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

Review of data needs for road noise source modelling

Internal report WP2: Demand and traffic flow management

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EXECUTIVE SUMMARY

The calculation of noise maps requires a noise source model for road vehicles, a network traffic model, and a sound propagation model. The output data from the traffic model are input to the noise source model, which should then provide the yearly averaged noise emission levels for each period (day, evening and night). The main purpose of this report is to identify the data needs for the calculation of road noise emission, i.e. which parameters are input to the noise source model and what should thus be the output parameters of the traffic flow model?

In order to describe this, the road noise source model is analysed and its data needs are identified and set off against the data that is provided by four types of traffic models. As the four traffic model types vary in complexity and level of detail in output data (intensities, speeds), four different methods of calculations for the aggregation from single vehicle to traffic flow are proposed. These four methods have been applied in some typical (theoretical) traffic situations, to see how the outcomes vary according to level of detail of the data (i.e. what is the added value of more detailed traffic data). Also, the sensitivity of the noise source model to variations in traffic parameters (intensity, speed, acceleration, traffic composition) has been explored, in order to establish which traffic parameters should be modelled most accurately

With respect to the various levels of detail available, it may be concluded that the minimum amount of information to allow calculation of the sound power level of a certain road segment is the traffic intensity and the average vehicle speed for each of the main vehicle categories for each period of day. The accuracy and representativeness of the results will be further enhanced if the distribution of vehicle speeds and acceleration values are included. The highest level of detail is to have the vehicle category, speed and acceleration for each vehicle at each road segment.

In general, situations with low vehicle speeds and high acceleration values demand more detailed information. It is concluded that for a motorway situation, using only the traffic intensity and average speed results in a minor error, which may be improved by the inclusion of a (rough) speed distribution. For an urban 50 km/h road situation, the inclusion of a distribution of acceleration values is necessary for an acceptably accurate result. For the modelling of a road intersection, neglecting acceleration altogether causes a large error; the use of individual vehicle data is necessary to assess the overall noise level with an acceptable error. As intersections are not always modelled separately in traffic models, corrections factors may have to be derived for different types of intersections.

With respect to the sensitivity of the noise source model for the various traffic parameters, it may be concluded that the noise model is less sensitive to variations in the total vehicle intensity than to the percentage of heavy motor vehicles (HMV) and the average vehicle speed. Furthermore, the inclusion of a vehicle speed and/or acceleration distribution may have a significant positive influence on the results, but the resolution of these distributions does not seem to be very important.

The work in tasks 2.2 and 2.3 should focus on the accuracy of the traffic model output data and its consequences for the calculated noise levels. Furthermore, the details of the aggregation from single vehicle instantaneous noise levels to a larger traffic flow should be investigated.

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1 Introduction

1.1 Scope

The goal of the IMAGINE project is to define a method to generate noise maps that contain the noise levels of road and rail traffic, aircraft and industrial noise, to identify problem areas and to evaluate noise action plans. For road noise, these noise levels are calculated using a vehicle noise source model on one hand combined with a road network traffic model on the other hand. The output data from the traffic model, i.e. vehicle intensities, speeds, etc., are input to the noise source model, which should then provide the yearly averaged noise emission levels for the day, evening and night periods for each road segment within the area. An acoustic propagation model is then used to calculate the noise immission levels at each desired receiver point. This implies that the emission model and the propagation model can be regarded as being independent, or in other words, all road noise sources are considered to be incoherent.

Within the project, Work Package 2 is responsible for the development of guidelines for the use of traffic flow models in a suitable way for noise calculations. The main purpose of this report, which is the result of the work in task 2.1 of WP2, is to identify the data needs for the calculation of road noise emission, i.e. which parameters are input to the noise source model and what should thus be the output parameters of traffic flow models? In this report, these parameters will be discussed and the sensitivity of the calculated noise levels for each of these parameters will be assessed. Furthermore, the required accuracy of the output parameters will be discussed, as well as the requirements for a traffic model capable of evaluating noise action plans.

To evaluate the influence of each traffic flow parameter, some calculation examples are given for a number of typical traffic situations that are interesting from a noise mapping point of view. To allow these calculations, some basic assumptions and formulas are given for the aggregation from one single vehicle to an entire traffic flow. Using these aggregation methods, insight can be gathered in the requirements of the traffic model. With the results from this work, practical approaches for the aggregation to a traffic flow will be developed in subsequent tasks in this Work Package – tasks 2.2 will review traffic models in more detail and task 2.3 will develop strategies for the use of (different types of) traffic models to supply input data for the noise source model.

1.2 Structure of this report

In chapter 2, the noise source model that will be used in IMAGINE is described with respect to its basic structure and equations, and the required input and possible output parameters. Chapter 3 describes the characteristics of the most common types of traffic models, in order to describe the differences in the level of detail of their output. In chapter 4, the calculation and aggregation methods which can be used to evaluate the noise levels for various levels of detail of the traffic data are described. The actual analysis is done in chapter 5. First, three typical traffic situations are described, in terms of their vehicle intensity, speed and acceleration distributions. Then, the influence of the level of detail on the output noise levels for each defined traffic situation is investigated. In chapter 6, the sensitivity of the model for deviations in the traffic data is assessed. Chapter 7 then describes the requirements for the evaluation of noise action plans. Chapter 8 contains the conclusions from this analysis and recommendations for future tasks.

2 The road noise source model

2.1 General acoustical concepts

2.1.1 The decibel (dB) scale

Generally, sound levels are expressed on a logarithmic scale with the decibel (dB) unit. The sound pressure level L_p is the strength of the acoustical pressure wave in dB, calculated by

$$L_p = 10 \cdot \log_{10}\left(\frac{p^2}{p_{ref}^2}\right), \tag{2.1}$$

where p is the amplitude of the pressure wave and p_{ref} is usually equal to $2 \cdot 10^{-5}$ Pa. The acoustic energy E of a sound wave is proportional to the value of p^2, therefore the ratio of p^2/p_{ref}^2 is sometimes replaced by E/E_{ref} .

The use of this logarithmic scale has some typical features with respect to performing calculations with sound levels. For instance, adding two equal noise sources does not lead to a *doubling* of L_p: the total level of both sources will be approximately 3 dB higher than the L_p of each separate source, which can be seen from (2.1) by doubling p^2. Furthermore, the average of two unequal sound levels will always be close to the highest level of the two. General formulas for averaging and addition of sound levels are given in paragraph 4.1.

The hearing range of the (healthy) human ear is approximately 20 µPa to 63 Pa, which corresponds to a sound pressure level of 0 to 120 dB. The logarithmic scale roughly corresponds to the way sound levels are perceived by the human auditory system. Generally speaking, a sound level difference of 1 dB can just be perceived, whereas a difference of 10 dB is perceived as a doubling of the perceived loudness.

2.1.2 Frequency weighting

A sound wave usually consists of multiple frequencies. The human auditory system processes all frequencies at once, so it is perceived as one single ‘sound’. However, the ear is not equally sensitive for each frequency. The normal audible frequency range runs from 20 Hz to 20 kHz, where the ear is most sensitive for frequencies around 1 to 3 kHz and the sensitivity for very high and very low frequencies is much less. Thus, a particular sound wave with a frequency of 10 kHz and a sound level of 60 dB will be perceived much softer than a wave with the same sound level but a frequency of 1 kHz.

