall**
1	Residential 30	07:00 – 19:00	45.3	47.5	49.3
		19:00 – 23:00	42.7	46.4	47.7
		23:00 – 07:00	37.9	41.0	42.4
		L_{den}, 24h weighted			51.2
2	Residential 50	07:00 – 19:00	44.8	50.1	51.0
		19:00 – 23:00	42.4	49.0	49.6
		23:00 – 07:00	37.4	43.6	44.3
		L_{den}, 24h weighted			53.0
3	Urban main 50	07:00 – 19:00	62.0	64.1	65.8
		19:00 – 23:00	57.8	63.1	63.9
		23:00 – 07:00	53.4	58.1	59.2
		L_{den}, 24h weighted			67.8
4	Urban main 70	07:00 – 19:00	61.3	66.3	67.5
		19:00 – 23:00	57.5	65.0	65.7
		23:00 – 07:00	53.5	62.1	62.7
		L_{den}, 24h weighted			70.4
5	Rural 70	07:00 – 19:00	57.4	63.1	64.1
		19:00 – 23:00	53.5	61.6	62.1
		23:00 – 07:00	49.3	56.3	56.9
		L_{den}, 24h weighted			65.8
6	Rural 100	07:00 – 19:00	57.9	65.7	66.3
		19:00 – 23:00	54.8	64.1	64.6
		23:00 – 07:00	50.1	58.8	59.3
		L_{den}, 24h weighted			68.1
7	Motorway 120	07:00 – 19:00	65.7	73.1	73.8
		19:00 – 23:00	63.3	71.6	72.2
		23:00 – 07:00	58.9	65.9	66.7
		L_{den}, 24h weighted			75.6

Examples of the contribution that different vehicle categories, subcategories and layers make to the overall level are shown in Figure 8.2 to Figure 8.7and in Table 8.5 to Table 8.7 for three of the road types considered (i.e. residential 30, urban 50 and motorway 120). The relatively high importance of the noise contribution from cars and HDV to the total L_{Aeq} (0700 - 1900) is clearly shown.

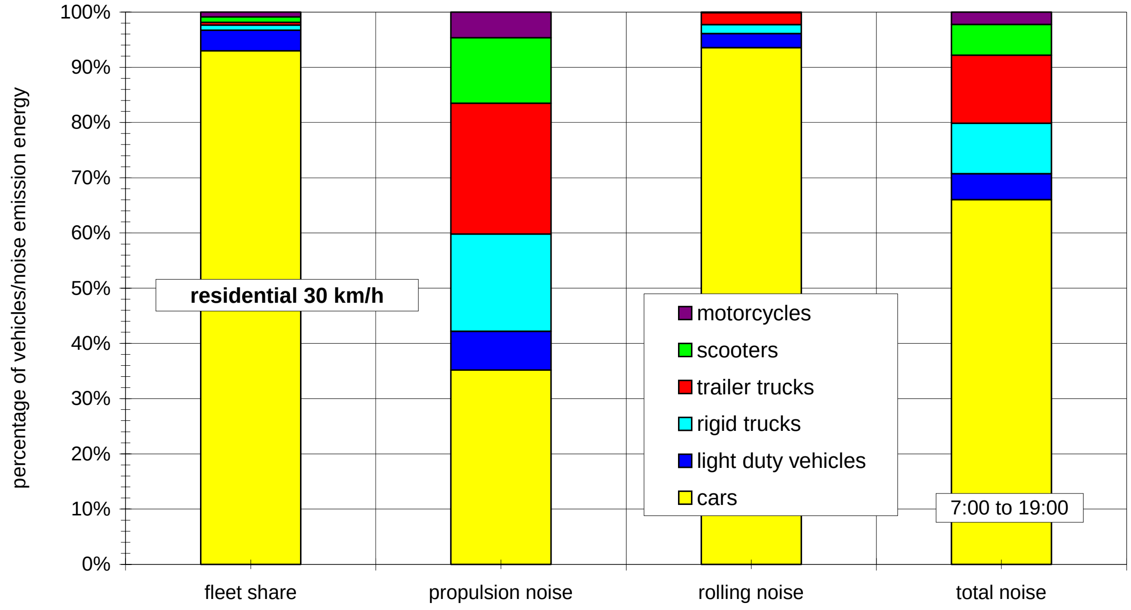

Figure 8.2: Contributions of different vehicle categories on total noise emission (Baseline category 1: Residential 30)

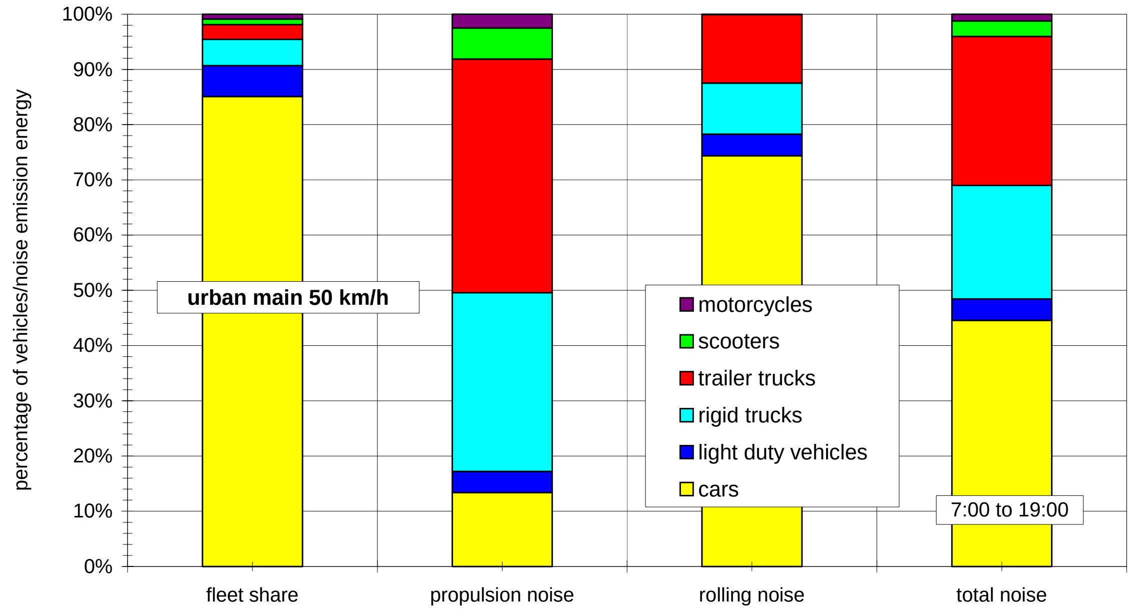

Figure 8.3: Contributions of different vehicle categories on total noise emission (Baseline category 3: Urban main 50)

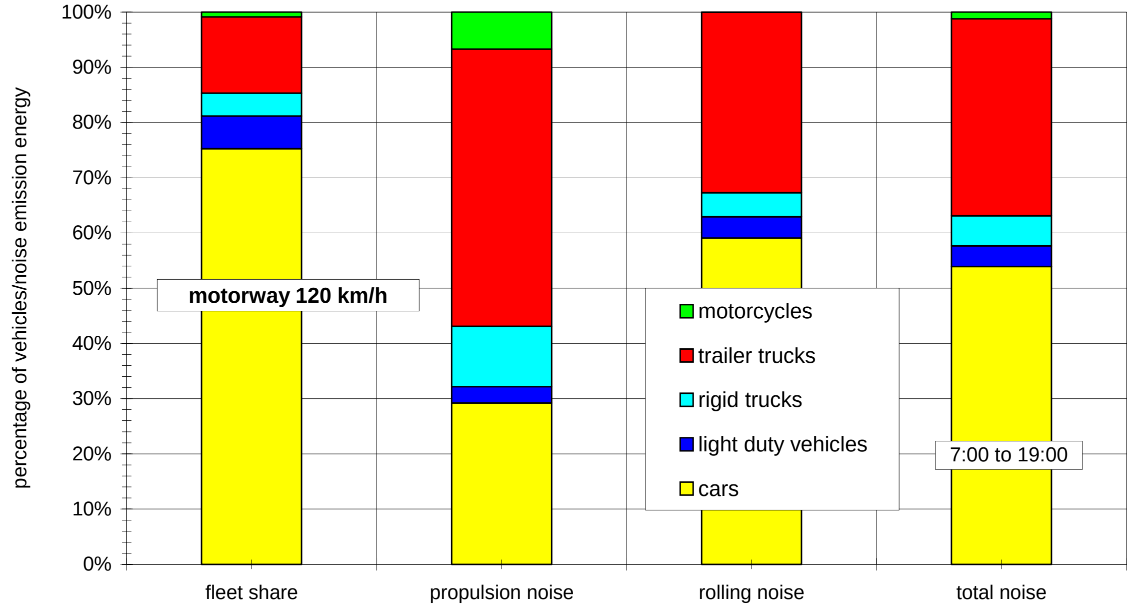

Figure 8.4: Contributions of different vehicle categories on total noise emission (Baseline category 7: Motorway 120)

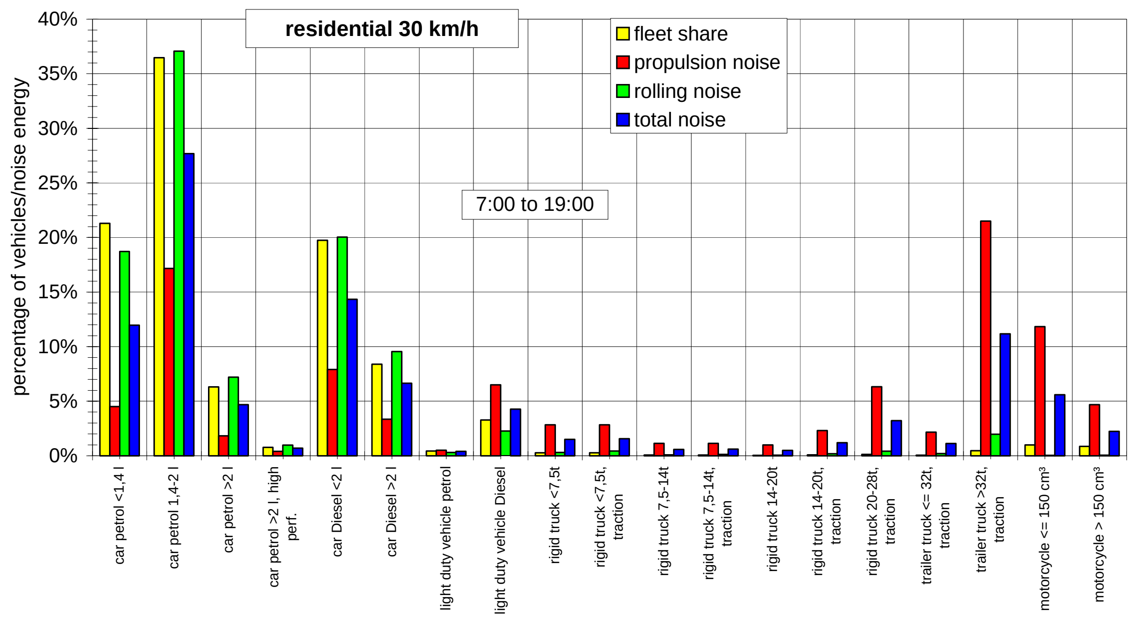

Figure 8.5: Contributions of different vehicle subcategories on total noise emission (Baseline category 1: Residential 30)

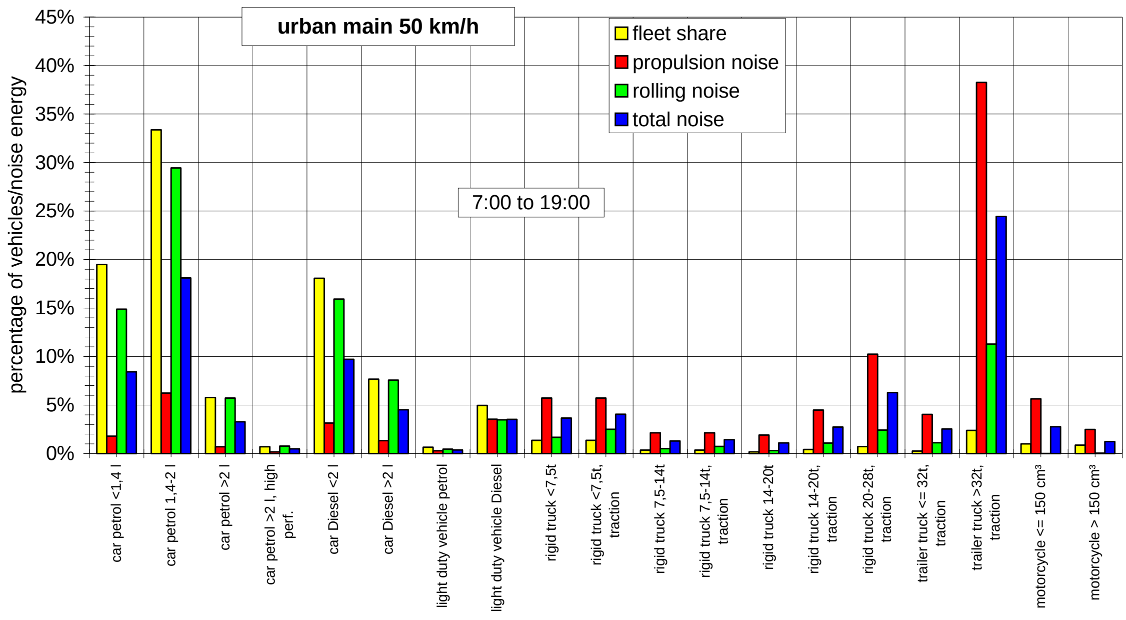

Figure 8.6: Contribution of different vehicle subcategories to total noise emission (Baseline category 3: Urban main 50)

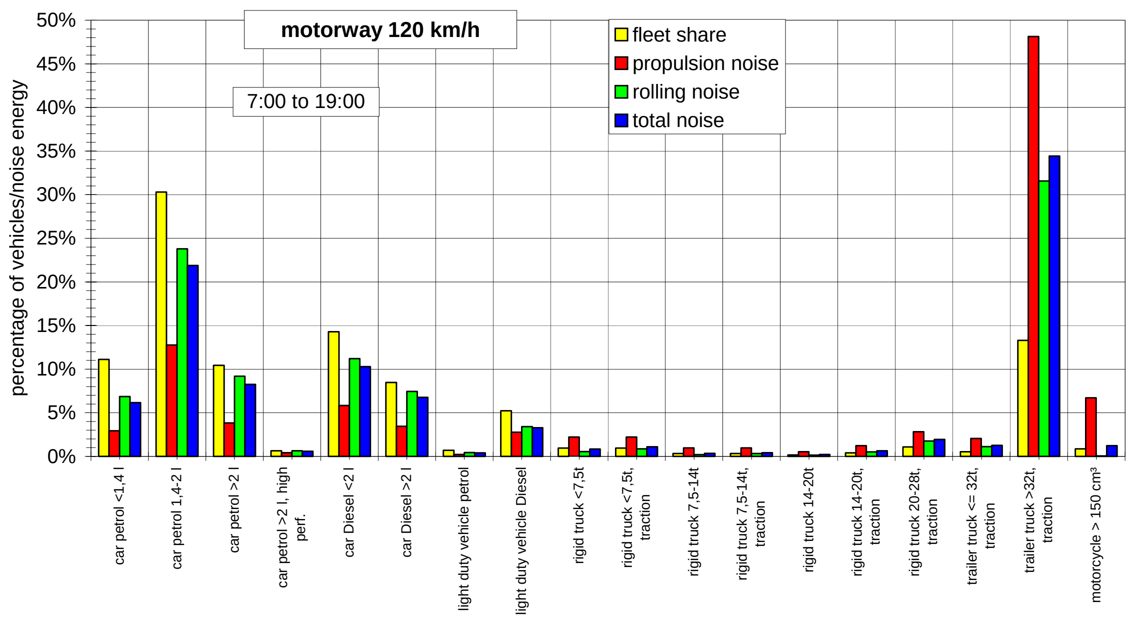

Figure 8.7: Contributions of different vehicle subcategories to total noise emission (Baseline category 7: Motorway 120)

Table 8.5: Contributions of different vehicle layers to total noise emission for Residential 30 road type