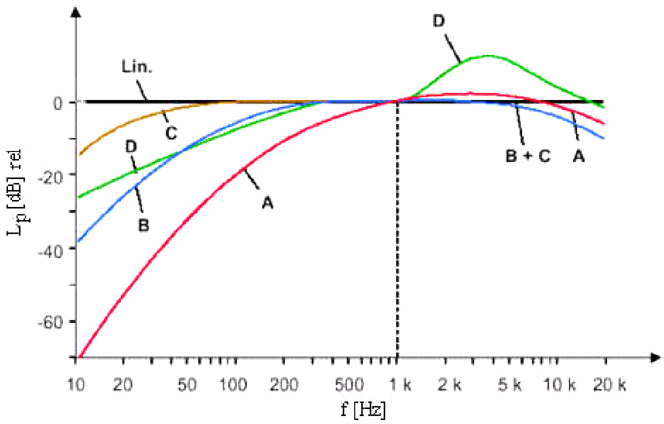

figure 1: Frequency weighting curves, showing the attenuation factor for each frequency

Within the field of noise impact calculations, it is therefore common practice to account for this human sensitivity by applying *weighting factors* for each frequency. In figure 1, some weighting curves are given that are commonly used. The red curve, labelled *A*, is most commonly used. The application of this 'A-weighting' is usually conveyed by expressing the calculated sound level in the dB(A) unit.

2.1.3 Equivalent sound levels

Sound levels, and especially *noise* levels, may vary quickly over time, whereas the exact nature of these variations is usually of no interest for noise impact calculations. Therefore, a time-averaged sound level is desired. The *equivalent* sound level, L_{eq}, is defined as

$$L_{eq} = 10 \cdot \log_{10}\left(\frac{1}{T}\int_{t_1}^{t_2} \frac{p_{rms}^2(t)}{p_{ref}^2}\,dt\right). \qquad (2.2)$$

This L_{eq} expresses the equivalent sound level over the time period $T = t_2 - t_1$, which is the sound level corresponding to the total acoustic energy of the time-varying signal $p_{rms}^2(t)$ smeared out over this time period. The exact value of L_{eq} is dependant on the length of the time period *T*. Within the field of traffic noise calculations, a common unit is the 'sound exposure level', or *SEL*, which is the equivalent sound level for a vehicle passing by, with a time-base of one second.

The use of equivalent sound levels also allows for comparison of noise levels between different traffic streams. For example, if at a certain road segment only one car passes by generating a SEL of 90 dB(A), then the equivalent sound level $L_{eq,1h}$ for that hour is equal to $90 - 10 \cdot \log 3600 = 54$ dB(A), whereas one of these vehicles every minute would give a $L_{eq,1h}$ of 72 dB(A).

2.1.4 Yearly averaged noise indicators

According to the EU noise directive, which is the basis for the `IMAGINE` project, the noise indicators to be used for noise mapping calculations are L_{den} and L_{night}. L_{den} is defined by:

$$L_{den} = 10 \cdot \log_{10}\left[\frac{12}{24}10^{\frac{L_{day}}{10}} + \frac{4}{24}10^{\frac{L_{evening}+5}{10}} + \frac{8}{24}10^{\frac{L_{night}+10}{10}}\right], \qquad (2.3)$$

where

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods of a year,
- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a year,

- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year.

In this directive, the day period is 12 hours, the evening 4 hours and the night 8 hours. The Member States may shorten the evening period by one or two hours and lengthen the day and/or the night period accordingly, provided that this choice is the same for all the sources. Furthermore, the start of the day (and consequently the start of the evening and the start of the night) shall be chosen by the Member State (that choice shall be the same for noise from all sources); the default values are 07.00 to 19.00, 19.00 to 23.00 and 23.00 to 07.00 local time.

The definition of these noise indicators require from the traffic flow model that:

- it provides separate traffic parameter values for day, evening and night periods;
- these periods are adaptable, according to the remarks above; this may require the traffic flow model to evaluate the traffic on an hour-to-hour basis.

2.2 Source model description

Within the IMAGINE project, Work Package 5 is responsible for the development of the databases for road noise source modelling. The modelling of road noise sources will be based on the approach and methodology, developed within the EU 5th framework project HARMONOISE [1]. In this paragraph, the description of road noise source modelling will be described. A description of further developments within IMAGINE will be given in paragraph 2.2.3.

2.2.1 The main source model

The HARMONOISE description contains a methodology to describe the noise production of a European Road Vehicle in terms of a set of mathematical equations representing the three main noise sources:

- rolling noise due to the tyre/road interaction,
- propulsion noise caused by the noise production of the driveline of the vehicle,
- aero-dynamical noise due to the turbulent flow along the car body.

The total noise production is the energetic sum of these three; however, the aero-dynamical noise source is incorporated in the rolling noise.

Lay-out of model

- The model is designed to calculate the *instantaneous* noise level for *one single vehicle* at the *source points* as a function of the vehicle category and additional vehicle parameters, driving behaviour, road surface parameters, and meteorological conditions.
- Each vehicle category is represented by two point sources, each having a specified sound power L_W, having contributions from rolling noise and propulsion noise. The aero dynamical sources are incorporated in the rolling noise source.
- As a minimum 3 vehicle categories are used: passenger cars, medium heavy and heavy vehicles, where the medium heavy vehicle has two axles and the average heavy vehicle has been assumed to have 4 axles, with a correction for other axle numbers. However, to account for local situations with exceptional vehicles and to be able to account for variations in fleet composition over regions, in total 18 different sub-categories are defined. These also include categories for two-wheelers.
- All default data refer to a reference condition: constant speed, 20 °C and the average of DAC 0/11 and SMA 0/11 road surface. Deviations from these conditions are corrected for (see paragraph 2.2.2).

Vehicle categorization

In table I, the vehicle categories used in the source modelling and data collection are given. Note that the HARMONOISE model coefficients are based on the first five main categories only, while the sub-categories are used just for data collection, at least until now.

table I **Summary of vehicle categories as used in HARMONOISE**

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

Reference condition

The reference air temperature is 20 °C, and the reference road surface is a virtual surface consisting of a mixture of DAC 0/11 and SMA 0/11 surfaces with an age of 1 year or more but not at the end of their lifetime.

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[1] 3-4 axles on car + trailer or car + caravan

[2] Hybrid vehicles driven in combustion engine mode: Classify as either 1a or 1b

[3] Also 4-wheel trucks, if it is evident that they are >3,5 tons

[4] For example, there are some delivery trucks designed for extra low noise (meeting more stringent standards than the current EU limiting levels) combined with a driving mode called "whisper mode"

[5] If a high exhaust is noted,categorize this as 3b′, 3c′, 3d′ or 4a′

Source strength – sound power level

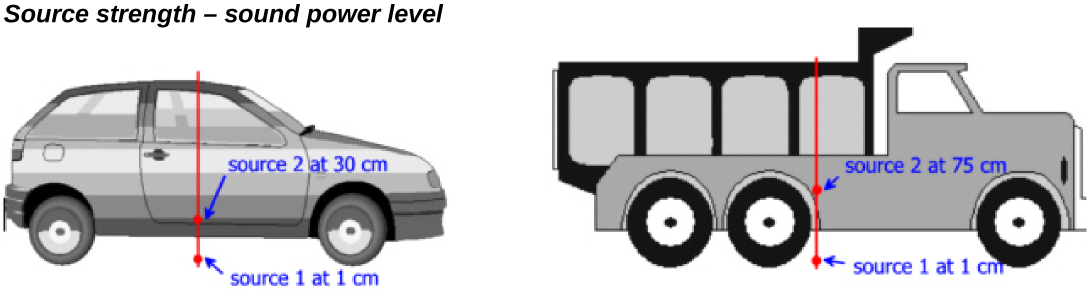

figure 2: Drawing of noise source positions

For the given reference condition, the sound power L_W of a vehicle from each of the main vehicle categories is a sum of rolling noise and propulsion noise.
The sound level of the rolling noise L_{WR} is calculated by

$$L_{WR} = a_R(f) + b_R(f) \cdot \lg\left[\frac{v}{v_{ref}}\right];\ v_{ref} = 70\ \text{km/h}, \quad (2.4)$$

where v is the vehicle driving speed, and the coefficients a_R and b_R are given for each 1/3-octave band frequency f from 25 to 10000 Hz, for vehicles of category 1 and 2. The values for category 3 heavy vehicles can be found by adding $10 \cdot \log(\#\,axles/2)$, where '# *axles*' is the number of axles on the vehicle. Accurate data for categories 4 and 5 are not yet available. The rolling noise is assumed to be distributed over two point sources, where 80% of the sound power is radiated by a point source at 0,01 above the road surface and the remaining 20% is radiated by a second point source which is assumed to be located at 0,3 m height for category 1 vehicles, and at 0,75 m for category 2 and 3 vehicles (see figure 2).