Vehicle layer	Emission stage	Fleet share (%)	% Contribution to L_{day}		
			Propulsion	Rolling	Overall
Car, petrol, < 1.4 l	1982 to 1988	0.8	0.2	0.6	0.4
Car, petrol, < 1.4 l	1989 to 1995	6.9	1.8	5.8	3.9
Car, petrol, < 1.4 l	From 1996	13.6	2.5	12.3	7.6
Car, petrol, 1.4 – 2 l	1982 to 1988	1.3	0.9	1.2	1.0
Car, petrol, 1.4 – 2 l	1989 to 1995	11.9	6.7	11.5	9.2
Car, petrol, 1.4 – 2 l	From 1996	23.3	9.6	24.4	17.4
Car, petrol, > 2 l	1982 to 1988	0.2	0.1	0.2	0.2
Car, petrol, > 2 l	1989 to 1995	2.1	0.7	2.2	1.5
Car, petrol, > 2 l	From 1996	4.0	1.0	4.7	3.0
Car, petrol, > 2 l, high perf.	1982 to 1988	0.0	0.0	0.0	0.0
Car, petrol, > 2 l, high perf.	1989 to 1995	0.3	0.2	0.3	0.2
Car, petrol, > 2 l, high perf.	From 1996	0.5	0.2	0.6	0.4
Car, diesel, < 2 l	1982 to 1988	1.1	0.6	1.0	0.8
Car, diesel, < 2 l	1989 to 1995	6.1	2.9	5.9	4.5
Car, diesel, < 2 l	From 1996	12.6	4.4	13.2	9.1
Car, diesel, > 2 l	1982 to 1988	0.5	0.3	0.5	0.4
Car, diesel, > 2 l	1989 to 1995	2.6	1.2	2.8	2.1
Car, diesel, > 2 l	From 1996	5.3	1.9	6.3	4.2
Light duty vehicle, petrol	1982 to 1988	0.0	0.0	0.0	0.0
Light duty vehicle, petrol	1989 to 1995	0.2	0.2	0.1	0.2
Light duty vehicle, petrol	From 1996	0.2	0.2	0.2	0.2
Light duty vehicle, diesel	1982 to 1988	0.2	0.7	0.1	0.4
Light duty vehicle, diesel	1989 to 1995	1.3	2.9	0.9	1.8
Light duty vehicle, diesel	From 1996	1.7	2.9	1.3	2.0
Rigid truck, < 7.5 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t	1985 to 1989	0.0	0.3	0.0	0.2
Rigid truck, < 7.5 t	1990 to 1995	0.1	1.1	0.1	0.6
Rigid truck, < 7.5 t	From 1996	0.2	1.4	0.2	0.7
Rigid truck, < 7.5 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t, traction	1985 to 1989	0.0	0.3	0.0	0.2
Rigid truck, < 7.5 t, traction	1990 to 1995	0.1	1.1	0.1	0.6
Rigid truck, < 7.5 t, traction	From 1996	0.2	1.4	0.3	0.8

Table 8.5: Contributions of different vehicle layers to total noise emission for residential 30 road type (continued)

Vehicle layer	Emission stage	Fleet share (%)	Contribution to L_{day}		
			Propulsion	Rolling	Overall
Rigid truck, 7.5 – 14 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t	1985 to 1989	0.0	0.1	0.0	0.1
Rigid truck, 7.5 – 14 t	1990 to 1995	0.0	0.4	0.0	0.2
Rigid truck, 7.5 – 14 t	From 1996	0.0	0.6	0.1	0.3
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	0.0	0.1	0.0	0.1
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	0.0	0.4	0.0	0.2
Rigid truck, 7.5 – 14 t, traction	From 1996	0.0	0.6	0.1	0.3
Rigid truck, 14 – 20 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t	1985 to 1989	0.0	0.1	0.0	0.1
Rigid truck, 14 – 20 t	1990 to 1995	0.0	0.4	0.0	0.2
Rigid truck, 14 – 20 t	From 1996	0.0	0.5	0.0	0.2
Rigid truck, 14 – 20 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t, traction	1985 to 1989	0.0	0.3	0.0	0.1
Rigid truck, 14 – 20 t, traction	1990 to 1995	0.0	0.9	0.1	0.5
Rigid truck, 14 – 20 t, traction	From 1996	0.1	1.1	0.1	0.6
Rigid truck, 20 – 28 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	0.0	0.9	0.0	0.4
Rigid truck, 20 – 28 t, traction	1990 to 1995	0.0	2.7	0.1	1.3
Rigid truck, 20 – 28 t, traction	From 1996	0.1	2.8	0.3	1.4
Trailer truck, <= 32 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Trailer truck, <= 32 t, traction	1985 to 1989	0.0	0.2	0.0	0.1
Trailer truck, <= 32 t, traction	1990 to 1995	0.0	0.8	0.1	0.4
Trailer truck, <= 32 t, traction	From 1996	0.0	1.1	0.1	0.6
Trailer truck, > 32 t, traction	1982 to 1984	0.0	0.2	0.0	0.1
Trailer truck, > 32 t, traction	1985 to 1989	0.0	2.3	0.1	1.1
Trailer truck, > 32 t, traction	1990 to 1995	0.1	7.8	0.5	4.0
Trailer truck, > 32 t, traction	From 1996	0.3	11.2	1.3	6.0
Motorcycle, ≤ 150cm^3	Stage 0	0.8	8.2	0.0	3.9
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	0.2	3.6	0.0	1.7
Motorcycle, > 150 cm^3	Stage 0	0.7	2.4	0.0	1.2
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	0.2	2.2	0.0	1.1

Table 8.6: Contributions of different vehicle layers to total noise emission for Urban 40 road type

Vehicle layer	Emission stage	Fleet share (%)	Contribution to L_{day}		
			Propulsion	Rolling	Overall
Car, petrol, < 1.4 l	1982 to 1988	0.7	0.1	0.5	0.3
Car, petrol, < 1.4 l	1989 to 1995	6.4	0.7	4.6	2.7
Car, petrol, < 1.4 l	From 1996	12.4	1.0	9.8	5.5
Car, petrol, 1.4 – 2 l	1982 to 1988	1.2	0.3	0.9	0.6
Car, petrol, 1.4 – 2 l	1989 to 1995	10.9	2.4	9.2	5.9
Car, petrol, 1.4 – 2 l	From 1996	21.3	3.5	19.4	11.6
Car, petrol, > 2 l	1982 to 1988	0.2	0.0	0.2	0.1
Car, petrol, > 2 l	1989 to 1995	1.9	0.3	1.8	1.0
Car, petrol, > 2 l	From 1996	3.7	0.4	3.8	2.1
Car, petrol, > 2 l, high perf.	1982 to 1988	0.0	0.0	0.0	0.0
Car, petrol, > 2 l, high perf.	1989 to 1995	0.2	0.1	0.2	0.2
Car, petrol, > 2 l, high perf.	From 1996	0.4	0.1	0.5	0.3
Car, diesel, < 2 l	1982 to 1988	1.0	0.2	0.8	0.5
Car, diesel, < 2 l	1989 to 1995	5.6	1.1	4.7	3.0
Car, diesel, < 2 l	From 1996	11.5	1.8	10.5	6.3
Car, diesel, > 2 l	1982 to 1988	0.4	0.1	0.4	0.2
Car, diesel, > 2 l	1989 to 1995	2.4	0.5	2.2	1.4
Car, diesel, > 2 l	From 1996	4.9	0.7	5.0	2.9
Light duty vehicle, petrol	1982 to 1988	0.0	0.0	0.0	0.0
Light duty vehicle, petrol	1989 to 1995	0.3	0.1	0.2	0.2
Light duty vehicle, petrol	From 1996	0.3	0.1	0.3	0.2
Light duty vehicle, diesel	1982 to 1988	0.4	0.4	0.2	0.3
Light duty vehicle, diesel	1989 to 1995	2.0	1.6	1.3	1.5
Light duty vehicle, diesel	From 1996	2.6	1.6	1.9	1.8
Rigid truck, < 7.5 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t	1985 to 1989	0.1	0.7	0.1	0.4
Rigid truck, < 7.5 t	1990 to 1995	0.4	2.3	0.5	1.4
Rigid truck, < 7.5 t	From 1996	0.9	2.7	1.0	1.8
Rigid truck, < 7.5 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t, traction	1985 to 1989	0.1	0.7	0.1	0.4
Rigid truck, < 7.5 t, traction	1990 to 1995	0.4	2.3	0.8	1.5
Rigid truck, < 7.5 t, traction	From 1996	0.9	2.7	1.6	2.1

Table 8.6: Contributions of different vehicle layers to total noise emission for Urban 40 road type (continued)

Vehicle layer	Emission stage	Fleet share (%)	Contribution to L_{day}		
			Propulsion	Rolling	Overall
Rigid truck, 7.5 – 14 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t	1985 to 1989	0.0	0.3	0.0	0.1
Rigid truck, 7.5 – 14 t	1990 to 1995	0.1	0.8	0.2	0.5
Rigid truck, 7.5 – 14 t	From 1996	0.2	1.0	0.3	0.7
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	0.0	0.3	0.0	0.1
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	0.1	0.8	0.2	0.5
Rigid truck, 7.5 – 14 t, traction	From 1996	0.2	1.0	0.5	0.7
Rigid truck, 14 – 20 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t	1985 to 1989	0.0	0.3	0.0	0.1
Rigid truck, 14 – 20 t	1990 to 1995	0.1	0.8	0.1	0.4
Rigid truck, 14 – 20 t	From 1996	0.1	0.9	0.2	0.5
Rigid truck, 14 – 20 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t, traction	1985 to 1989	0.0	0.6	0.1	0.3
Rigid truck, 14 – 20 t, traction	1990 to 1995	0.1	1.8	0.3	1.1
Rigid truck, 14 – 20 t, traction	From 1996	0.3	2.0	0.7	1.3
Rigid truck, 20 – 28 t, traction	1982 to 1984	0.0	0.1	0.0	0.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	0.0	1.4	0.1	0.8
Rigid truck, 20 – 28 t, traction	1990 to 1995	0.2	4.3	0.8	2.5
Rigid truck, 20 – 28 t, traction	From 1996	0.5	4.5	1.5	3.0
Trailer truck, <= 32 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Trailer truck, <= 32 t, traction	1985 to 1989	0.0	0.4	0.1	0.2
Trailer truck, <= 32 t, traction	1990 to 1995	0.1	1.5	0.3	0.9
Trailer truck, <= 32 t, traction	From 1996	0.2	2.1	0.8	1.4
Trailer truck, > 32 t, traction	1982 to 1984	0.0	0.4	0.0	0.2
Trailer truck, > 32 t, traction	1985 to 1989	0.1	4.1	0.5	2.3
Trailer truck, > 32 t, traction	1990 to 1995	0.6	13.9	3.1	8.4
Trailer truck, > 32 t, traction	From 1996	1.7	19.9	7.7	13.6
Motorcycle, ≤ 150cm^3	Stage 0	0.8	4.0	0.0	2.0
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	0.2	1.7	0.0	0.8
Motorcycle, > 150 cm^3	Stage 0	0.7	1.3	0.0	0.7
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	0.2	1.2	0.0	0.6

Table 8.7: Contributions of different vehicle layers to total noise emission for Motorway 120 road type

Vehicle layer	Emission stage	Fleet share (%)	Contribution to L_{day}		
			Propulsion	Rolling	Overall
Car, petrol, < 1.4 l	1982 to 1988	0.4	0.2	0.2	0.2
Car, petrol, < 1.4 l	1989 to 1995	3.6	1.2	2.1	2.0
Car, petrol, < 1.4 l	From 1996	7.1	1.6	4.5	4.0
Car, petrol, 1.4 – 2 l	1982 to 1988	1.1	0.7	0.8	0.7
Car, petrol, 1.4 – 2 l	1989 to 1995	9.9	5.2	7.4	7.0
Car, petrol, 1.4 – 2 l	From 1996	19.3	6.9	15.6	14.1
Car, petrol, > 2 l	1982 to 1988	0.4	0.2	0.3	0.3
Car, petrol, > 2 l	1989 to 1995	3.4	1.6	2.9	2.6
Car, petrol, > 2 l	From 1996	6.7	2.1	6.0	5.3
Car, petrol, > 2 l, high perf.	1982 to 1988	0.0	0.0	0.0	0.0
Car, petrol, > 2 l, high perf.	1989 to 1995	0.2	0.1	0.2	0.2
Car, petrol, > 2 l, high perf.	From 1996	0.4	0.3	0.4	0.4
Car, diesel, < 2 l	1982 to 1988	0.8	0.5	0.5	0.5
Car, diesel, < 2 l	1989 to 1995	4.4	2.2	3.3	3.1
Car, diesel, < 2 l	From 1996	9.1	3.1	7.4	6.7
Car, diesel, > 2 l	1982 to 1988	0.5	0.3	0.4	0.3
Car, diesel, > 2 l	1989 to 1995	2.6	1.3	2.2	2.0
Car, diesel, > 2 l	From 1996	5.4	1.8	4.9	4.4
Light duty vehicle, petrol	1982 to 1988	0.0	0.0	0.0	0.0
Light duty vehicle, petrol	1989 to 1995	0.3	0.1	0.2	0.2
Light duty vehicle, petrol	From 1996	0.4	0.1	0.2	0.2
Light duty vehicle, diesel	1982 to 1988	0.4	0.3	0.2	0.2
Light duty vehicle, diesel	1989 to 1995	2.1	1.2	1.3	1.3
Light duty vehicle, diesel	From 1996	2.8	1.2	1.9	1.8
Rigid truck, < 7.5 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t	1985 to 1989	0.0	0.3	0.0	0.1
Rigid truck, < 7.5 t	1990 to 1995	0.3	1.0	0.2	0.3
Rigid truck, < 7.5 t	From 1996	0.6	0.9	0.3	0.4
Rigid truck, < 7.5 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, < 7.5 t, traction	1985 to 1989	0.0	0.3	0.1	0.1
Rigid truck, < 7.5 t, traction	1990 to 1995	0.3	1.0	0.3	0.4
Rigid truck, < 7.5 t, traction	From 1996	0.6	0.9	0.5	0.6

Table 8.7: Contributions of different vehicle layers to total noise emission for Motorway 120 road type (continued)

Vehicle layer	Emission stage	Fleet share (%)	Contribution to L_{day}		
			Propulsion	Rolling	Overall
Rigid truck, 7.5 – 14 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t	1985 to 1989	0.0	0.1	0.0	0.0
Rigid truck, 7.5 – 14 t	1990 to 1995	0.1	0.4	0.1	0.1
Rigid truck, 7.5 – 14 t	From 1996	0.2	0.4	0.1	0.2
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	0.0	0.1	0.0	0.0
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	0.1	0.4	0.1	0.2
Rigid truck, 7.5 – 14 t, traction	From 1996	0.2	0.4	0.2	0.2
Rigid truck, 14 – 20 t	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t	1985 to 1989	0.0	0.1	0.0	0.0
Rigid truck, 14 – 20 t	1990 to 1995	0.1	0.2	0.0	0.1
Rigid truck, 14 – 20 t	From 1996	0.1	0.2	0.1	0.1
Rigid truck, 14 – 20 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 14 – 20 t, traction	1985 to 1989	0.0	0.2	0.0	0.1
Rigid truck, 14 – 20 t, traction	1990 to 1995	0.1	0.5	0.2	0.2
Rigid truck, 14 – 20 t, traction	From 1996	0.2	0.5	0.3	0.4
Rigid truck, 20 – 28 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	0.1	0.4	0.1	0.1
Rigid truck, 20 – 28 t, traction	1990 to 1995	0.3	1.2	0.6	0.7
Rigid truck, 20 – 28 t, traction	From 1996	0.7	1.3	1.1	1.1
Trailer truck, <= 32 t, traction	1982 to 1984	0.0	0.0	0.0	0.0
Trailer truck, <= 32 t, traction	1985 to 1989	0.0	0.2	0.1	0.1
Trailer truck, <= 32 t, traction	1990 to 1995	0.1	0.7	0.3	0.4
Trailer truck, <= 32 t, traction	From 1996	0.4	1.1	0.8	0.8
Trailer truck, > 32 t, traction	1982 to 1984	0.0	0.5	0.1	0.1
Trailer truck, > 32 t, traction	1985 to 1989	0.6	5.2	1.5	2.2
Trailer truck, > 32 t, traction	1990 to 1995	3.5	17.6	8.6	10.1
Trailer truck, > 32 t, traction	From 1996	9.3	24.9	21.4	22.0
Motorcycle, > 150 cm^3	Stage 0	0.7	3.7	0.0	0.7
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	0.2	3.0	0.0	0.5

The contributions made by propulsion noise sources and tyre/road noise sources to the overall L_{Aeq} levels are shown for each vehicle layer in Table 8.8 to Table 8.10. In all cases, the tyre/road noise from the car layer is the dominant source. For HDVs at low speeds propulsion noise is the dominant source. However, at higher speeds tyre/road noise is also dominating for today's vehicles. It is observed that some of the rolling noise contributions for trucks in the emission stage 1982-1984 are negative. This occurs when the weighting values are combined with very low numbers of vehicles (i.e. when the fleet contribution is less than 0.01%), and as such, it can be assumed that there is zero contribution from these vehicles. This issue will be addressed in later versions of the model.

Table 8.8: Contributions of different vehicle layers to the L_{Aeq} for Residential 30 road type

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Car, petrol, < 1.4 l	1982 to 1988	20.9	25.7	26.7	4.9
Car, petrol, < 1.4 l	1989 to 1995	29.6	35.6	36.3	6.1
Car, petrol, < 1.4 l	From 1996	31.1	38.9	39.2	7.8
Car, petrol, 1.4 – 2 l	1982 to 1988	26.6	28.7	30.5	2.1
Car, petrol, 1.4 – 2 l	1989 to 1995	35.3	38.6	40.0	3.3
Car, petrol, 1.4 – 2 l	From 1996	36.9	41.9	42.7	5.0
Car, petrol, > 2 l	1982 to 1988	16.8	21.6	22.5	4.7
Car, petrol, > 2 l	1989 to 1995	25.6	31.5	32.2	5.9
Car, petrol, > 2 l	From 1996	27.2	34.7	35.1	7.5
Car, petrol, > 2 l, high perf.	1982 to 1988	10.1	12.9	14.5	2.8
Car, petrol, > 2 l, high perf.	1989 to 1995	18.9	22.8	24.0	4.0
Car, petrol, > 2 l, high perf.	From 1996	20.6	26.1	26.9	5.4
Car, diesel, < 2 l	1982 to 1988	25.0	27.8	29.3	2.8
Car, diesel, < 2 l	1989 to 1995	31.7	35.7	36.8	4.0
Car, diesel, < 2 l	From 1996	33.5	39.2	39.9	5.7
Car, diesel, > 2 l	1982 to 1988	21.2	24.6	26.0	3.3
Car, diesel, > 2 l	1989 to 1995	28.0	32.5	33.5	4.5
Car, diesel, > 2 l	From 1996	29.8	36.0	36.6	6.2
Light duty vehicle, petrol	1982 to 1988	12.0	8.5	13.4	-3.5
Light duty vehicle, petrol	1989 to 1995	20.9	18.9	22.9	-2.1
Light duty vehicle, petrol	From 1996	20.8	20.2	23.3	-0.7
Light duty vehicle, diesel	1982 to 1988	25.3	19.6	26.3	-5.8
Light duty vehicle, diesel	1989 to 1995	31.7	27.4	33.0	-4.3
Light duty vehicle, diesel	From 1996	31.7	29.0	33.4	-2.7
Rigid truck, < 7.5 t	1982 to 1984	7.7	-6.3	7.9	-14.0
Rigid truck, < 7.5 t	1985 to 1989	22.4	10.6	22.7	-11.9
Rigid truck, < 7.5 t	1990 to 1995	27.6	17.9	28.0	-9.7
Rigid truck, < 7.5 t	From 1996	28.4	20.8	29.0	-7.6
Rigid truck, < 7.5 t, traction	1982 to 1984	7.7	-4.7	7.9	-12.4
Rigid truck, < 7.5 t, traction	1985 to 1989	22.4	12.1	22.8	-10.3
Rigid truck, < 7.5 t, traction	1990 to 1995	27.6	19.5	28.2	-8.2
Rigid truck, < 7.5 t, traction	From 1996	28.4	22.3	29.3	-6.1

Table 8.8: Contributions of different vehicle layers to the L_{Aeq} for Residential 30 road type (continued…)

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Rigid truck, 7.5 – 14 t	1982 to 1984	3.6	-11.6	3.7	-15.1
Rigid truck, 7.5 – 14 t	1985 to 1989	18.4	5.3	18.5	-13.1
Rigid truck, 7.5 – 14 t	1990 to 1995	23.6	12.6	23.9	-11.0
Rigid truck, 7.5 – 14 t	From 1996	24.5	15.5	25.0	-9.0
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	3.6	-10.0	3.7	-13.6
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	18.4	6.8	18.6	-11.5
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	23.6	14.2	24.0	-9.4
Rigid truck, 7.5 – 14 t, traction	From 1996	24.5	17.0	25.2	-7.5
Rigid truck, 14 – 20 t	1982 to 1984	3.6	-13.6	3.7	-17.2
Rigid truck, 14 – 20 t	1985 to 1989	18.1	3.3	18.3	-14.9
Rigid truck, 14 – 20 t	1990 to 1995	23.1	10.6	23.3	-12.5
Rigid truck, 14 – 20 t	From 1996	23.7	13.5	24.0	-10.2
Rigid truck, 14 – 20 t, traction	1982 to 1984	7.3	-8.3	7.4	-15.6
Rigid truck, 14 – 20 t, traction	1985 to 1989	21.8	8.5	22.0	-13.3
Rigid truck, 14 – 20 t, traction	1990 to 1995	26.8	15.8	27.1	-11.0
Rigid truck, 14 – 20 t, traction	From 1996	27.3	18.7	27.9	-8.6
Rigid truck, 20 – 28 t, traction	1982 to 1984	12.1	-5.0	12.2	-17.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	26.5	11.9	26.6	-14.6
Rigid truck, 20 – 28 t, traction	1990 to 1995	31.4	19.2	31.6	-12.1
Rigid truck, 20 – 28 t, traction	From 1996	31.5	22.1	31.9	-9.4
Trailer truck, <= 32 t, traction	1982 to 1984	10.3	-5.2	10.4	-15.5
Trailer truck, <= 32 t, traction	1985 to 1989	20.8	7.6	21.0	-13.2
Trailer truck, <= 32 t, traction	1990 to 1995	26.0	15.2	26.3	-10.8
Trailer truck, <= 32 t, traction	From 1996	27.6	19.2	28.2	-8.5
Trailer truck, > 32 t, traction	1982 to 1984	20.1	4.8	20.2	-15.2
Trailer truck, > 32 t, traction	1985 to 1989	30.7	17.7	30.9	-13.0
Trailer truck, > 32 t, traction	1990 to 1995	36.0	25.3	36.3	-10.7
Trailer truck, > 32 t, traction	From 1996	37.6	29.3	38.1	-8.3
Motorcycle, ≤ 150cm^3	Stage 0	36.2	12.0	36.3	-24.3
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	32.6	6.0	32.6	-26.7
Motorcycle, > 150 cm^3	Stage 0	30.9	14.4	31.0	-16.5
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	30.6	8.4	30.6	-22.2

Table 8.9: Contributions of different vehicle layers to the L_{Aeq} for Urban 50 road type

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Car, petrol, < 1.4 l	1982 to 1988	33.5	41.3	41.4	7.8
Car, petrol, < 1.4 l	1989 to 1995	42.2	51.2	51.1	9.0
Car, petrol, < 1.4 l	From 1996	43.7	54.5	54.1	10.8
Car, petrol, 1.4 – 2 l	1982 to 1988	38.8	44.3	44.8	5.4
Car, petrol, 1.4 – 2 l	1989 to 1995	47.5	54.2	54.5	6.7
Car, petrol, 1.4 – 2 l	From 1996	49.1	57.4	57.4	8.4
Car, petrol, > 2 l	1982 to 1988	29.3	37.2	37.2	7.9
Car, petrol, > 2 l	1989 to 1995	38.1	47.1	47.0	9.0
Car, petrol, > 2 l	From 1996	39.6	50.3	50.0	10.7
Car, petrol, > 2 l, high perf.	1982 to 1988	23.0	28.5	29.1	5.5
Car, petrol, > 2 l, high perf.	1989 to 1995	31.8	38.4	38.7	6.6
Car, petrol, > 2 l, high perf.	From 1996	33.6	41.7	41.7	8.1
Car, diesel, < 2 l	1982 to 1988	37.5	43.4	43.8	5.8
Car, diesel, < 2 l	1989 to 1995	44.3	51.3	51.5	7.0
Car, diesel, < 2 l	From 1996	46.1	54.8	54.7	8.7
Car, diesel, > 2 l	1982 to 1988	33.8	40.2	40.5	6.3
Car, diesel, > 2 l	1989 to 1995	40.6	48.1	48.2	7.5
Car, diesel, > 2 l	From 1996	42.4	51.5	51.4	9.2
Light duty vehicle, petrol	1982 to 1988	25.9	26.9	29.1	1.0
Light duty vehicle, petrol	1989 to 1995	34.9	37.3	38.9	2.4
Light duty vehicle, petrol	From 1996	34.8	38.6	39.6	3.8
Light duty vehicle, diesel	1982 to 1988	39.3	38.0	41.4	-1.3
Light duty vehicle, diesel	1989 to 1995	45.7	45.8	48.4	0.1
Light duty vehicle, diesel	From 1996	45.7	47.4	49.2	1.7
Rigid truck, < 7.5 t	1982 to 1984	27.5	17.7	27.9	-9.8
Rigid truck, < 7.5 t	1985 to 1989	42.2	34.6	42.8	-7.6
Rigid truck, < 7.5 t	1990 to 1995	47.3	41.9	48.3	-5.4
Rigid truck, < 7.5 t	From 1996	48.0	44.8	49.4	-3.2
Rigid truck, < 7.5 t, traction	1982 to 1984	27.5	19.4	28.1	-8.1
Rigid truck, < 7.5 t, traction	1985 to 1989	42.2	36.3	43.0	-5.9
Rigid truck, < 7.5 t, traction	1990 to 1995	47.3	43.6	48.6	-3.7
Rigid truck, < 7.5 t, traction	From 1996	48.0	46.5	50.0	-1.5

Table 8.9: Contributions of different vehicle layers to the L_{Aeq} for Urban 50 road type (continued…)

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Rigid truck, 7.5 – 14 t	1982 to 1984	23.1	12.5	23.4	-10.6
Rigid truck, 7.5 – 14 t	1985 to 1989	37.8	29.3	38.3	-8.5
Rigid truck, 7.5 – 14 t	1990 to 1995	43.0	36.7	43.7	-6.3
Rigid truck, 7.5 – 14 t	From 1996	43.8	39.5	45.0	-4.3
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	23.1	14.2	23.5	-8.9
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	37.8	31.0	38.5	-6.8
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	43.0	38.4	44.1	-4.6
Rigid truck, 7.5 – 14 t, traction	From 1996	43.8	41.2	45.5	-2.6
Rigid truck, 14 – 20 t	1982 to 1984	23.2	10.4	23.4	-12.8
Rigid truck, 14 – 20 t	1985 to 1989	37.7	27.2	38.0	-10.5
Rigid truck, 14 – 20 t	1990 to 1995	42.7	34.6	43.2	-8.1
Rigid truck, 14 – 20 t	From 1996	43.1	37.4	44.0	-5.7
Rigid truck, 14 – 20 t, traction	1982 to 1984	26.8	15.7	27.1	-11.1
Rigid truck, 14 – 20 t, traction	1985 to 1989	41.4	32.6	41.8	-8.8
Rigid truck, 14 – 20 t, traction	1990 to 1995	46.3	39.9	47.1	-6.4
Rigid truck, 14 – 20 t, traction	From 1996	46.8	42.8	48.0	-4.0
Rigid truck, 20 – 28 t, traction	1982 to 1984	30.7	19.3	31.0	-11.4
Rigid truck, 20 – 28 t, traction	1985 to 1989	45.1	36.1	45.6	-9.0
Rigid truck, 20 – 28 t, traction	1990 to 1995	50.0	43.5	50.8	-6.5
Rigid truck, 20 – 28 t, traction	From 1996	50.2	46.3	51.5	-3.8
Trailer truck, <= 32 t, traction	1982 to 1984	29.6	18.9	29.9	-10.7
Trailer truck, <= 32 t, traction	1985 to 1989	40.1	31.7	40.6	-8.4
Trailer truck, <= 32 t, traction	1990 to 1995	45.3	39.4	46.2	-6.0
Trailer truck, <= 32 t, traction	From 1996	46.9	43.3	48.3	-3.6
Trailer truck, > 32 t, traction	1982 to 1984	39.2	29.0	39.6	-10.2
Trailer truck, > 32 t, traction	1985 to 1989	49.8	41.8	50.4	-8.0
Trailer truck, > 32 t, traction	1990 to 1995	55.1	49.4	56.0	-5.7
Trailer truck, > 32 t, traction	From 1996	56.7	53.4	58.1	-3.3
Motorcycle, ≤ 150cm^3	Stage 0	49.7	28.0	49.7	-21.7
Motorcycle, ≤ 150 cm^3, illegal silencers	Stage 0	45.9	22.0	45.9	-23.9
Motorcycle, > 150 cm^3	Stage 0	44.9	30.2	45.0	-14.6
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	44.4	24.2	44.4	-20.2

Table 8.10: Contributions of different vehicle layers to the L_{Aeq} for Motorway 120 road type

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Car, petrol, < 1.4 l	1982 to 1988	38.9	46.9	47.5	8.0
Car, petrol, < 1.4 l	1989 to 1995	47.5	56.8	57.3	9.3
Car, petrol, < 1.4 l	From 1996	48.8	60.0	60.3	11.3
Car, petrol, 1.4 – 2 l	1982 to 1988	45.3	52.3	53.1	7.0
Car, petrol, 1.4 – 2 l	1989 to 1995	53.9	62.2	62.8	8.3
Car, petrol, 1.4 – 2 l	From 1996	55.2	65.4	65.8	10.3
Car, petrol, > 2 l	1982 to 1988	40.0	48.2	48.8	8.2
Car, petrol, > 2 l	1989 to 1995	48.7	58.1	58.5	9.3
Car, petrol, > 2 l	From 1996	49.9	61.3	61.6	11.4
Car, petrol, > 2 l, high perf.	1982 to 1988	29.4	36.5	37.3	7.1
Car, petrol, > 2 l, high perf.	1989 to 1995	38.5	46.4	47.0	7.8
Car, petrol, > 2 l, high perf.	From 1996	40.9	49.6	50.2	8.7
Car, diesel, < 2 l	1982 to 1988	43.6	50.8	51.5	7.2
Car, diesel, < 2 l	1989 to 1995	50.3	58.7	59.3	8.4
Car, diesel, < 2 l	From 1996	51.7	62.2	62.6	10.5
Car, diesel, > 2 l	1982 to 1988	41.3	49.0	49.7	7.7
Car, diesel, > 2 l	1989 to 1995	48.0	56.9	57.4	8.9
Car, diesel, > 2 l	From 1996	49.4	60.4	60.7	11.0
Light duty vehicle, petrol	1982 to 1988	28.2	35.8	36.5	7.5
Light duty vehicle, petrol	1989 to 1995	37.0	46.2	46.7	9.1
Light duty vehicle, petrol	From 1996	36.7	47.4	47.8	10.7
Light duty vehicle, diesel	1982 to 1988	41.4	46.9	47.9	5.4
Light duty vehicle, diesel	1989 to 1995	47.7	54.7	55.5	7.0
Light duty vehicle, diesel	From 1996	47.7	56.3	56.8	8.6
Rigid truck, < 7.5 t	1982 to 1984	27.6	21.8	28.6	-5.8
Rigid truck, < 7.5 t	1985 to 1989	41.9	38.7	43.6	-3.3
Rigid truck, < 7.5 t	1990 to 1995	46.6	46.0	49.3	-0.7
Rigid truck, < 7.5 t	From 1996	46.4	48.9	50.7	2.5
Rigid truck, < 7.5 t, traction	1982 to 1984	27.6	23.7	29.1	-3.8
Rigid truck, < 7.5 t, traction	1985 to 1989	41.9	40.6	44.3	-1.3
Rigid truck, < 7.5 t, traction	1990 to 1995	46.6	47.9	50.3	1.3
Rigid truck, < 7.5 t, traction	From 1996	46.4	50.8	52.1	4.4

Table 8.10: Contributions of different vehicle layers to the L_{Aeq} for Motorway 120 road type (continued…)