For propulsion noise, the sound power level L_{WP} is given by

$$L_{WP} = a_P(f) + b_P(f) \cdot \left[\frac{v - v_{ref}}{v_{ref}}\right];\ v_{ref} = 70\ \text{km/h}, \quad (2.5)$$

where the coefficients a_P and b_P are also given per 1/3-octave frequency band. For propulsion noise, 20% of the sound power is appointed to a point source at 0,01 m height, and 80% is appointed to the second noise source at 0,3 m or 0,75 m for light and heavy vehicles, respectively.

2.2.2 Corrections to the reference condition

With equations (2.3) and (2.4), the total noise emission from a specific vehicle within the reference condition can be calculated. The HARMONOISE description of the source model also gives a number of correction factors for deviations from this reference condition. The correction factors will be shortly described below. For more detailed information, see [1].

- *Directivity*: Due to its geometry and complex noise generating mechanisms, a vehicle will not radiate noise equally in all directions, but is dependant on the horizontal and vertical angle. This can be described as a sound power level correction ΔL as function of the horizontal and vertical angle and of the frequency, which is generally different for both point noise sources and for propulsion or rolling noise.
- *Temperature*: The rolling noise is to be corrected for the air temperature θ, where the correction is dependant on the road surface type. The difference in the sound power level

ΔL is given in [1] for most road surface types as a function of the temperature difference $\theta - \theta_{ref}$, where $\theta_{ref} = 20°C$.

- *Tyre type*: Within the model description, there is only a correction for studded winter tyres, of the form $\Delta L = a(f) + b(f) \cdot \lg(v)$ with *a* and *b* known as a function of frequency.
- *Road surface*: Corrections to the rolling noise can be made for the influence that the road surface has on the rolling noise level of a tyre. The relevant properties of the road surface in this respect are its type, age and wear condition (because they are directly related to the acoustic relevant properties of road texture and acoustic absorption) and the wetness/snowiness of the surface. Furthermore, the acoustical impedance of the road surface will influence near field propagation of propulsion noise. All corrections are dependant on frequency, vehicle category and vehicle speed, and are usually in the form $\Delta L = a(f) + b(f) \cdot \lg(v/v_{ref})$. The HARMONOISE description provides correction values for the impedance, for a number of road surface types either within or outside of the reference cluster, road surface age, and the surface wetness. More correction values for other road surfaces will come from the EU 5^{th} Framework project SILVIA.
- *Acceleration/deceleration*: The rolling noise is assumed not to depend on acceleration or deceleration. For propulsion noise, a correction is given by $\Delta L = C \cdot a$, where the acceleration *a* is expected not to exceed the range from -2 to +2 m/s^2. The coefficient C is given for the overall level per vehicle category. Although the nature of the effect of engine load on acceleration and on propulsion noise is very complicated and requires detailed knowledge on the vehicle engine condition, it was found that as a general descriptor acceleration works fine and that a linear relation of the acceleration effect was applicable.

2.2.3 Parameter databases and further improvements

The HARMONOISE description of the source model will be the main basis for the work on road noise sources within IMAGINE WP 5. The main task within this Work Package will be to fill in the coefficients for this model based on measurement data, and to provide a database with actual, accurate and reliable correction values for all relevant local variations in the road traffic situation as they exist over Europe. Besides the parameter database, the source model itself will be reviewed and possible improvements will be carried out.

Regional differences

The HARMONOISE description of road noise source modelling, as described in [1], contains a set of coefficients to calculate the noise emission of a road vehicle. All coefficients are average values, based upon measurement data from various European countries. In some regions, however, the average values for these coefficients may deviate to some extent as a result of differences in the 'average' traffic situation in this region. Factors that are region-dependant are:

- *average vehicle weight*: for instance, vehicles in the Nordic countries tend to be generally heavier (Volvo V70 being the most common car in Sweden) than those in Italy (small Fiat vehicles dominate traffic);
- *composition of engine types*: mainly the average fraction of diesel engines vs. gasoline engines, this fraction varies from practically zero diesel engines to more than half of the population, depending mainly on tax regulations;
- *average vehicle age and state of maintenance*: older cars tend to be generally more noisy due to both less stringent regulations at the time of manufacturing and deterioration of the engine/outlet, etc.;
- *typical tyre composition*: as indicated in the HARMONOISE description, the use of studded winter tyres has an important influence on the rolling noise; there may also be an influence of the average tyre width, which is higher for regions with heavier cars, for

instance; for truck tyres, there is a significant difference in noise generation between traction tyres and steering tyres;
- *average composition of each vehicle class*: this refers to the fraction of each vehicle sub-category to the main categories; for instance, the amount of light vans or 4WD cars in category 1 will influence the average noise emission.

Each of these factors may be expressed in a correction for the coefficients for each vehicle class, either for the overall vehicle sound level or for propulsion noise and rolling noise separately, if necessary per 1/3-octave frequency band. It will then be necessary also to define a reference for each correction category, i.e. a reference average weight for each vehicle category. For the 'vehicle maintenance' corrections, a set of concrete, measurable parameters should be defined.

2.3 Model in- and output

2.3.1 Input

General model

For the calculation of the sound source levels of a vehicle in the reference situation, the following information is needed:

1. the vehicle category, according to table I,
2. the vehicle speed in km/h.

Corrections

To provide more detailed and accurate sound levels, the necessary corrections mentioned in 2.2.2 should be applied if there are deviations from the reference conditions; therefore it is necessary to know:

3. the air temperature in °C,
4. the tyre type,
5. the road surface type, age and wetness, according to the descriptions given in [1],
6. the vehicle acceleration in m/s^2.

According to the regional corrections to be developed within IMAGINE WP5, the geographic location of the road segment should also be known, and possibly additional corrections for specific vehicle characteristics (weight, age, etc.) as mentioned in 2.2.3.

Traffic flow data

When the input data mentioned above are known, the sound source level of the road vehicle can be calculated. In paragraph 4.1 below, it will be described how to calculate the noise levels from a specific traffic flow of vehicles. What needs to be defined for such a traffic flow is at least:

7. the vehicles density, i.e. the number of vehicles per road length unit,
8. the composition of traffic, i.e. the percentage of vehicles for each vehicle category, according to table I,
9. the average vehicle speed per category.

Note that the vehicle density could also be calculated by dividing the vehicle intensity (i.e. number of vehicles per time unit) by the average vehicle speed.
If the variations in vehicle speed are large, then it is also necessary to know:

10. the distribution of vehicle speeds per vehicle category.

For a more accurate result, the correction factors should be correctly applied to the vehicle stream, therefore it is needed to know:

11. the distribution of acceleration values for each vehicle category,
12. the distribution of vehicle tyre types per vehicle category.

Remarks

- From the list of input data, a division can be made into data that are absolutely necessary for the sound source model and data that are supplementary to improve the accuracy and representativeness of the calculated noise levels.
- The vehicle category and vehicle speed (1 and 2) are essential, since they determine the source equations. If the calculations are done for a vehicle flow, then the number of vehicles per category (7 and 8) and their average speed (9) need to be known.
- To improve the results, one of more of the corrective equations (3 to 6) may be used. If no information is given for these corrections, or one is not interested in their influence, then a default value may be used. The importance of each correction factor is different, however, so the error made by neglecting it varies for each parameter. The importance of each correction factor will be discussed later in this report.
- For the calculation of L_{den} and L_{night} values, all traffic parameters should be available for each day, evening and night period separately.
- The traffic parameters are likely to be different for adjacent road lanes, and for different travel directions. Values may be calculated for the road segment as a whole, but for more accurate calculations, the traffic parameter values are required separately for each road lane.

2.3.2 Output

The road noise source model will calculate the sound power levels in dB(A), per 1/3-octave frequency band from 25 Hz to 10 kHz, corresponding to the input data. Thus, if the model input is a traffic flow of one vehicle category with just an average speed value, then the output will be the average sound power source level for this vehicle stream. If a more detailed composition into vehicle classes and vehicle speed ranges is available, then the model may give the sound power levels for each category and speed range, and the total equivalent sound power level.

2.3.3 Example of results

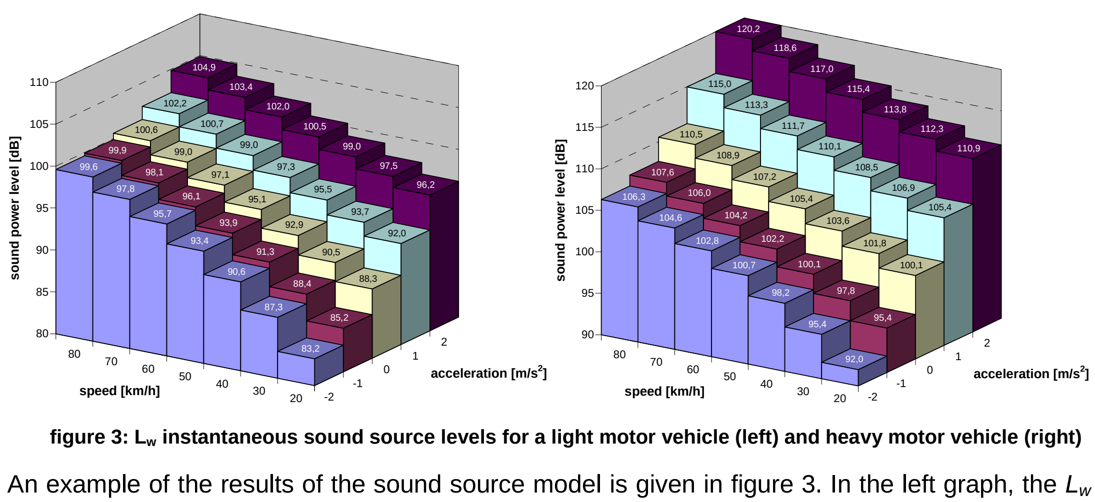

figure 3: L_W instantaneous sound source levels for a light motor vehicle (left) and heavy motor vehicle (right)

An example of the results of the sound source model is given in figure 3. In the left graph, the L_W source levels for a single light motor vehicle are given as a function of the vehicle speed and acceleration, whereas the right graph shows the levels for a heavy (cat.3) motor vehicle. Since the other correction factors (i.e. road surface, air temperature) have an influence mainly on the overall average level, they are not accounted for here.

Note that the levels depicted here are *instantaneous*, so there is no correction for the duration of the vehicle pass-by. A vehicle driving at 80 km/h may produce more noise than at 20 km/h, but it will pass by more quickly, which would have a decreasing influence on the time-equivalent sound power level. This time influence, however, is not included here and will be discussed later. It should also be noted that the directivity of the vehicle sources is disregarded here.

From these graphs, it can be concluded that:

- a vehicle speed increasing from 20 to 80 km/h increases L_w with 8,5 to 16,5 dB(A) for light motor vehicles and from 9,5 to 14,5 dB(A) for heavy motor vehicles;
- the vehicle acceleration for a light motor vehicle ranging from -2 to +2 m/s^2 causes a sound level correction of -5 to +8 dB(A) at 20 km/h, and of -1 to +4,3 dB(A) at 80 km/h; however, an acceleration of +2 m/s^2 at 80 km/h may not be very realistic;
- the influence of the acceleration is larger at low vehicle speeds than at high vehicle speeds, which is mainly due to the dominance of rolling noise over propulsion noise above approximately 35 km/h (for light motor vehicles);
- the influence of the acceleration is higher for the heavy motor vehicles; however, the absolute value of the acceleration will generally be less for heavy motor vehicles, where a value of +2 m/s^2 may not be very realistic, which partially cancels this difference.

These graphs are for just for one light or heavy motor vehicle. In chapter 5.2 it will be discussed how these conclusions differ for a traffic flow with various properties.

3 Description of traffic models

3.1 Classes of traffic flow models

3.1.1 General properties of traffic flow models

The traffic models that will be used for the traffic noise emission calculations are *network* traffic models. These models are intended to predict and analyse various aspects of the traffic on a road network, such as the amount of traffic as a function of time, the average travelling time from one place to another, etc. To do so, various modelling techniques are available, all of which focus on one or more parts of the 'transportation chain of decisions', which is:

1. the choice to make or not to make a trip,
2. the choice of destination,
3. the choice of travel mode (car/bus/train/etc.),
4. the choice of departure time,
5. the choice of route,
6. the choice of driving manoeuvres.

A wide range of network traffic prediction models is currently available, where each model can be applied to predict certain parameters of a traffic situation. These models differ as to:

- the required input:
    - a road network definition,
    - travel time functions, either static or dynamic,
    - some models need an origin/destination (OD) matrix, while other models may generate such a matrix based on socio-economic data and zone definitions,
    - driving behaviour characteristics;
- the amount of output information and level of detail given for:
    - traffic intensity, density and composition,
    - vehicle speed and driving behaviour;
- their ability for dynamic traffic characteristics:
    - dynamic travel time calculations,
    - changes in route assignment and departure times due to changes in network occupation;
- their minimum and maximum geographic scale.

Based on these parameters, four classes of traffic models can generally be distinguished, each of which is given in the following paragraphs, roughly ranking from simpler to more complex models.

3.1.2 Static models

General description

The static traffic models are the simplest and oldest class of models, but are nowadays still often used because of their limited computation and calibration needs and of their suitability for large area road networks, such as the national motorway system, and for long term predictions of traffic developments. Static models may also include the choice of travel mode.

Static models are able to compute from a definition of socio-economic zones the transportation demand from each zone to another. Once the OD matrix is calculated, the amount of traffic for each OD route is calculated using static travel time functions for each route. Some models allow for changes in travel times due to congestion on certain routes which, by successive model iterations, allows modelling of the distribution of traffic over other possible routes.

Input
To generate the OD matrix, the static models need a zone definition and socio-economic data (e.g. land use, amount of industry, population density, car ownership) for each zone. Furthermore, the travel times from each zone to each other zone must be known.

Output
A static model will usually generate the intensity of traffic on each link (road segment) and the average vehicle speed over the link. The output values are not a function of time, but merely average values for a given period (for which the origin-destination matrix is available – e.g. peak and off-peak periods, sometimes evening and night periods as well).

3.1.3 Dynamic Traffic Assignment (DTA) models

General description
DTA models focus mainly on the choices of route and, possibly, departure time. These models usually start from a given OD matrix and use dynamic travel time functions to predict the traffic flows on the road network segments as a function of time. Thus, if a certain link becomes busier, the travel time will increase and the route will become less favourable, which will cause part of the traffic to flow to another route.
Besides off-line assessment of traffic flows for modelled situations, DTA models are also often used for on-line traffic and congestion control.