Vehicle layer	Emission stage	L_{prop_Aeq} dB	L_{roll_Aeq} dB	L_{tot_Aeq} dB	L_{roll_Aeq} - L_{prop_Aeq} dB
Rigid truck, 7.5 – 14 t	1982 to 1984	23.6	17.3	24.5	-6.2
Rigid truck, 7.5 – 14 t	1985 to 1989	38.0	34.2	39.5	-3.9
Rigid truck, 7.5 – 14 t	1990 to 1995	42.9	41.5	45.2	-1.4
Rigid truck, 7.5 – 14 t	From 1996	43.0	44.4	46.7	1.4
Rigid truck, 7.5 – 14 t, traction	1982 to 1984	23.6	19.3	24.9	-4.3
Rigid truck, 7.5 – 14 t, traction	1985 to 1989	38.0	36.1	40.2	-1.9
Rigid truck, 7.5 – 14 t, traction	1990 to 1995	42.9	43.4	46.2	0.6
Rigid truck, 7.5 – 14 t, traction	From 1996	43.0	46.3	48.0	3.3
Rigid truck, 14 – 20 t	1982 to 1984	20.8	15.8	22.0	-5.0
Rigid truck, 14 – 20 t	1985 to 1989	35.3	32.7	37.2	-2.6
Rigid truck, 14 – 20 t	1990 to 1995	40.2	40.0	43.1	-0.2
Rigid truck, 14 – 20 t	From 1996	40.4	42.9	44.9	2.4
Rigid truck, 14 – 20 t, traction	1982 to 1984	24.5	21.5	26.2	-3.0
Rigid truck, 14 – 20 t, traction	1985 to 1989	39.0	38.3	41.7	-0.7
Rigid truck, 14 – 20 t, traction	1990 to 1995	43.9	45.6	47.8	1.7
Rigid truck, 14 – 20 t, traction	From 1996	44.1	48.5	49.8	4.4
Rigid truck, 20 – 28 t, traction	1982 to 1984	27.8	26.8	30.3	-1.0
Rigid truck, 20 – 28 t, traction	1985 to 1989	42.4	43.7	46.1	1.3
Rigid truck, 20 – 28 t, traction	1990 to 1995	47.5	51.0	52.6	3.6
Rigid truck, 20 – 28 t, traction	From 1996	47.9	53.9	54.8	6.0
Trailer truck, <= 32 t, traction	1982 to 1984	29.8	27.8	31.9	-1.9
Trailer truck, <= 32 t, traction	1985 to 1989	40.3	40.7	43.5	0.4
Trailer truck, <= 32 t, traction	1990 to 1995	45.5	48.3	50.1	2.8
Trailer truck, <= 32 t, traction	From 1996	47.0	52.3	53.3	5.3
Trailer truck, > 32 t, traction	1982 to 1984	43.4	42.4	46.0	-1.0
Trailer truck, > 32 t, traction	1985 to 1989	53.9	55.2	57.7	1.3
Trailer truck, > 32 t, traction	1990 to 1995	59.2	62.8	64.4	3.6
Trailer truck, > 32 t, traction	From 1996	60.7	66.8	67.8	6.1
Motorcycle, > 150 cm^3	Stage 0	52.5	38.7	52.7	-13.8
Motorcycle, > 150 cm^3, illegal silencers	Stage 0	51.6	32.7	51.6	-18.9

8.2.2 *Category 1 scenarios: The effects of changes in fleet composition – current generation vehicles*

In order to demonstrate the effects on traffic noise levels of changes in fleet composition the following cases were defined and calculated:

- Fleet composition representative for former Eastern Bloc/accession countries. In order to consider the significant differences in vehicle age for this region compared to the baseline scenario the calculations were repeated for the reference year 1993. This case is called "Eastern".
- Fleet composition representative for regions with high motorcycle and scooter traffic volumes. Compared to the baseline scenario the motorcycle and scooter percentages were increased in urban areas to total up to 20% of the overall traffic volume (i.e. 5% motorcycles and 15% scooters). This case is called "Motorcycles".
- The fleet composition was modified so that it consists only of state-of-the-art vehicles (i.e. post 1996 vehicles). This case is called "Modern".

As mentioned above, the road surface for this and all other case study calculations was stone mastic asphalt (0/11).

The results of these calculations are summarised in Table 8.11. Compared to the baseline scenario the differences in noise levels for the different fleet composition changes are relatively small. The noise levels for the "Eastern" case are slightly higher whereas the noise levels for the "Motorcycle" case are slightly lower than the corresponding values given in the baseline case. Overall the differences are generally less than 1 dB(A). Also the "Modern" case shows no significant difference to the baseline case. This is because the major part of the fleet included in the baseline scenario already consists of state-of-the-art vehicles.

8.2.3 *Category 2 scenarios: The effects of changes in fleet composition – the use of quieter vehicles*

In order to demonstrate the effects of introducing quieter vehicles the following cases were defined and calculated:

- All cars and LDV in the baseline scenario were replaced by prop stage 2 vehicles (case 2.1),
- All HDV were replaced by prop stage 2 vehicles (case 2.2),
- All cars and LDV were replaced by roll stage 2 vehicles (case 2.3),
- All cars and LDV were replaced by roll stage 2 vehicles and all HDV by prop stage 2 vehicles (case 2.4),
- All cars and LDV were replaced by roll stage 2 vehicles and all HDV by prop stage 2, roll stage 2 vehicles (case 2.5),
- All cars and LDV were replaced by roll stage 3 vehicles, all HDV by prop stage 2, roll stage 3 vehicles (case 2.6),
- Same as case 2.6 but for fleet composition with 20% two wheeled vehicles (case 2.7).

The results of the calculations for these scenarios are shown in Table 8.12. The results clearly show the benefits in terms of noise level reductions that could be achieved through the introduction of quieter vehicle. Overall benefits from the baseline situation range between 3- 4 dB(A) approximately with the greatest overall benefits appearing for the motorway 120 road category. The introduction of a greater proportion of motorcycles does however, offset these gains, with the effects being most noticeable in the residential streets. As might be expected, increases in the numbers of motorcycles on motorways produces little additional noise.

Table 8.11: Results for the category 1 scenarios

No.	Road category	Rating Time	L_{Aeq} dB			
			Baseline	**Eastern**	**M/cycles**	**Modern**
1	Residential 30	07:00 – 19:00	49.7	50.7	52.3	49.5
		19:00 – 23:00	48.1	48.6	50.8	48.0
		23:00 – 07:00	42.9	43.5	45.6	42.7
		L_{den}, 24h weighted	51.6	52.4	54.3	51.5
2	Residential 50	07:00 – 19:00	51.3	51.8	53.3	51.2
		19:00 – 23:00	50.0	50.1	51.9	49.9
		23:00 – 07:00	44.6	44.9	46.7	44.6
		L_{den}, 24h weighted	53.4	53.6	55.4	53.3
3	Urban main 50	07:00 – 19:00	66.0	67.7	67.6	65.7
		19:00 – 23:00	64.1	64.8	65.8	64.0
		23:00 – 07:00	59.4	60.3	60.9	59.3
		L_{den}, 24h weighted	68.0	69.1	69.5	67.8
4	Urban main 70	07:00 – 19:00	67.7	68.7	69.1	67.5
		19:00 – 23:00	65.9	66.2	67.9	65.9
		23:00 – 07:00	62.9	63.1	64.8	62.9
		L_{den}, 24h weighted	70.6	71.0	72.4	70.6
5	Rural 70	07:00 – 19:00	64.3	65.3	65.0	64.2
		19:00 – 23:00	62.4	62.7	63.1	62.4
		23:00 – 07:00	57.2	57.8	57.9	57.2
		L_{den}, 24h weighted	66.1	66.7	66.7	66.0
6	Rural 100	07:00 – 19:00	66.6	67.0	67.3	66.5
		19:00 – 23:00	64.9	64.9	65.7	64.9
		23:00 – 07:00	59.6	59.8	60.4	59.6
		L_{den}, 24h weighted	68.4	68.6	69.2	68.4
7	Motorway 120	07:00 – 19:00	73.9	74.5	74.0	73.8
		19:00 – 23:00	72.3	72.6	72.4	72.2
		23:00 – 07:00	66.8	67.5	66.9	66.6
		L_{den}, 24h weighted	75.7	76.3	75.8	75.6

Table 8.12: Results for the category 2 scenarios

No.	Road category	Rating Time	L_{Aeq} dB								
			Base line	Case 2.1	Case 2.2	Case 2.3	Case 2.4	Case 2.5	Case 2.6	M/ cycles	Case 2.7
1	Residential 30	07:00 – 19:00	49.7	49.3	49.2	48.3	47.5	47.4	46.8	52.3	51.2
		19:00 – 23:00	48.1	47.7	47.9	46.4	46.1	46.1	45.4	50.8	49.8
		23:00 – 07:00	42.9	42.5	42.6	41.3	40.8	40.8	40.1	45.6	44.6
		L_{den}, 24h weighted	51.6	51.2	51.3	50.1	49.5	49.5	48.8	54.3	53.3
2	Residential 50	07:00 – 19:00	51.3	51.1	51.0	49.5	49.0	48.9	48.0	53.3	51.8
		19:00 – 23:00	50.0	49.8	49.8	47.9	47.7	47.6	46.7	51.9	50.5
		23:00 – 07:00	44.6	44.4	44.4	42.6	42.3	42.3	41.4	46.7	45.3
		L_{den}, 24h weighted	53.4	53.2	53.2	51.4	51.1	51.0	50.1	55.4	54.0
3	Urban main 50	07:00 – 19:00	66.0	65.9	64.9	64.8	63.3	63.0	62.2	67.6	65.5
		19:00 – 23:00	64.1	64.0	63.7	62.3	61.7	61.5	60.6	65.8	64.0
		23:00 – 07:00	59.4	59.3	58.9	57.8	57.0	56.7	55.8	60.9	59.1
		L_{den}, 24h weighted	68.0	67.9	67.3	66.5	65.5	65.2	64.3	69.5	67.6
4	Urban main 70	07:00 – 19:00	67.7	67.6	67.1	66.1	65.3	64.8	63.8	69.1	67.1
		19:00 – 23:00	65.9	65.9	65.7	63.9	63.5	63.3	62.3	67.9	66.1
		23:00 – 07:00	62.9	62.9	62.8	60.9	60.6	60.4	59.3	64.8	63.2
		L_{den}, 24h weighted	70.6	70.6	70.3	68.7	68.3	68.0	66.9	72.4	70.7
5	Rural 70	07:00 – 19:00	64.3	64.3	63.8	62.8	62.0	61.5	60.5	65.0	62.1
		19:00 – 23:00	62.4	62.3	62.2	60.4	60.0	59.8	58.7	63.1	60.4
		23:00 – 07:00	57.2	57.2	56.9	55.4	54.9	54.6	53.5	57.9	55.3
		L_{den}, 24h weighted	66.1	66.0	65.7	64.3	63.7	63.4	62.3	66.7	64.0
6	Rural 100	07:00 – 19:00	66.6	66.5	66.3	64.8	64.4	63.9	62.8	67.3	64.6
		19:00 – 23:00	64.9	64.8	64.8	62.7	62.5	62.3	61.2	65.7	63.1
		23:00 – 07:00	59.6	59.6	59.4	57.6	57.3	57.0	56.0	60.4	58.0
		L_{den}, 24h weighted	68.4	68.4	68.2	66.4	66.1	65.8	64.7	69.2	66.6
7	Motorway 120	07:00 – 19:00	73.9	73.8	73.6	72.4	71.9	71.0	69.8	74.0	70.3
		19:00 – 23:00	72.3	72.2	72.1	70.4	70.1	69.5	68.4	72.4	68.9
		23:00 – 07:00	66.8	66.7	66.4	65.4	64.9	63.8	62.6	66.9	63.1
		L_{den}, 24h weighted	75.7	75.6	75.4	74.2	73.7	72.8	71.6	75.8	72.1

8.2.4 Category 3 scenarios: The effects of the evolution of quieter vehicles and quieter tyres

The overall effects of introducing quieter vehicles in the fleet is shown as part of scenario 2. However, in practice the introduction of quieter vehicles will require a significant period of time to take full effect. This will be dependent on the rate of replacement of older generation vehicles in the fleet as well as the starting date when the new generation vehicle are first produced.

To calculate how the reductions in noise could develop over time the following scenarios were defined:

It is assumed that vehicles of roll stage 1 and prop stage 1 will be introduced from 2006 on, vehicles of roll stage 2 and prop stage 2 from 2010 on and vehicles of roll stage 3 and prop stage 2 from 2015 on. For motorcycles and scooters the introduction of stage 1 vehicles is assumed from 2006 and stage 2 vehicles from 2011. In this example calculation, the lifecycle of a vehicle is assumed to be 20 years. In a second scenario no further reduction at sources was assumed.

The results of these calculations are shown in figures 8.8 and 8.9 for different road categories. It can be seen that gradual improvements occur over the time span considered reflecting the replacement with quieter vehicles in the vehicle fleet. Overall the maximum reductions in traffic noise predicted using the model amount to approximately 4 dB(A) from current conditions. It should be noted, however, that no adjustment for increases in traffic flows over the assessment period have been made. Clearly any growth in traffic volume could affect the final noise levels.

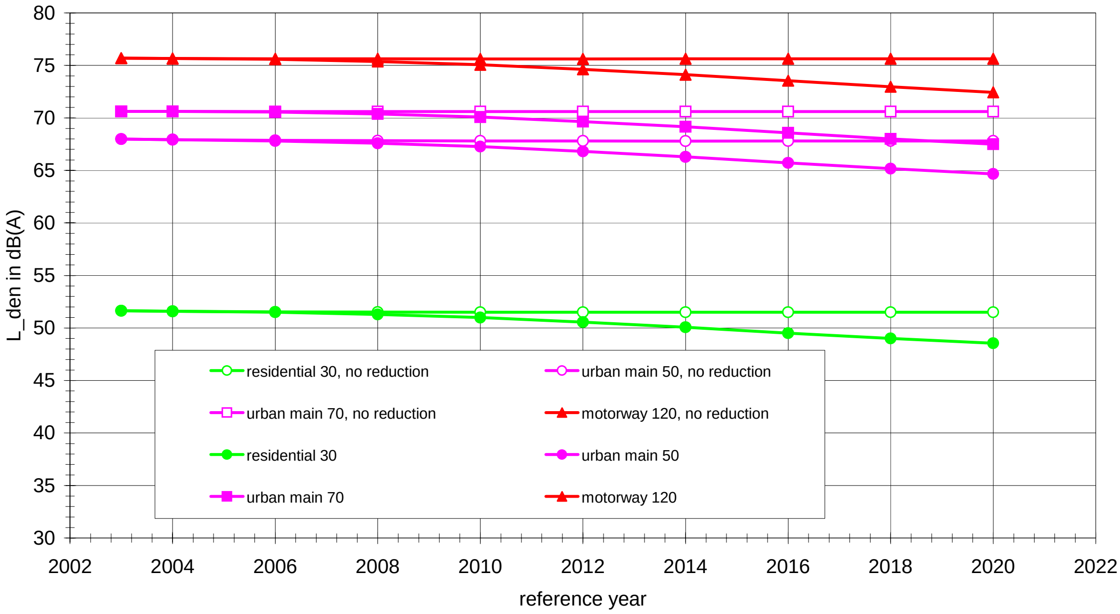

Figure 8.8: Comparison of L_{den} versus reference year with and without further reduction at source

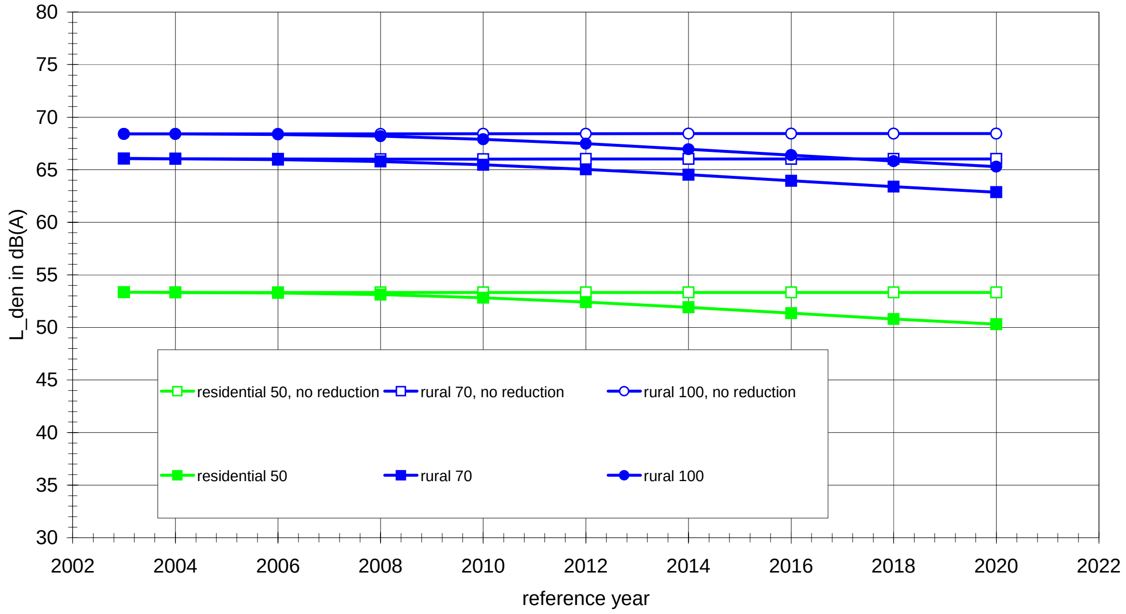

Figure 8.9: Comparison of L_{den} versus reference year with and without further reduction at source

8.2.5 Category 4 scenarios: The effects of introducing quieter surfaces

In order to demonstrate the effects of the use of quieter road surfaces some of the cases defined previously were recalculated for new drainage asphalt twin layer instead of stone mastic asphalt. The following cases have been calculated:

- Baseline scenario, but twin layer (case 4.1)
- All HDV were replaced by prop stage 2 vehicles (case 4.2),
- All cars and LDV were replaced by roll stage 2 vehicles and all HDV by prop stage 2 vehicles (case 4.3),
- All cars and LDV were replaced by roll stage 3 vehicles, all HDV by prop stage 2, roll stage 3 vehicles (case 4.4)

The results are shown in Table 8.13. In this set of scenarios, the overall reductions in traffic noise indicate substantial benefits of up to 7 dB(A) approximately if all projected vehicle emission reductions are employed. In this case the greatest benefits occur for the motorway and rural 100 road categories with the smallest benefits (4-6 dB(A)) occurring in the residential streets.