Input
DTA models need a predefined OD matrix and dynamic travel time functions or a more detailed ‘network loading’ model to predict how the traffic propagates over the road network.

Output
The dynamic traffic assignment models will give the traffic intensity and the average vehicle speed for each link, and the travel times for each OD route, all of which are calculated as a function of time.

3.1.4 Continuum models

General description
The continuum models use the principle physics equations for gas dynamics, using instead of the ‘conservation of mass’ principle the ‘conservation of vehicles on a link’ principle. Traffic is described using the density k, the flow q, and the vehicle speed u, the three of which are related by the ‘fundamental diagrams’.
Continuum models focus on the choice of driving behaviour and on traffic operations, and are often used for congestion spill-back, for instance at critical junctions or traffic lights. Such a model may be used as a ‘network loading’ model, as input for a dynamic traffic assignment model. Continuum models are currently mainly used in academic research only.

Input

The continuum models need the dynamic flow characteristics of the road network. These can be described using either a dynamic OD-matrix or a static OD-matrix and for each node in the network the proportions of traffic flowing to each node branch.

Output

The continuum models will give each of the traffic flow variables (density, flow, average speed and speed variance) as a function of time and the position on the link. The latter is thus a difference with the previous models, where the link is regarded as a whole, with only average values for the entire segment.

3.1.5 Microsimulation models

General description

With a microsimulation model, the traffic is described using discrete individual vehicles. These models are of a stochastic, ‘black-box’ nature, thus assuming a certain (random) distribution of vehicles and driving parameters, and assuming certain rules for driving behaviour (i.e. lane changing and car following rules).
Due to their complexity and large computational demands, the microsimulation models usually focus on off-line use and are not suitable for large road networks. In general, implementation and calibration of microsimulation models for a certain road network is rather complicated.

Input

The input needed for a microsimulation model is the same as for the continuum models, with the addition of certain dynamic traffic behaviour rules.

Output

Microsimulation models provide a very detailed output of traffic. For every vehicle in the network at any time, and thus for the entire traffic flow, all behavioural and vehicle parameters (position, velocity, speed variance and vehicle acceleration) can be determined.

3.2 General remarks

Regarding the general description of traffic models in the previous paragraph, it should be marked that:

- although traffic models might be able to model vehicle speeds, care should be taken to check if these speeds represent realistic values; traffic models do not always predict accurate actual vehicle speeds;
- from a noise modelling point of view, micro-simulation seems to be ideal, as the data it produces is very close to what is needed for the noise model; however, while the data are very detailed, it can be a false level of detail because micro-simulation models are stochastic based; micro-simulation models may produce different results for each time they are recalculated;
- the final traffic model to be used should perhaps be a combination of different model types, e.g. a static model for mode choice and route choice uses as input for a continuum or micro-simulation model;
- usually, traffic models and modellers are focused on road network capacity and performance, signal control and congestion management; these, however, may not be the main important problem areas for noise modelling since free-flowing traffic may produce more noise than congested traffic.

4 Calculating traffic noise

4.1 Aggregation to traffic flow

4.1.1 Introduction

The road noise source model as described in chapter 2 describes the noise emission (source) level of one single vehicle at an instantaneous time, taking into account the specifications of the vehicle, road and meteorological data. For the yearly averaged values as required for the noise mapping, however, it may be too complex to calculate the sound levels for each vehicle at every time. Furthermore, most traffic models will not be able to provide data on single vehicles. Only a microsimulation model generates data for single, discrete vehicles.

In this chapter, it will be explained how the overall source noise levels from each of the traffic flows defined in chapter 4 can be calculated for different levels of detail in the data coming from traffic models. The amount of information available will determine the calculation method of the overall L_{eq}. The various levels of detail to be distinguished are, ordered from little to very much detail:

1. the traffic intensity *Q* in veh/hour and average speed in km/h for each vehicle category;
2. this, plus a distribution of vehicle speeds per category, i.e. the amount of vehicles per speed range;
3. this, plus a distribution of vehicle acceleration values per category, i.e. the amount of vehicles per acceleration range;
4. specific values of vehicle category, speed and acceleration for each single vehicle.

The distributions of vehicle speeds and accelerations mentioned in this report are distributions over *time* for that particular road segment. They are regarded from a measurement point of view – as if a speed radar was placed at one particular point near the road and the instantaneous speed and acceleration values for each passing vehicle are recorded for a certain period of time (one hour). The speed distribution is the histogram of the recorded speed values in the designated ranges. The road source noise level of the traffic flow is then calculated per unit length and is assumed to be constant over the road segment.

In the calculation methods presented here, as well as in the definitions of traffic situations, the road is regarded as one single driving lane. For the calculation of traffic noise over a larger area, the input to the noise propagation model should (ideally) be a single line source for each road lane.

For each level, the content and detail of the results will be different, and thus a different link with the traffic model is needed. In paragraph 4.2, therefore, it will be described how the results from the traffic model providing each of these information levels could be used to predict the overall noise levels. First, paragraph 5.1.2 and 5.1.3 describe how noise levels as needed for noise maps are calculated (regardless of which data is available).

4.1.2 Calculating equivalent sound pressure and sound power levels

As was explained in paragraph 2.1.3, the instantaneous, single-vehicle source level L_W needs to be translated to an *equivalent sound pressure level*, L_{eq}, which is the sound pressure level at a receiver position averaged over a certain time period. This equivalent sound pressure level may contain multiple source points (vehicles), as well as attenuation of the received sound level by distance and further 'excess' attenuation (by air and ground absorption, reflection, sound screens, etc.). The calculation of the sound pressure level at the receiver position from the sound *power* level generated by the noise source is done by means of a propagation model containing all attenuation factors and the methods of integration over a certain area. The propagation model to be used within the IMAGINE project is described in [5].

For the current analysis, the interest is in the equivalent sound power level at the position of the source, so both the geometrical and excess attenuation are not regarded. What is actually calculated is the equivalent line-source strength level per unit length for the road segment under study. This line source level will be labeled $L_{W,line,eq}$, and the derivation can be found in [3] and [4]. In this label, the subscript *W* denotes that it is a *source* (sound power) level, the *line* means that it is a line source level per unit length (constant over the link) and the *eq* means it is a time-equivalent instead of an instantaneous sound power level. $L_{W,line,eq}$ is thus constant over the entire road segment and is given, for each vehicle category, by

$$L_{W,line,eq} = L_{W,0} + 10 \cdot \lg\left(\frac{Q}{v}\right), \qquad (4.1)$$

where $L_{W,0}$ is the sound power level from the road noise source model integrated during a complete pass-by. This means that the directivity is not regarded here; this should be accounted for in the noise propagation modelling. Furthermore, *Q* is the number of vehicles per time unit and *v* is the average vehicle speed of these *Q* vehicles. The actual time period *T* for which the $L_{W,line,eq}$ is calculated is expressed in the units of *Q* and *v*: if the intensity *Q* is given in vehicles per hour, and *v* is the average speed in km/h, then the results of (4.1) is the hour-based $L_{W,line,eq}$ for that road segment, per km road length; if the $L_{W,line,eq}$ is desired per m road length, then multiply *v* by 1000.

It should be noted that this definition of *equivalent* sound power levels thus includes the influence of the pass-by time of the vehicle. Thus, a vehicle passing by at a lower speed will be heard longer, which has an increasing effect on the equivalent sound power level $L_{W,line,eq}$. This will thus raise the sound levels of slow traffic relative to those of fast traffic.