Table 8.13: Results for the category 4 scenarios

No.	Road category	Rating Time	L_{Aeq} dB				
			Base line	Case 4.1	Case 4.2	Case 4.3	Case 4.4
1	Residential 30	07:00 – 19:00	49.7	47.5	46.6	45.6	45.3
		19:00 – 23:00	48.1	45.5	45.2	44.1	43.8
		23:00 – 07:00	42.9	40.5	39.9	38.9	38.6
		L_{den}, 24h weighted	51.6	49.3	48.6	47.6	47.3
2	Residential 50	07:00 – 19:00	51.3	48.1	47.4	46.2	45.7
		19:00 – 23:00	50.0	46.3	46.1	44.7	44.2
		23:00 – 07:00	44.6	41.2	40.7	39.5	39.0
		L_{den}, 24h weighted	53.4	49.9	49.5	48.2	47.7
3	Urban main 50	07:00 – 19:00	66.0	63.8	61.7	60.9	60.2
		19:00 – 23:00	64.1	60.8	59.9	58.7	58.1
		23:00 – 07:00	59.4	56.2	55.1	53.9	53.3
		L_{den}, 24h weighted	68.0	65.1	63.7	62.6	62.0
4	Urban main 70	07:00 – 19:00	67.7	64.3	62.9	61.8	60.9
		19:00 – 23:00	65.9	61.8	61.2	59.8	59.0
		23:00 – 07:00	62.9	58.5	58.0	56.7	55.9
		L_{den}, 24h weighted	70.6	66.6	65.8	64.5	63.7
5	Rural 70	07:00 – 19:00	64.3	60.8	59.6	58.5	57.6
		19:00 – 23:00	62.4	58.2	57.6	56.3	55.5
		23:00 – 07:00	57.2	53.3	52.5	51.3	50.5
		L_{den}, 24h weighted	66.1	62.2	61.3	60.1	59.3
6	Rural 100	07:00 – 19:00	66.6	62.3	61.6	60.4	59.5
		19:00 – 23:00	64.9	60.2	59.9	58.4	57.7
		23:00 – 07:00	59.6	55.1	54.7	53.3	52.5
		L_{den}, 24h weighted	68.4	64.0	63.4	62.1	61.3
7	Motorway 120	07:00 – 19:00	73.9	69.4	68.6	67.5	65.9
		19:00 – 23:00	72.3	67.4	66.9	65.5	64.4
		23:00 – 07:00	66.8	62.5	61.4	60.5	58.8
		L_{den}, 24h weighted	75.7	71.2	70.3	69.3	67.7

8.2.6 Category 5 scenarios: The effects of traffic management measures

Traffic management measures are often introduced in towns and cities primarily to ease congestion and to reduce the risk of accidents. However, some of these measures can also be used to affect noise levels. For example, speed reduction and traffic calming measures are primarily used to reduce accidents but they also can provide reductions in traffic noise. To some extent the effects of reducing speed on traffic noise levels can already be seen by comparing residential 50 and residential 30 or rural 100 and rural 70. However, in addition to these cases, the following traffic management measures have been examined using the model:

- Concentration of HGV’s onto less sensitive routes. To simulate this case the following modifications were made for urban 50 and urban 70: the HDV were set to zero in one case (case 5.1.1) and doubled in the other case (case 5.1.2), the number of vehicles for all other categories were kept constant,
- No HDV traffic during night-time periods (case 5.2),
- Motorway with speed limit of 100 km/h (case 5.3.1) and 80 km/h (case 5.3.2) instead of 120 km/h.

For all cases the road surface assumed in the model was stone mastic asphalt 0/11.

The results of the calculations are shown in Table 8.14. For these cases, it can be seen that the effects of a night ban on HDV's had little effect on the noise levels for all roads apart from the urban main 50 category where the reductions in noise predicted for L_{den} was 1.6 dB(A). Moving HDV traffic from urban main 50 and urban main 70 routes produced significant reductions in noise levels. The corresponding increases in noise caused by doubling HDV's on the same routes was marginally smaller.

Table 8.14: Results for the category 5 scenarios

No.	Road category	Rating Time	L_{Aeq} dB					
			Base line	**Case 5.1.1**	**Case 5.1.2**	**Case 5.2**	**Case 5.3.1**	**Case 5.3.2**
1	Residential 30	07:00 – 19:00	49.7	---	---	49.8	---	---
		19:00 – 23:00	48.1	---	---	48.1	---	---
		23:00 – 07:00	42.9	---	---	42.4	---	---
		L_{den}, 24h weighted	51.6	---	---	51.4	---	---
2	Residential 50	07:00 – 19:00	51.3	---	---	51.4	---	---
		19:00 – 23:00	50.0	---	---	50.0	---	---
		23:00 – 07:00	44.6	---	---	44.3	---	---
		L_{den}, 24h weighted	53.4	---	---	53.2	---	---
3	Urban main 50	07:00 – 19:00	66.0	64.0	67.5	66.1	---	---
		19:00 – 23:00	64.1	63.3	64.5	64.2	---	---
		23:00 – 07:00	59.4	58.4	60.2	58.4	---	---
		L_{den}, 24h weighted	68.0	66.7	68.9	67.6	---	---
4	Urban main 70	07:00 – 19:00	67.7	66.2	68.6	67.8	---	---
		19:00 – 23:00	65.9	65.4	66.4	66.0	---	---
		23:00 – 07:00	62.9	62.5	63.5	62.4	---	---
		L_{den}, 24h weighted	70.6	69.9	71.3	70.4	---	---
5	Rural 70	07:00 – 19:00	64.3	---	---	64.4	---	---
		19:00 – 23:00	62.4	---	---	62.4	---	---
		23:00 – 07:00	57.2	---	---	56.4	---	---
		L_{den}, 24h weighted	66.1	---	---	65.7	---	---
6	Rural 100	07:00 – 19:00	66.6	---	---	66.6	---	---
		19:00 – 23:00	64.9	---	---	64.9	---	---
		23:00 – 07:00	59.6	---	---	59.0	---	---
		L_{den}, 24h weighted	68.4	---	---	68.2	---	---
7	Motorway 120	07:00 – 19:00	73.9	---	---	74.1	73.4	72.4
		19:00 – 23:00	72.3	---	---	72.4	71.6	70.5
		23:00 – 07:00	66.8	---	---	64.6	66.3	65.4
		L_{den}, 24h weighted	75.7	---	---	75.0	75.1	74.2

9 Summary and conclusions

The study described in this report was commissioned by the European Union Working Group 8: Road Traffic. The main aim of the study was to develop a noise prediction model that would allow comprehensive evaluations of different vehicle and traffic noise control scenarios. It was anticipated that the model, when developed would be used in association with the development of area-wide noise control strategies.

9.1 Study design

A primary objective of this work was to ensure that the developed model would be sufficiently versatile to allow accurate forecasts to be made for the different traffic conditions encountered across the member states of the European Union. The model would, therefore, have to take account of area dependant factors such as vehicle fleet compositions, age distribution of vehicles, local road surfaces etc. In addition, it was important to model the traffic stream using a larger number of different vehicle types (layers) than has previously been used in traffic noise models. This feature was important as it would then facilitate the evaluation of a broad range of traffic based noise control options such as restricting access of vehicles of a specified type.

It was also considered important that, in order that the model should be capable of examining different noise source control options, it should be able to discriminate between the major source groups associated with an operating vehicle. In particular the model would need to discriminate between rolling noise sources and propulsion noise sources. Finally it was considered important that the model should be capable of dealing adequately with future scenarios including the use of new technologies and the effects on noise of vehicle and road surface design improvements.

Prior to setting up the project it was decided by Working Group 8 that the most appropriate model to use as a basis for the traffic noise prediction model was that developed for the German Environmental Agency (UBA) over the period 1998-2000. The model, *TraNECam*, is essentially a detailed vehicle noise source model where the overall traffic noise levels are determined by summing the various source components for each vehicle type operating in the traffic stream taking into account traffic speeds and other operational factors and traffic volumes.

The main advantages in using this type of model are that it potentially offers the opportunity to examine a range of vehicle noise control scenarios that can be related to both traffic management and vehicle noise source-reduction measures. For example, the potential for reducing traffic noise impacts through better tyre and road surface design can be examined as well as a wide range of traffic management options that might affect vehicle mix, speed, and overall traffic volumes.

Despite the existence of this model it was clear that a considerable amount of work was needed to adapt it to the aims and objectives of this study. For example, in order for the model to work effectively for this type of application it needed to be made more user friendly and needed to be expanded to improve its versatility in dealing with the noise control options of interest. In particular, the noise emission factors used in the model that covered the generation of rolling and propulsion noise sources needed to be updated. It was considered important, for example, to ensure that the range of road surfaces included in the model covered the surface types commonly employed in the EU and also reflected likely future developments in surface and tyre design. Similar requirements and objectives were considered to be appropriate for propulsion noise sources.

The study has therefore been designed so that it focussed on two main areas of work. Firstly, the development of the programme algorithms so that the model was tailored to the specific objectives of this study and was user friendly, e.g. the use of common language and technical expressions located within the program's dialogue. Secondly, to establish improvements that expanded the range of tyre/road surface and propulsion noise sources that can be modelled. It was decided that this second task would require a comprehensive literature review as a precursor to establishing appropriate emission factors in the model.

9.2 Tyre/road noise

The review of both the technical and legislative issues associated with tyre/road noise established the main mechanisms governing the generation and propagation of tyre noise, the methods used to measure both tyre and surface related noise and the prospects for noise quieter tyres and surfaces in the future.

The quieter surfaces identified as part of the reviewed included:

Thin surfacings: These surfaces are now frequently used for low-cost repairs or surface replacements. They are, however, increasingly being specified for new road surfaces. They possess a property known as negative texture that can be beneficial for noise reduction.

Exposed aggregate concrete surfaces: This surface type is a form of concrete texturing that produces a randomised surface finish similar to an asphalt based surface materials. Results of tests carried out on these surfaces constructed with a 10 – 6 mm maximum aggregate size produced, on average, about 1.7 dB(A) less noise for light vehicles and 1.3 dB(A) less noise for heavy vehicles than a corresponding Hot Rolled Asphalt surface.

Porous road surfaces: These surfaces are known to possess unique noise reducing properties that are related to the porosity of the surface layer. Variants of this class of surface have been examined that include double layer porous surfaces and poroelastic materials. The double layer surface was designed to reduce clogging of the surface layer with detritus thereby retaining the open structure and hence the noise benefits for longer periods in-service. Poroelastic surfaces incorporate rubber granules in the surface layer to reduce the rigidity of the surface and are claimed to reduce noise by lessening "vibrational-excited" tyre/road noise.

Other low noise surfaces reviewed included pavements designed for rapid replacement of existing surfaces. These surfaces have been designed primarily to reduce the disruption caused by road maintenance work but also can be designed with lower noise characteristics. Research was identified that is currently attempting to optimise the performance of these surfaces.

The prospects for quieter tyres included:

Matching tyre and road surface design. A major study of tyre and road surface noise demonstrated the potential for reducing road/tyre noise by simply matching tyres and road surfaces so that the design features of each interact symbiotically to reduce noise. It was shown, for example, that for car tyres, the difference in noise between the quietest and noisiest tyre/road surface combination was 9dB(A). The corresponding difference for van tyres was also 9 dB(A) and for truck tyres, 7 dB(A). These numbers indicate that there are substantial opportunities for reducing overall levels of traffic noise and hence the noise-impact on communities. However, it was pointed out that while such changes in design should be encouraged there is a significant time lag involved before the benefits are fully realised, particularly for road surface replacement.

Reducing speed. Although not a tyre design feature, the importance of speed in relation to noise generation by tyres was also highlighted in the report. It was shown, for example, that noise from air pumping was generally more dynamically related to speed than tread block noise generation. This, of course, points to the advantages offered by tyre/surface combinations that tend to produce lower levels of air pumping noise particularly for high-speed road applications.

Tread pattern. Tyres with rib style patterns tend to produce less noise than tyres with predominantly block style patterns. Largely due to legislation and improvements in compound technology, there are moves to develop quieter rib type patterns broken up by narrow cross grooves with the blocks located closer together. With this type of design it is claimed that the tyre achieves better dry grip and improved durability but also no significant loss in wet grip and, of course, potentially less noise. There are also practical acoustical advantages in employing tyres with directional tread pattern designs over tyres with no directional features.

9.3 Propulsion noise

In parallel with the review of tyre/road noise the review of propulsion noise sources focussed on an examination and definition of the sources that comprise propulsion noise and the legislation currently used to control it. The review also examined the prospects for future reductions in propulsion noise. Again the intention in carrying out the review was to provide background and support for the establishment of noise emission factors for vehicle propulsion noise to be included in the formulation of the revised model.

The main observations resulting from the review of propulsion noise were:

Cars and light duty vehicles: The main contributions come from the engine, the intake and exhaust. The contribution of intake and exhaust noise varies between 6-10 dB below the total sound power (depending upon the vehicle concept and the engine speed). For sports cars the contribution from engine and exhaust noise sources tends to be higher (4-5 dB below the total sound power). The precise rank order depends upon the vehicle type, transmission characteristics and the gear selected. Regarding the prospects for reducing propulsion noise it was found that the variance of engine noise fitted to the current vehicle fleet is 7 dB(A) over the whole speed range. The noisier 50% of cars in-service have engines that are no longer regarded as state-of-the-art engines. This suggests that a further reduction of 3dB(A) approximately is possible as these vehicle types are replaced with current generation vehicles. Hybrid vehicles and vehicles powered solely by electric motors will offer substantially lower noise from propulsion sources.

Heavy-duty vehicles: The engine is the dominant source under the current type approval conditions, where the manufacturer can choose the tyres used for the test. The contributions of other sources are typically up to 8dB(A) below the engine noise. Heavy-duty vehicles with high rated power values (above 320 kW) are already equipped with some form of engine encapsulation that can result in a 3 dB(A) reduction in engine noise. Encapsulation is needed in order to reach the current 80 dB(A) limit. Regarding the prospects for lower levels of propulsion noise, it was noted that reductions of intake and exhaust noise could be achieved using greater silencer volumes and double-walled silencers. Gearbox and drive train noise could be reduced further through improved engineering practices to achieve a higher degree of refinement and alignment. This was particularly important for the reduction of gear meshing noise sources. Advanced encapsulation and the de-coupling of the engine and gearbox are additional techniques that could help to reduce these noise sources.

The concept of a ‘silent’ truck was highlighted in the review. One manufacturer has demonstrated noise levels that are more than 10 dB(A) below current generation vehicles. The significance of the 'silent' truck is that it shows that some HDV's can be designed to meet the very lowest noise levels. Such vehicles could be used for operations in noise sensitive areas and at night.

9.4 Changes to the RWTÜV model

The main changes made to the model as part of this study were:

1. The dialog tools and control elements within the program have been modified so that the program dialog, i.e. all command windows and text prompts, are now in the English language.
2. The program has been refined to enable the use of different vehicle databases for different regions. This was achieved by creating additional tables and program forms to allow the user to choose the appropriate basic data. All tables with basic data such as vehicle type (layer characteristics) and weighting factors have therefore been duplicated and made accessible to the user.
3. Check routines have been written and installed to ensure the consistency of the databases.
4. The number of vehicle types (layers) that can be specified in the model has been extended to include high performance cars and motorcycles. In addition all heavy duty vehicles are now categorised according to whether they are fitted with traction tyres or not. (NB. Further vehicle

layers can be specified when required. For example, new technology vehicle types can be added as new data becomes available).

5. The number of road types and traffic categories that can be modelled has been expanded to cover a broader range of different scenarios.
6. Improvements have been made with regard to the modelling of propulsion noise sources for all vehicle layers. This helps facilitate the modelling of the effects of improved vehicle design on the propulsion noise functions. For example, the engine speed range can now be separated into 4 sections and individual functions used for each section.
7. As a result of the review of both tyre/road and propulsion noise sources, the noise emission factors used in the model have been updated. The factors used for these sources are now representative of a broader range of designs than previously and are indicative of the state-of-the-art.
8. In addition to these factors, further tyre noise layers have been added in the model. These assume a reduction of tyre road noise of 1.5 dB(A), 3 dB(A) and 4.5 dB(A) for all vehicle layers compared to the today's tyre and were chosen based on the evidence of research and expert judgement of the authors.
9. Two future stages have been added to represent, future generation, propulsion noise values. The reduced levels of propulsion noise have been assumed to be twice as high for full load operation compared to low load operation.

9.5 Example calculations

Some sample calculations of traffic noise levels have been made using the revised model. The results, for a single receptor position, demonstrate the various stages in the calculation process and illustrate the versatility of the model in being able to address specific questions regarding noise control options. Calculations were initially limited to individual vehicle layers and not combined into representative traffic flows. Traffic flows are site specific and traffic mixes, age etc., will be regionally dependent within the EU. Regional differences are taken into account when using the model by inputting appropriate weighting factors depending on the fleet composition.

In order to demonstrate the types of noise control issues that can be examined using the model a series of noise control scenarios have been examined. The situations that have been examined were selected following discussions with the membership of EU Working Group 8 and include scenarios related to fleet composition changes, the introduction of quieter vehicles, lower noise road surfaces and the benefits of some traffic management measures. The method adopted for each case study has been to compare model predictions for each noise control option considered against a baseline situation where the traffic flow, speed and composition is assumed. Each case study includes the results of calculations from a wide range of road types.

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Appendix A. Calculated noise levels for different vehicle layers and road category/traffic situations (State of art vehicles - post 1996)

The calculation results presented in this Appendix are based upon vehicles first registered after 1996, using the noise limits in operation at that time and are for a receiver position at 25 m from the road and a height of 4 m.

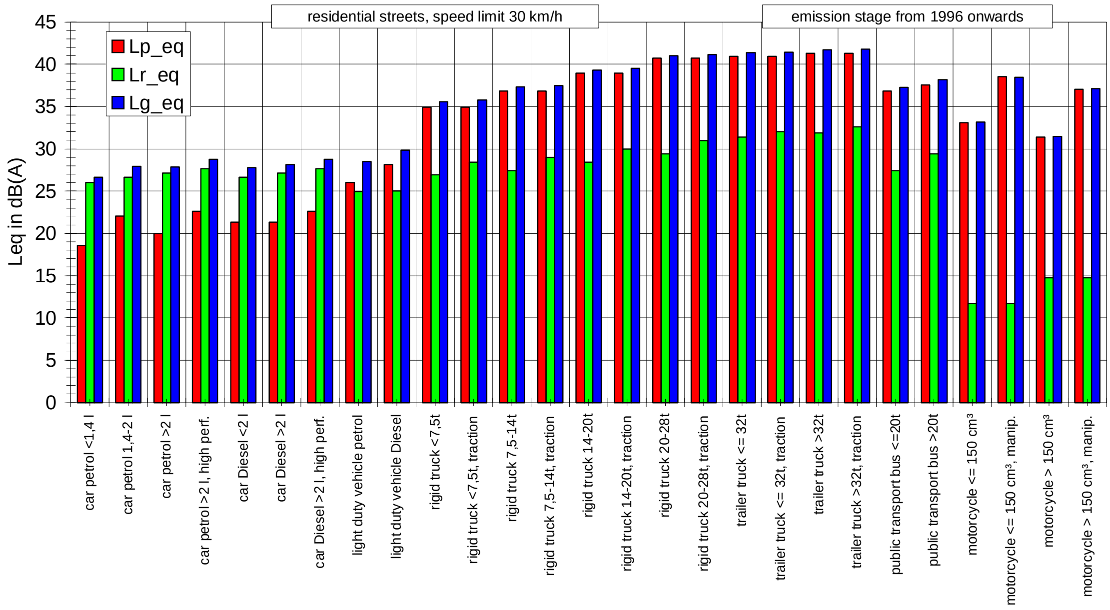


Figure A.1: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a residential street with a speed limit of 30 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

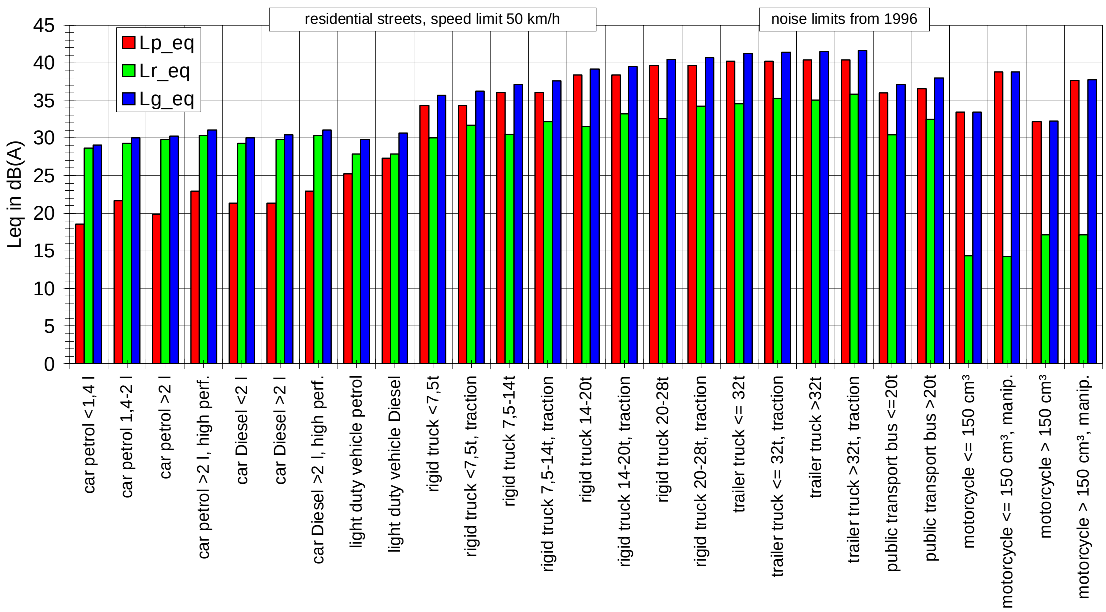


Figure A.2: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a residential street with a speed limit of 50 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

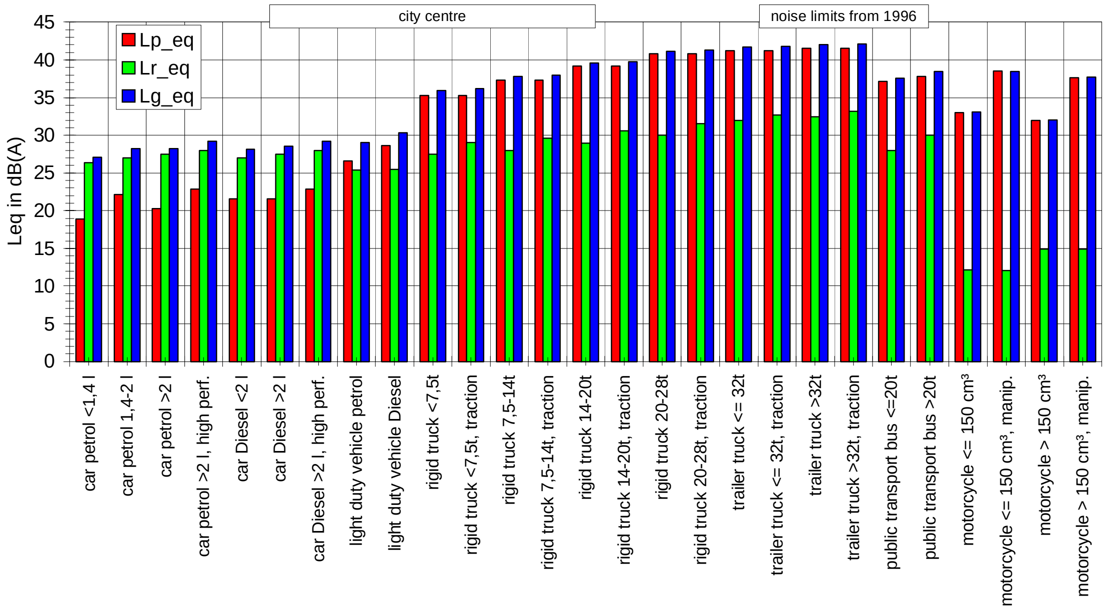


Figure A.3: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a city centre
L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

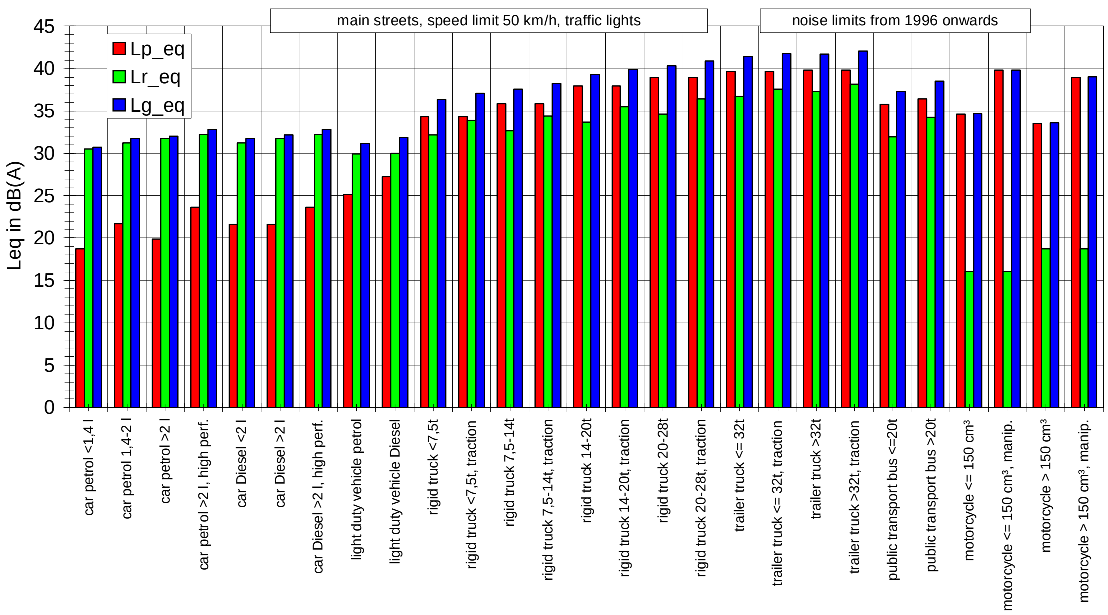


Figure A.4: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a main street with a speed limit of 50 km/h and traffic lights
L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

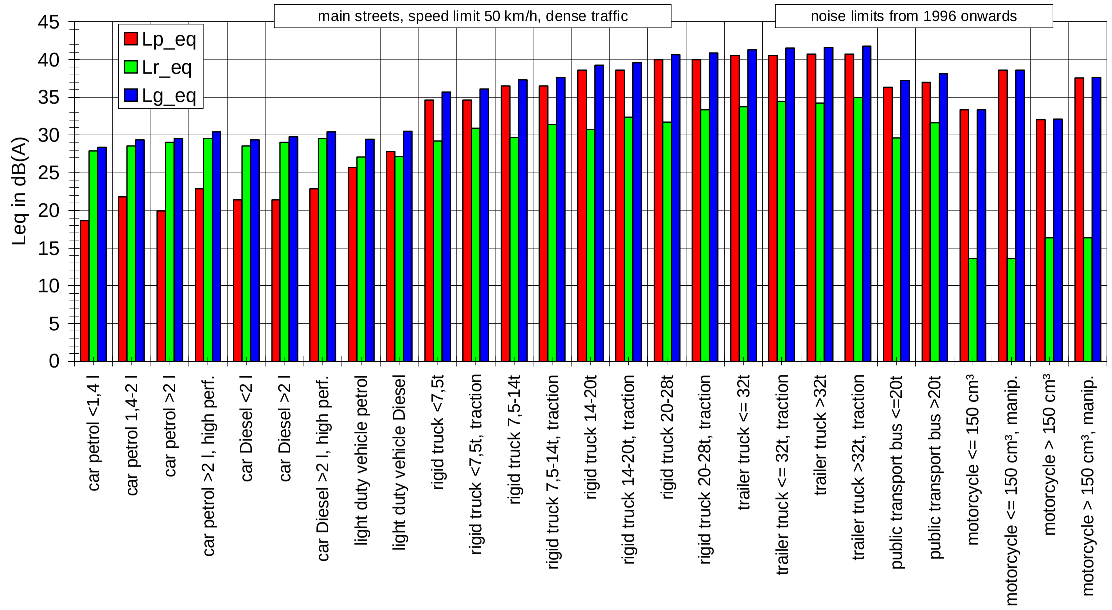


Figure A.5: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a main street with a speed limit of 50 km/h and dense traffic conditions

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

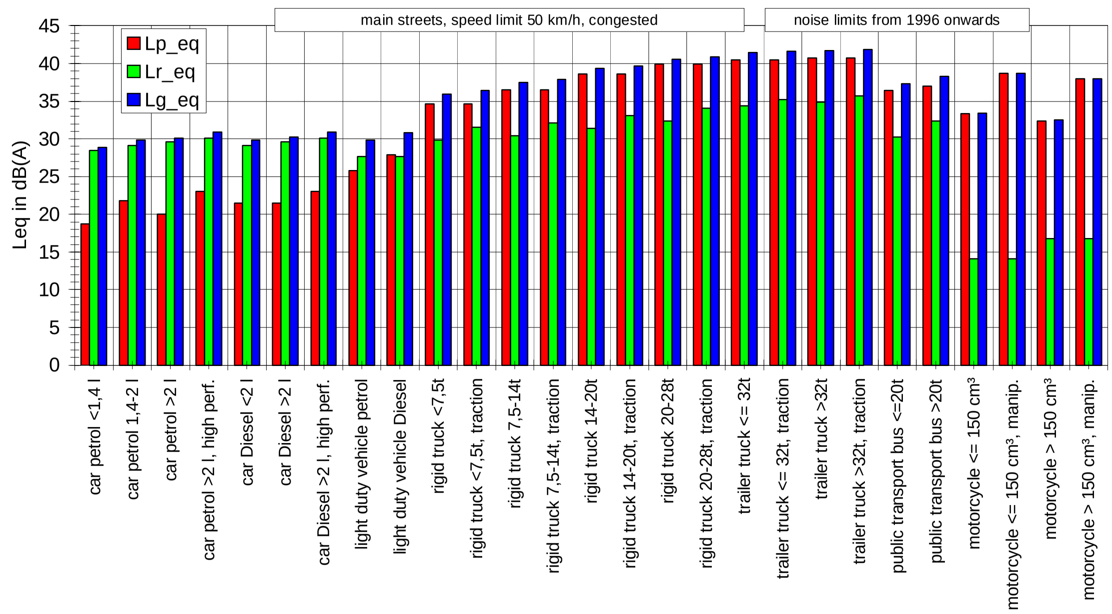


Figure A.6: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a main street with a speed limit of 50 km/h and congested traffic conditions