Using this equation, the equivalent sound power levels for different groups of vehicles (e.g. by vehicle or speed class) can be mutually compared and added up. The addition of equivalent sound levels, however, always needs to be done according to the 'equal energy'-principle, which is expressed by:

$$L_{W,eq,total} = 10 \cdot \lg\left[\sum_{i=1}^{N} 10^{L_{W,eq,i}/10}\right], \qquad (4.2)$$

where $L_{W,eq,i}$ are the *N* separate equivalent sound levels to be added. Similarly, the average equivalent sound power level of multiple $L_{W,eq,i}$ values is calculated by:

$$L_{W,eq,avg} = 10 \cdot \lg\left[\frac{1}{N}\sum_{i=1}^{N} 10^{L_{W,eq,i}/10}\right] = 10 \cdot \lg\left[\sum_{i=1}^{N} 10^{L_{W,eq,i}/10}\right] - 10 \cdot \lg N\,. \qquad (4.3)$$

4.1.3 Calculating yearly averaged values

In practice, for noise maps, the goal is to predict the *time-averaged* noise level for *each period of day* at the source of a traffic flow passing *one particular road lane segment.* For instance, it will be calculated what the average source noise level is at a particular single-lane urban road segment where 2000 vehicles pass per hour, of which 5% is heavy motor vehicles, assuming a certain average distribution of vehicle speed and acceleration values over these 2000 vehicles.

This total average noise level is projected onto a singular point source for that particular road segment. To calculate the yearly averaged noise indices as needed for the noise mapping, a propagation model from this source point to each receiver point is needed, and the contributions of all other source points in the respective area need to be included, where each road lane should be taken as a single noise source. Furthermore, the calculations should be done for the day, evening and night periods separately in order to assess the required L_{den} and L_{night} noise indicators.[6]

4.2 Calculation methods

4.2.1 Method A – Using vehicle intensity and average speed

For this method, it is assumed that the only information available from the traffic model is the vehicle intensity Q (average number of vehicles per hour) and the average vehicle speed $\bar{v}$. The number of medium heavy and heavy vehicles can also be predicted, including their separate average speed. These data can be calculated for each link in the traffic model. Note that in the types of models that provide data with such little detail intersections are often not modelled separately.

To calculate the equivalent sound power level for each link, the sound power levels $L_{W,1}$, $L_{W,2}$ and $L_{W,3}$ for each vehicle category 1, 2 and 3 will be calculated as if it were one vehicle driving continuously at the average speed (since there is no information about variations between and within vehicles). The equivalent sound levels $L_{W,line,eq,1}$, $L_{W,line,eq,2}$ and $L_{W,line,eq,3}$ are then calculated from 4.1, using the vehicle intensity and average speed for each vehicle category. The total $L_{W,line,eq}$ is then calculated by adding these three values using (4.2).

Thus, to calculate the noise level from the static model results:

1. the noise level for the average light motor vehicle is calculated,
2. this level is corrected for the light motor vehicle density,
3. the same is done for the medium heavy and heavy motor vehicles,
4. the three levels are (energetically) added.

4.2.2 Method B – Using a vehicle speed distribution

Now, the information available is the same as above, thus the vehicle intensity Q and average speed $\bar{v}$, but additional information about the distribution of speeds over the vehicles is also available.

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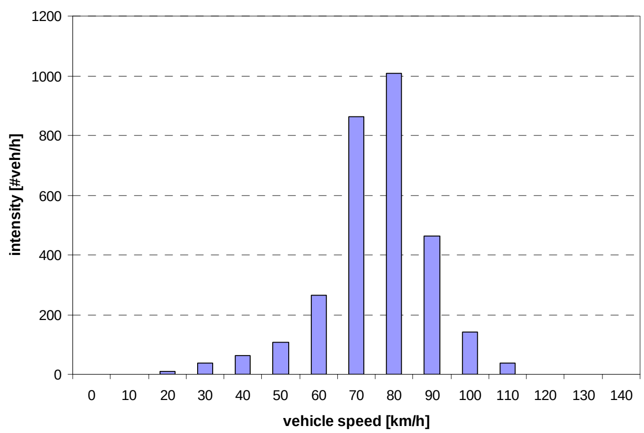
[6] The day is 12 hours, the evening 4 hours and the night eight hours. The Member states may shorten the evening period by one or two hours and lengthen the day and/or night period accordingly. Default values are: day = 07:00-19:00 hrs, evening = 19:00-23:00 hrs, and night = 23:00-07:00 hrs. See also [7].

Though the average speed for both methods is equal, the incorporation of a distribution of speeds will influence the equivalent sound power level. Due to the non-linearity of the speed dependence in the rolling noise model, i.e. $L_R = a + b \cdot \lg(v/v_{ref})$ and the 'equal energy'-principle of added sound levels, calculating the average noise level from 2 vehicles with different velocities is not the same as calculating the average noise level of one vehicle at the average of the two velocities.



speed	intensity
0	0
10	0
20	11
30	38
40	64
50	108
60	266
70	862
80	1009
90	462
100	143
110	37
120	0
130	0
140	0

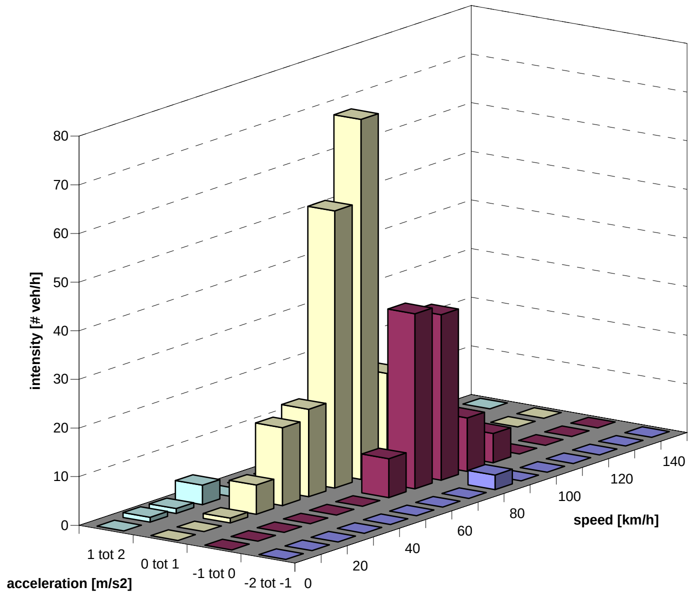
figure 4: Example of speed distribution

To calculate the equivalent sound power level of a vehicle flow with a certain speed distribution, the vehicle velocities are divided into different ranges, each with its own vehicle intensity, and the equivalent sound power level $L_{W,line,eq}$ is calculated by adding that of each range. Each range then represents the number of vehicles passing the link with a (constant) speed within the designated range.

In figure 4, an example of a possible speed distribution of 3000 light motor vehicles per hour on an urban 80 km/h road is given. The $L_{W,line,eq,i}$ of each range should be calculated using the intensities given in the table, and the total $L_{W,line,eq}$ is then calculated using (4.2). This should then be added to the results for the other vehicle categories.

The final results will be influenced by the choice of speed ranges. In the example above, there are 266 vehicles driving at an average of 60 km/h, but a more detailed model may provide separate values for 61, 62,… km/h, which could give a difference in $L_{W,line,eq}$.

4.2.3 Method C – Using vehicle acceleration values



		speed [km/h]														
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140
acceleration [m/s^2]	-2 tot -1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
	-1 tot 0	0	0	0	0	0	0	8	36	34	11	6	0	0	0	0
	0 tot 1	0	0	1	6	16	18	57	74	20	3	0	0	0	0	0
	1 tot 2	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0

figure 5: Example of speed/acceleration distribution

From certain traffic models, information may also be gathered about the acceleration of the vehicles. Thus, some vehicles may be in the same speed range, but some of them will be accelerating, and some will be decelerating. This will have an influence on the equivalent sound power level; again, the average sound level of one vehicle accelerating at 1 m/s^2 and one decelerating at -1 m/s^2 will not be equal to that of a vehicle at constant speed.