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

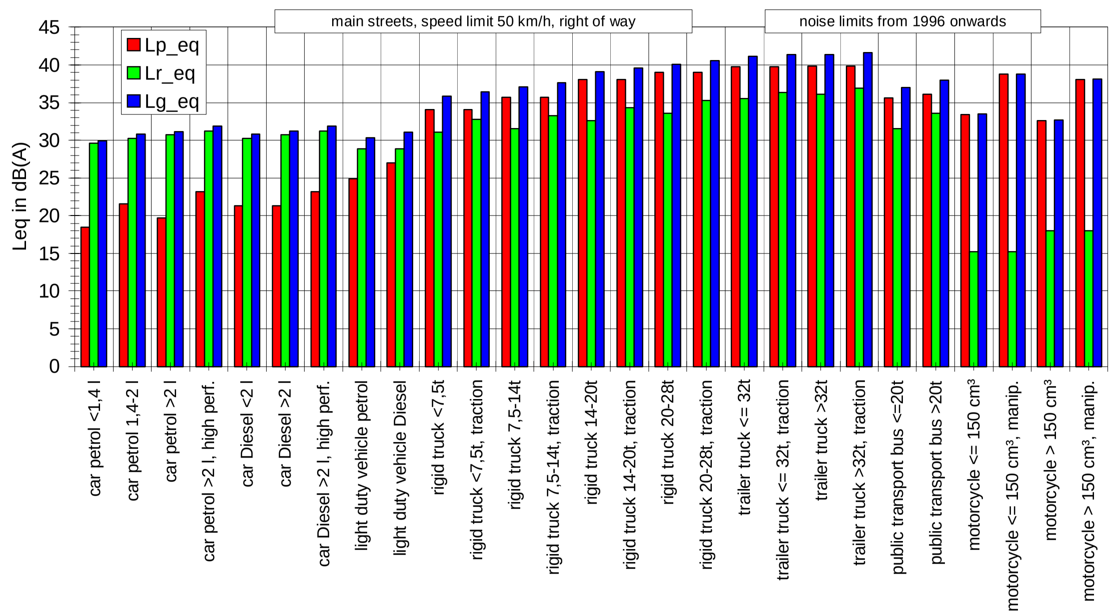


Figure A.7: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a main street with a speed limit of 50 km/h and right of way

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

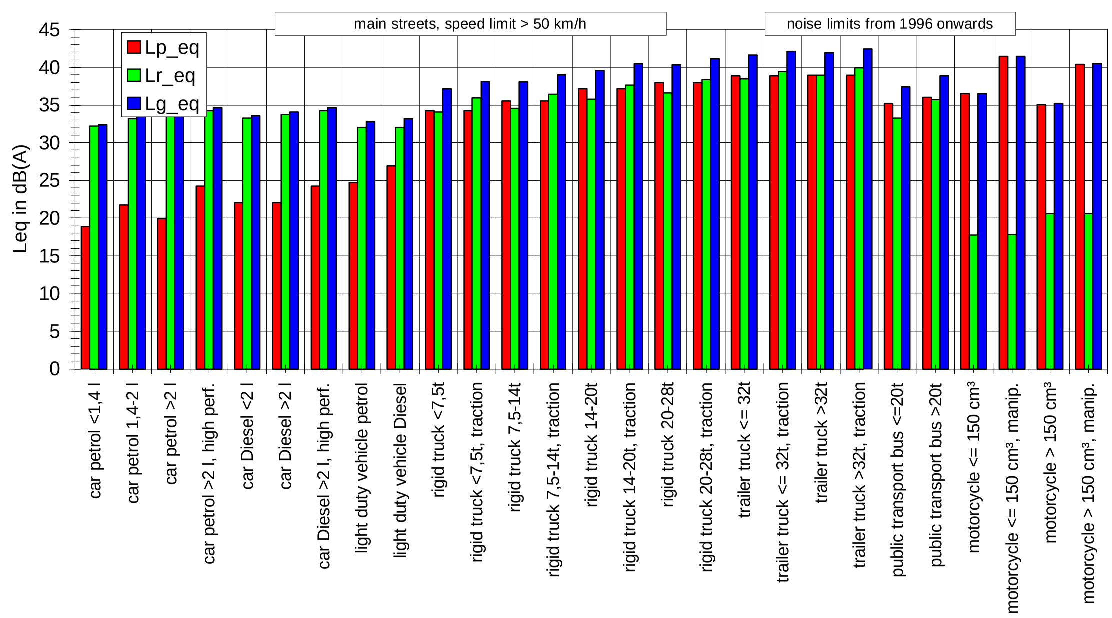


Figure A.8: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a main street with a speed limit greater than 50 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

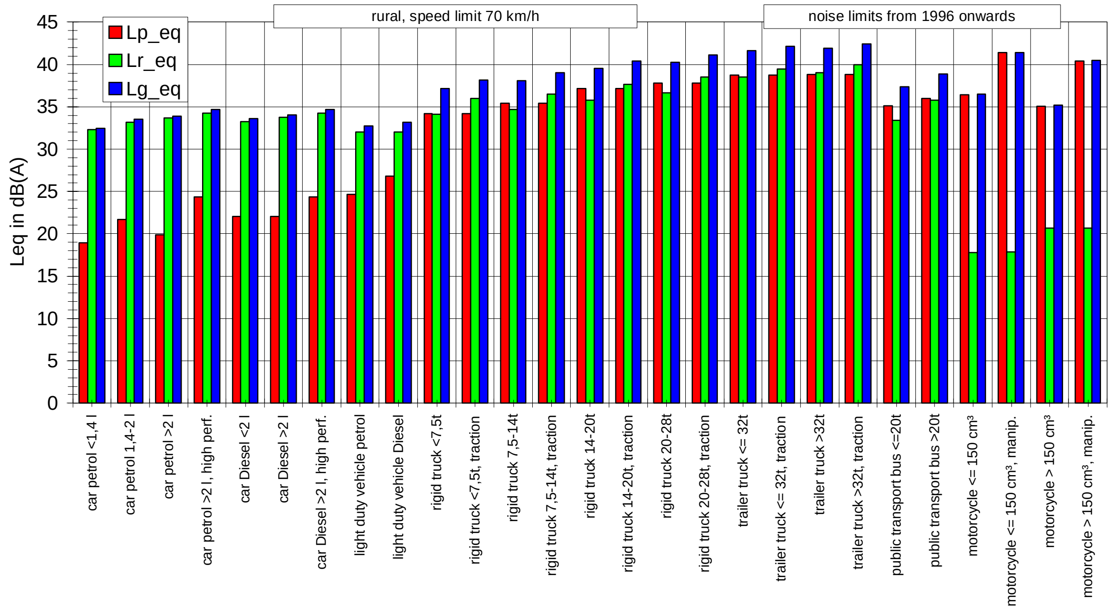


Figure A.9: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a rural area with a speed limit of 70 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

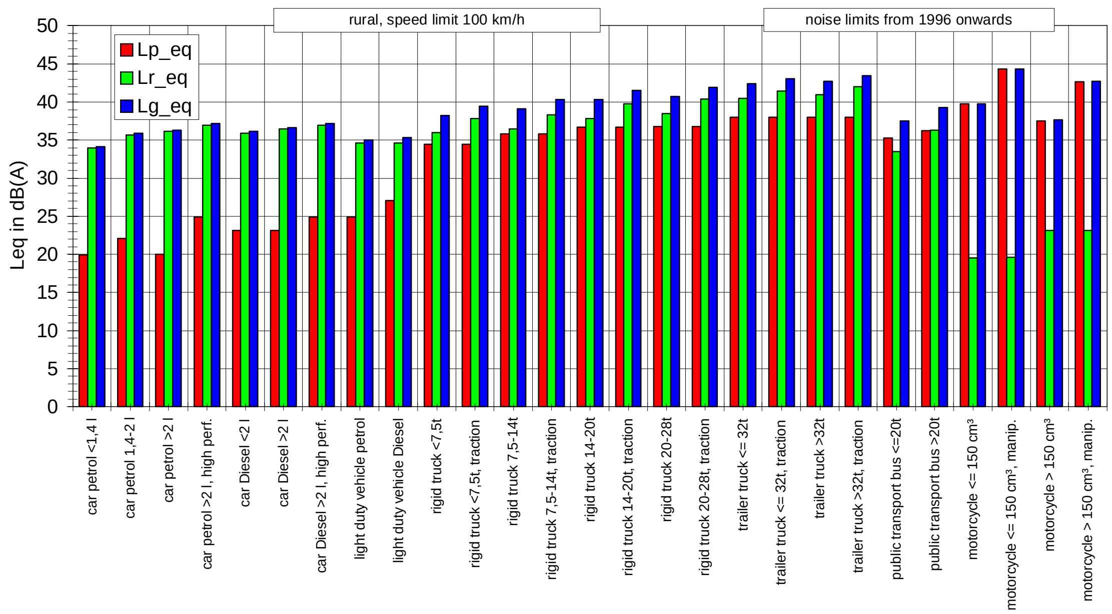


Figure A.10: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating in a rural area with a speed limit of 100 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

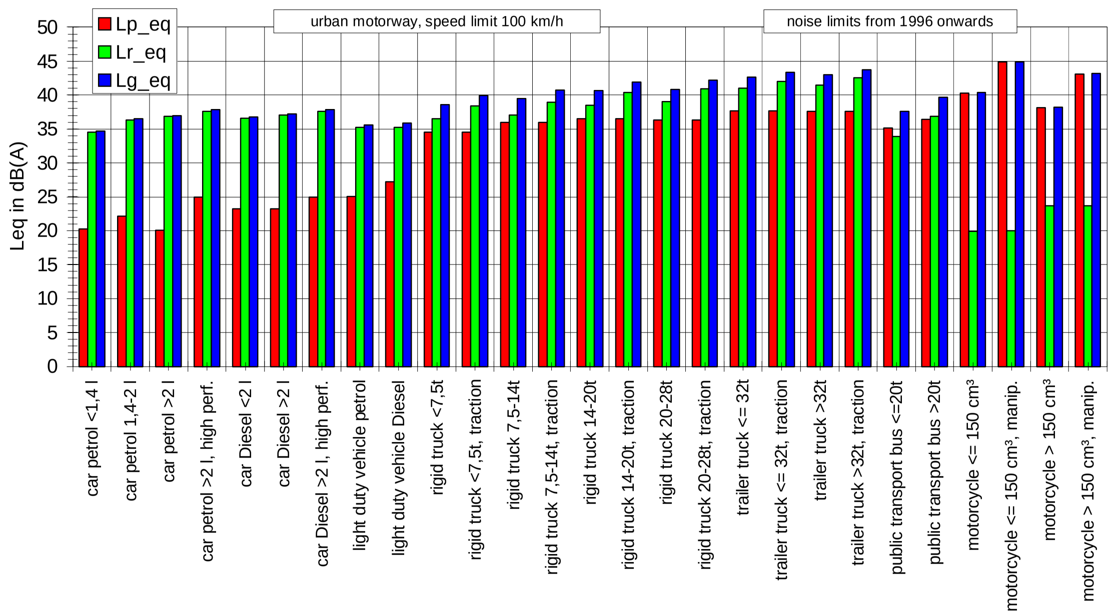


Figure A.11: $L_{Aeq,1hr}$ for a single vehicle by category/subcategory, operating on an urban motorway with a speed limit of 100 km/h

L_{p_eq}: Propulsion noise contribution; L_{r_eq}: Rolling noise contribution; L_{g_eq}: Total noise contribution

Appendix B. Operator manual for the RWTÜV noise model, *TraNECam*

B.1 General requirements

The model, *TraNECam*, is based on a Microsoft ACCESS database (version: MS Access 2000). The user must provide this program, otherwise the model cannot be used. The basic model needs a hard disc storage capacity of 700 MB. During the calculation the model size may be increased by another 700 MB. The size can be reduced after the calculations by using the repair and compress menu, but this needs the same size of free storage capacity on the computer as the program file size itself.

The calculation for streets is based on predefined emission factors for vehicle layers and predefined weighting factors for the contribution of these layers to the whole vehicle fleet.

B.2 Using the model

The main menu which is displayed on starting the program, as shown in Figure B.1, provides three options in the menu bar:

- *Define calculation case*
- *Results*
- *Additional*

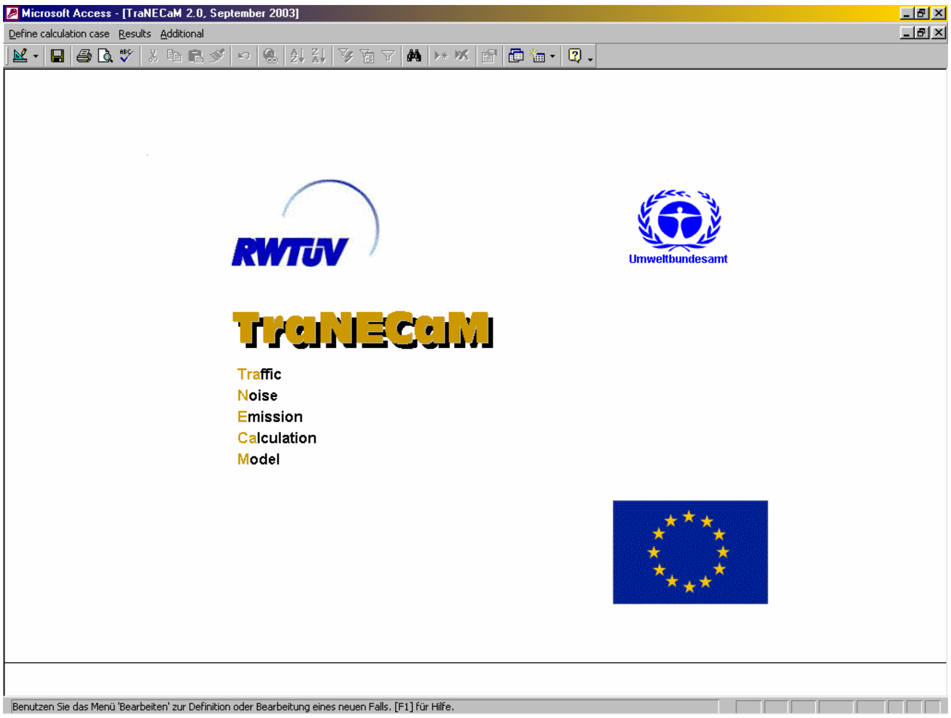


Figure B.1: Main menu screen within TraNECam

Selecting the "*Define calculation case*" option gives access to a submenu containing the following options:

- *Calculate street emission*

  This option allows the definition of the input data (traffic volume, fleet composition, road surface, road category etc.) for a series of streets and starts the calculation. When the calculations are finished, the results can be checked by selecting the "*Results*" option from the main menu screen.

- *Modify/define vehicle layers*

  This option is described in more detail in B.2.1

- *Modify/define vehicle layer weighting factors*

  This option is described in more detail in B.2.2

- *Reset*

  This option deletes all user-defined tables and restores the default values.

- *Close*

  This option closes the "*Define calculation case*" submenu

B.2.1 The "Modify/define vehicle layers" option

Selecting the "*Modify/define vehicle layers*" option leads to the following form:

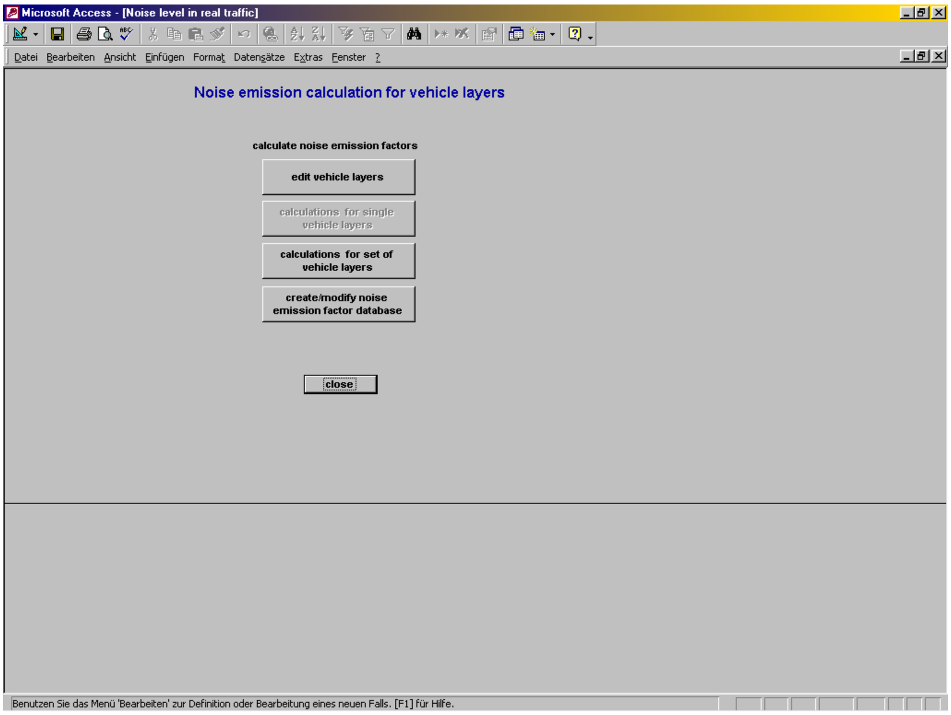


Figure B.2: "*Modify/define vehicle layers*" form within TraNECam

Selecting the "*Edit vehicle layer*" option from the "*Modify/define vehicle layers*" form opens a new form, as shown in Figure B.3, where vehicle layers can be modified or added.