In figure 5 an example of the resulting speed/acceleration distribution is given, e.g. the histogram of all vehicles passing the road segment during one hour. The distribution is purely imaginary, with an effect of slow vehicles having a preference for accelerating and fast vehicles having a preference for decelerating. For each combination of a vehicle velocity and acceleration range, a number of vehicles per hour is given.

To calculate the overall average $L_{W,line,eq}$ for that hour the $L_{W,line,eq,i}$ for each vehicle/acceleration range, thus for each stave in figure 5 or each cell in the table below, needs to be calculated. The total $L_{W,line,eq}$ is then the energetic sum of all $L_{W,line,eq,i}$ values.

4.2.4 Method D – Using discrete vehicle values

Finally, if a very detailed traffic model is available, the vehicle and acceleration output is given for each separate vehicle at each time-step (down to one second). To allow calculation of the noise levels in the current analysis, the vehicle data for one particular road segment should be recorded over a certain time period, resulting in the vehicle speed and acceleration for each separate vehicle passing that segment. The calculation of the total $L_{W,line,eq}$ is then quite straightforward:

1. calculate the $L_{W,line,eq,i}$ for each vehicle based on its vehicle category and its momentary speed and acceleration value for that link, using (4.1) with Q = 1 and v in km/h; the link length for a microsimulation model may be as short as a few metres;
2. these $L_{W,line,eq,i}$ values then represent the sound power energy of each vehicle spread out over one hour; perform the energetic sum of all $L_{W,line,eq,i}$'s using (4.2) to calculate the total $L_{W,line,eq}$.

5 Analysis of traffic flow data

5.1 Typical traffic situations

In this paragraph, three typical traffic situations are defined, being a motorway road, an urban road (50 km/h) and an intersection with traffic lights. These are interesting traffic situations to look at from a noise modelling point of view, because traffic characteristics differ considerably between these situations:

- motorways: large traffic flows with many heavy vehicles, high speeds, usually relatively low variation in speed;
- urban roads: lower flows and speeds, more variation in speeds;
- intersections: high dynamics (acceleration and deceleration).

For these traffic situations, the number of vehicles per category passing a certain road segment, and their speed and acceleration distribution have been defined. The vehicle data presented for each situation, as well as the speed and acceleration distributions, are not based on real data; they serve purely as examples to gain more insight into the way traffic parameters and level of detail influence road noise calculations. Again, the road is regarded as one single lane.

These situations are regarded as ‘actual’ traffic situations, with given levels of detail for the input data. In the next chapter, the expected traffic model output for each situation will be described using calculations methods that incorporate various levels of detail of the input data. This will show how the outcomes vary with the level of detail of the input data, which will give an indication of the suitability of the different types of models.

5.1.1 Motorway traffic

The first situation to be regarded is a typical motorway situation, with:

- a total traffic volume (intensity) of 8000 vehicles/hour,
- 10% heavy motor vehicles (HMV), of which 50% cat. 2 and 50% cat. 3 vehicles,
- a distribution of vehicle speeds for light and heavy motor vehicles as depicted in figure 6, corresponding to a speed limit of 120 km/h for light motor vehicles (LMV) and 80 km/h for heavy motor vehicles,
- an acceleration distribution ranging from -0,6 to +0,6 m/s^2 which includes a trend for slow vehicles to accelerate and for fast vehicles to decelerate.

The speed and acceleration distributions are assumed to be constant over the road segment under investigation, which may be several kilometres long for a straight, undisturbed highway.

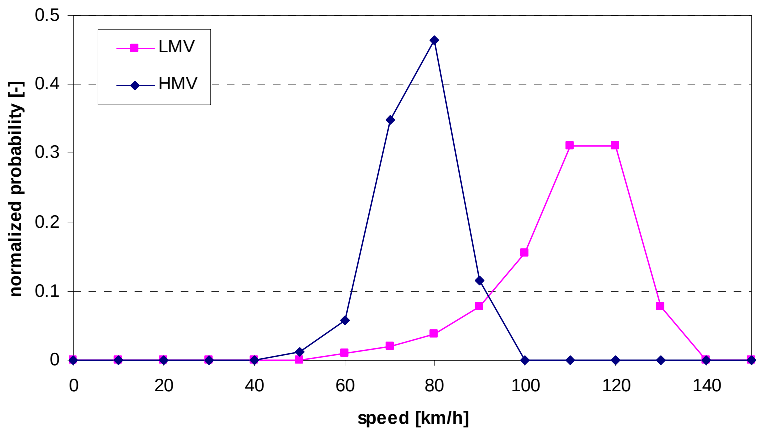


figure 6: Input speed distribution for motorway traffic situation

Given these reference conditions, random ‘vehicles’ are generated, each with its own vehicle speed and acceleration values. The final set then contains 7200 light motor vehicles and 800 heavy motor vehicles, with a speed and acceleration distribution as depicted in figure 7.

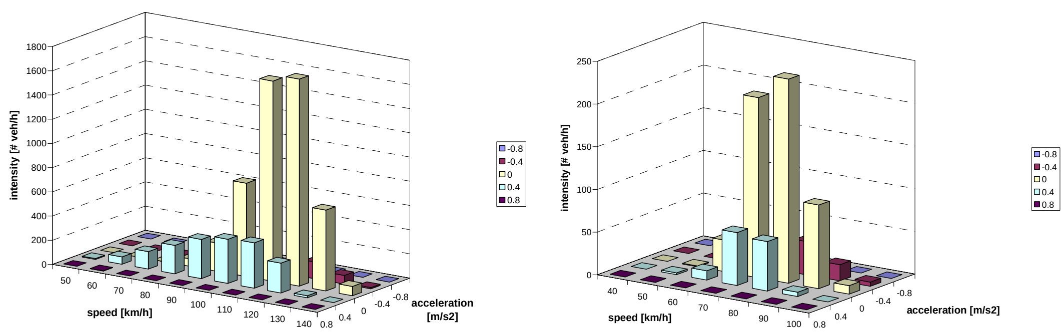


figure 7: Distributions of generated random vehicle speed and acceleration values for light motor vehicles (left) and heavy motor vehicles (right) on a motorway

5.1.2 Urban traffic

The next situation to be regarded is a typical urban road, with:

- a total traffic intensity of 2000 vehicles/hour,
- 5% heavy motor vehicles, of which 80% cat. 2 and 20% cat. 3 vehicles,
- a distribution of vehicle speeds for light and heavy motor vehicles as depicted in figure 8, corresponding to a speed limit of 50 km/h,
- an acceleration distribution ranging from -1,2 to +1,2 m/s^2 which includes a trend for slow vehicles to accelerate and for fast vehicles to decelerate.

The speed and acceleration distributions are assumed to be constant over the road segment under investigation, which, for an urban road situation may be anything from 50 m long up to a kilometre or more. Figure 9 shows the vehicle speed/acceleration distribution of the randomly generated vehicle values.