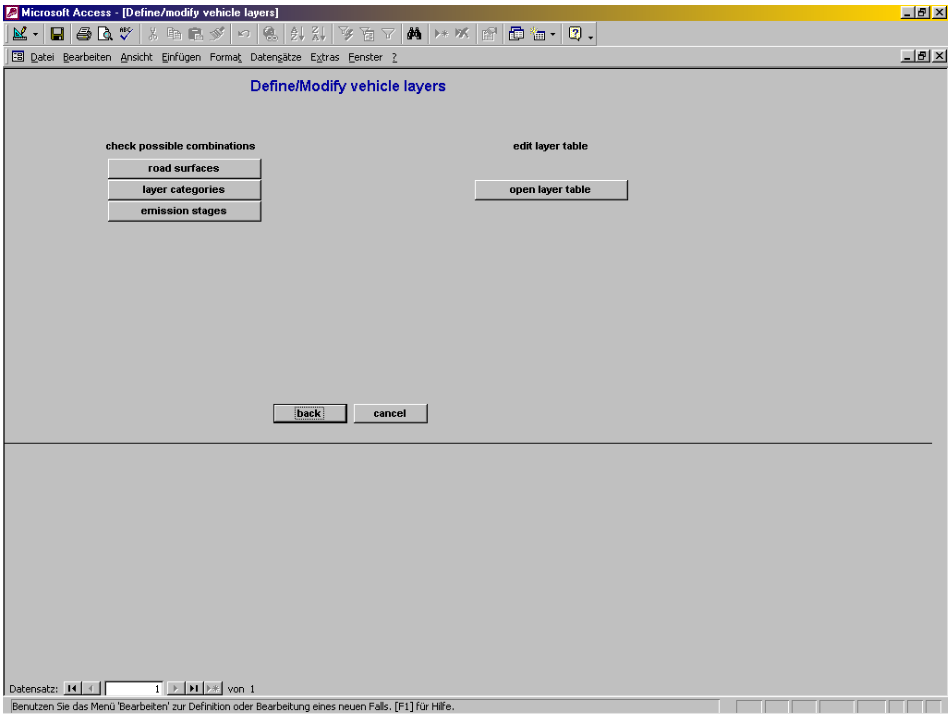


Figure B.3: "*Edit vehicle layer*" from within TraNECam

Selecting the "*Calculation for set of vehicle layers*" option from the "*Modify/define vehicle layers*" form opens a new form, shown in Figure B.4, where road surface and vehicle layer combinations for the emission factor calculation can be chosen:

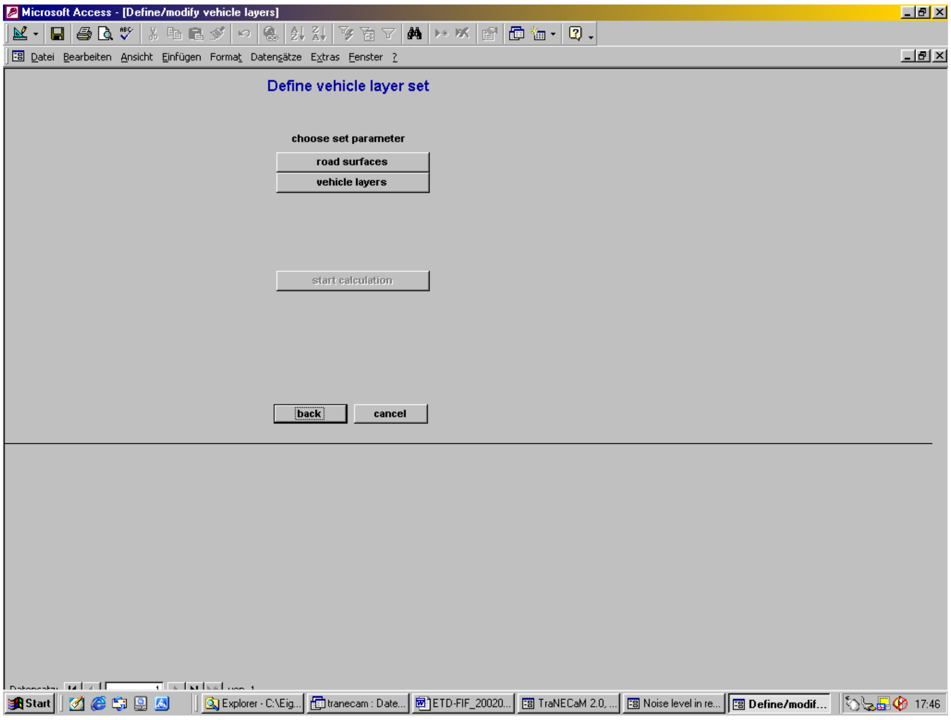
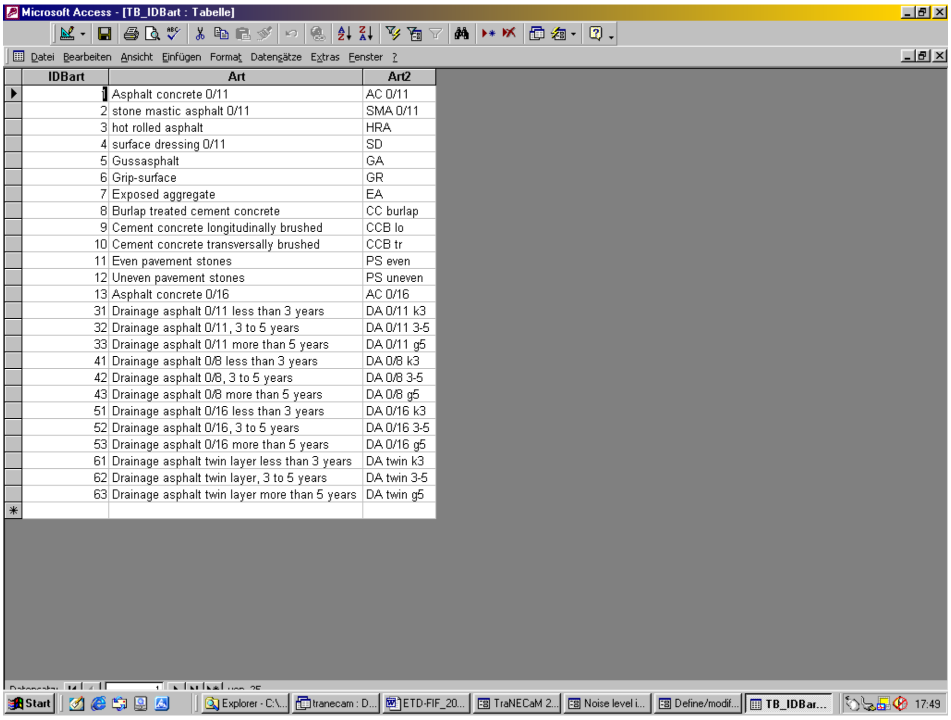


Figure B.4: "*Calculation for set of vehicle layers*" form within TraNECam

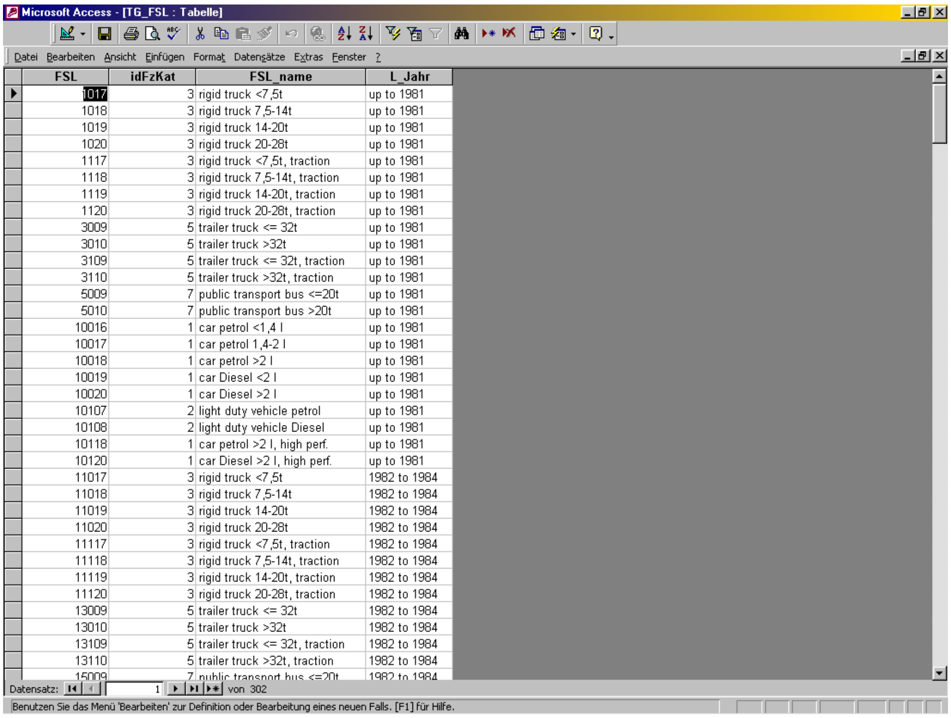
Selecting the "R*oad surfaces*" option from this form opens the road surface table with all predefined surfaces. You may choose the appropriate surfaces for your calculation by deleting the columns for those that are not needed.



IDBart	Art	Art2
1	Asphalt concrete 0/11	AC 0/11
2	stone mastic asphalt 0/11	SMA 0/11
3	hot rolled asphalt	HRA
4	surface dressing 0/11	SD
5	Gussasphalt	GA
6	Grip-surface	GR
7	Exposed aggregate	EA
8	Burlap treated cement concrete	CC burlap
9	Cement concrete longitudinally brushed	CCB lo
10	Cement concrete transversally brushed	CCB tr
11	Even pavement stones	PS even
12	Uneven pavement stones	PS uneven
13	Asphalt concrete 0/16	AC 0/16
31	Drainage asphalt 0/11 less than 3 years	DA 0/11 k3
32	Drainage asphalt 0/11, 3 to 5 years	DA 0/11 3-5
33	Drainage asphalt 0/11 more than 5 years	DA 0/11 g5
41	Drainage asphalt 0/8 less than 3 years	DA 0/8 k3
42	Drainage asphalt 0/8, 3 to 5 years	DA 0/8 3-5
43	Drainage asphalt 0/8 more than 5 years	DA 0/8 g5
51	Drainage asphalt 0/16 less than 3 years	DA 0/16 k3
52	Drainage asphalt 0/16, 3 to 5 years	DA 0/16 3-5
53	Drainage asphalt 0/16 more than 5 years	DA 0/16 g5
61	Drainage asphalt twin layer less than 3 years	DA twin k3
62	Drainage asphalt twin layer, 3 to 5 years	DA twin 3-5
63	Drainage asphalt twin layer more than 5 years	DA twin g5

Figure B.5: Road surfaces data table

A similar procedure applies on selecting the "*Vehicle layers*" option.



FSL	idFzKat	FSL_name	L_Jahr
1017	3	rigid truck <7,5t	up to 1981
1018	3	rigid truck 7,5-14t	up to 1981
1019	3	rigid truck 14-20t	up to 1981
1020	3	rigid truck 20-28t	up to 1981
1117	3	rigid truck <7,5t, traction	up to 1981
1118	3	rigid truck 7,5-14t, traction	up to 1981
1119	3	rigid truck 14-20t, traction	up to 1981
1120	3	rigid truck 20-28t, traction	up to 1981
3009	5	trailer truck <= 32t	up to 1981
3010	5	trailer truck >32t	up to 1981
3109	5	trailer truck <= 32t, traction	up to 1981
3110	5	trailer truck >32t, traction	up to 1981
5009	7	public transport bus <=20t	up to 1981
5010	7	public transport bus >20t	up to 1981
10016	1	car petrol <1,4 l	up to 1981
10017	1	car petrol 1,4-2 l	up to 1981
10018	1	car petrol >2 l	up to 1981
10019	1	car Diesel <2 l	up to 1981
10020	1	car Diesel >2 l	up to 1981
10107	2	light duty vehicle petrol	up to 1981
10108	2	light duty vehicle Diesel	up to 1981
10118	1	car petrol >2 l, high perf.	up to 1981
10120	1	car Diesel >2 l, high perf.	up to 1981
11017	3	rigid truck <7,5t	1982 to 1984
11018	3	rigid truck 7,5-14t	1982 to 1984
11019	3	rigid truck 14-20t	1982 to 1984
11020	3	rigid truck 20-28t	1982 to 1984
11117	3	rigid truck <7,5t, traction	1982 to 1984
11118	3	rigid truck 7,5-14t, traction	1982 to 1984
11119	3	rigid truck 14-20t, traction	1982 to 1984
11120	3	rigid truck 20-28t, traction	1982 to 1984
13009	5	trailer truck <= 32t	1982 to 1984
13010	5	trailer truck >32t	1982 to 1984
13109	5	trailer truck <= 32t, traction	1982 to 1984
13110	5	trailer truck >32t, traction	1982 to 1984
15009	7	public transport bus <=20t	1982 to 1984

Figure B.6: Vehicle layers data table

After this the calculation can be started by the "start calculation" button. Depending on the chosen combinations the calculation time may be several hours. For that reason the model contains already pre-calculated emission factors for all current layers and the major part of the surfaces. The results can be transferred to the emission factor database by selecting the "*Create/modify noise emission factor database*" option from the "*Modify/define vehicle layers*" form.

B.2.2 The "Modify/define vehicle layer weighting factors" option

Selecting the "*Modify/define vehicle layer weighting factors*" option leads to the following form:

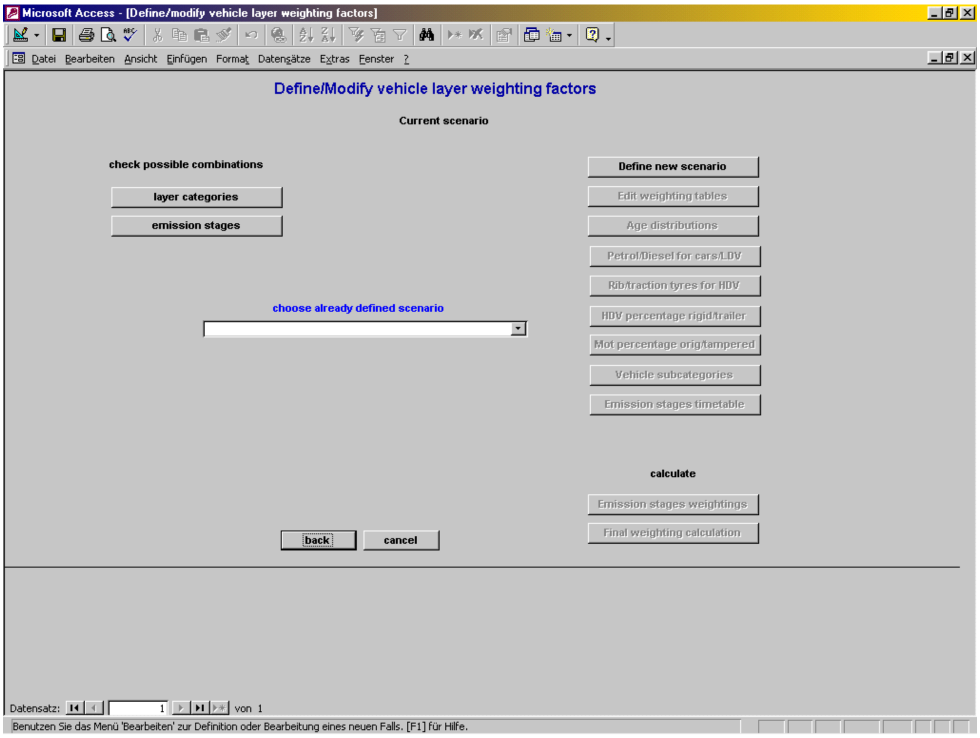


Figure B.7: "Modify/define vehicle layer weighting factors" from with TraNECam

You may choose one of the already predefined cases from the list and declare it as current case by pressing the "*Choose existing case*" button. You may also edit the weighting factors by modifying the weighting factor tables using the buttons on the right side of the form. Before pressing the "final weighting calculation" button you must define your new case by pressing the "edit case table" button and add the case to the table. You can then finalise the process by pressing the "final weighting calculation" button.

Important: the structure of the weighting factor tables must not be changed. All vehicle categories must be considered, even if the weighting is 100%.

The following distribution/weightings tables are necessary to calculate the final weighting factors for a given vehicle layer

- Age distribution
- Petrol/diesel percentage for cars and LDV,
- Traction tyres for HDV,
- Composition of rigid/trailer trucks,
- Original/manipulated exhaust systems for motorcycles,

- Subcategories within a vehicle category,
- Emission stages timetable.

All weighting factors are multiplied to get the final weighting factor of a layer for a given reference year.