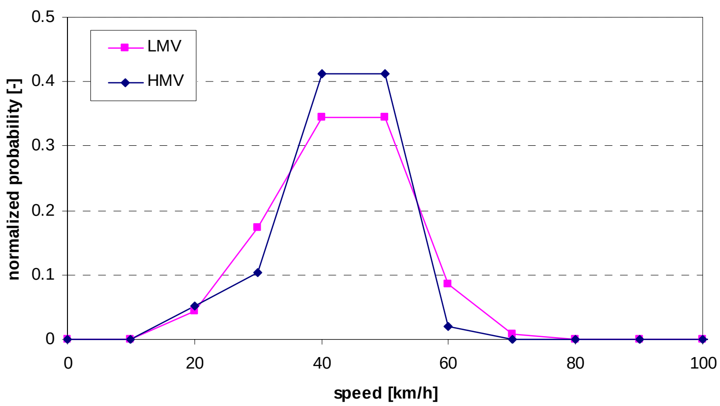


figure 8: Input speed distribution for urban road traffic

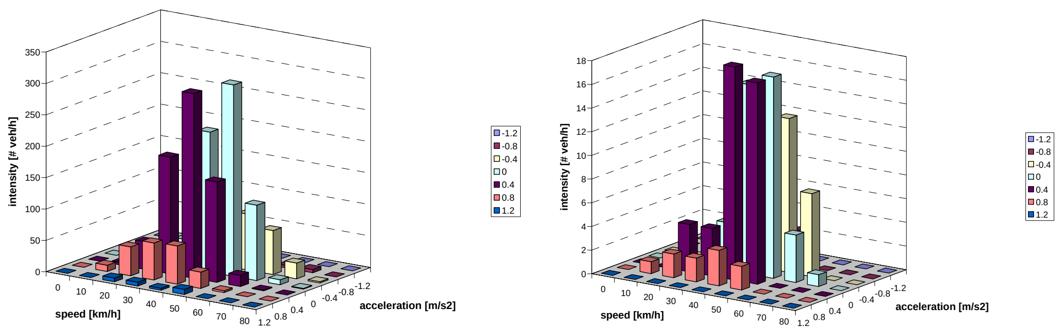


figure 9: Distributions of generated random vehicle speed and acceleration values for light motor vehicles (left) and heavy motor vehicles (right) on an urban 50 km/h road

5.1.3 Intersection modelling

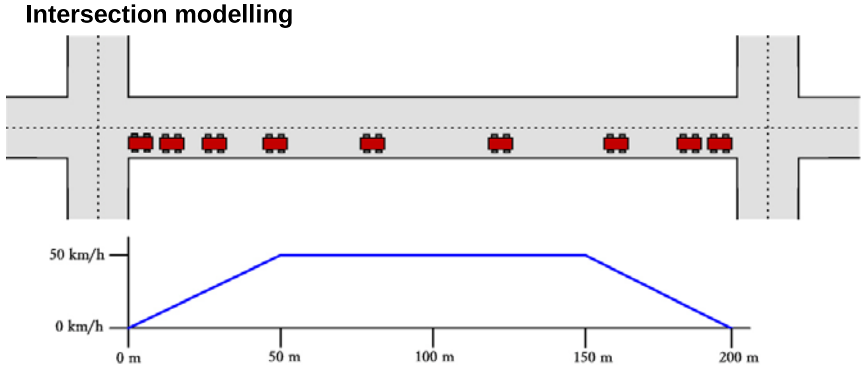


figure 10: Overview of road segment between intersections

When modelling an intersection, different areas may be regarded (see figure 10). The difference of this situation from the previous two is that the vehicle speed and driving behaviour cannot be assumed to be constant over the area regarded; some 50 to 100 m before the intersection, for an urban 50 km/h road, traffic may start decelerating down to the intersection itself, where the speed is low or even zero for a short or longer period of time. Downstream from the intersection, traffic will start accelerating back up to the road speed limit, which will take another 50 to 100 m. In reality, vehicle acceleration and deceleration will not be linear with distance, as depicted in figure 10, but this is just to give an idea of what happens.

For the analysis in this report, it should be determined what area to analyse. For a static or DTA traffic model, for instance, the link between two urban intersections would usually regarded as a whole, and the speed of each vehicle is considered to be constant and equal over this link. A microsimulation model will probably model the acceleration and deceleration profile of each vehicle over the link in more detail. While the average speed over the link will be equal for both types of models, the latter will then give a lower average speed over the acceleration and deceleration segments, and a higher average speed over the segment in between.

For the analysis of the intersection calculations, both the acceleration and the deceleration area will be analysed. Both situations will be defined separately below. It should be noted that the intersection type modelled here is a ‘stop sign crossing’, thus all traffic comes to a stop before the crossing and start accelerating from zero km/h. This is, from a noise point of view, a ‘worst case scenario’; a crossing with traffic lights, for instance, will also have periods of green light where traffic will flow through without decelerating, or at least not to a full stop. The difference between this situation and the free-flowing urban traffic will therefore be less for some other intersection types.

Downstream acceleration

The *acceleration* section will be defined as:

- a total traffic intensity of 1200 vehicles/hour,
- 5% heavy motor vehicles, of which 80% cat. 2 and 20% cat. 3 vehicles,
- a distribution of vehicle speeds for light and heavy motor vehicles as depicted in figure 11, corresponding to traffic accelerating from 1 km/h to the speed limit of 50 km/h,
- an acceleration distribution ranging approximately from 0 to +2 m/s^2 which includes a trend for slow vehicles to accelerate more.

Figure 12 shows the vehicle speed/acceleration distribution of the randomly generated vehicle values.

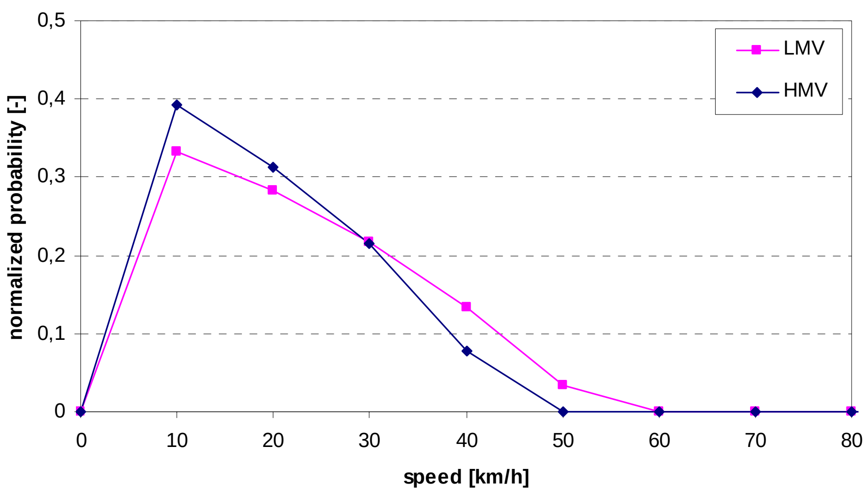


figure 11: Input speed distribution for intersection downstream traffic

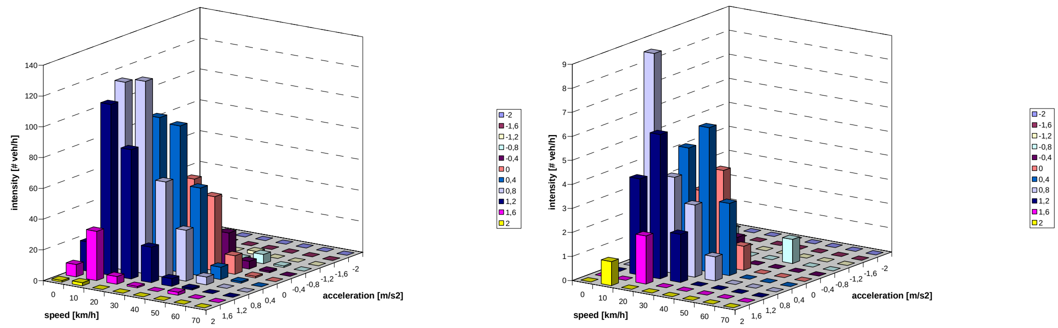


figure 12: Distributions of generated random vehicle speed and acceleration values for light motor vehicles (left) and heavy motor vehicles (right) downstream of an intersection

Upstream deceleration

The *deceleration* section will be defined as:

- a total traffic intensity of 1200 vehicles/hour,
- 5% heavy motor vehicles, of which 80% cat. 2 and 20% cat. 3 vehicles,
- a distribution of vehicle speeds for light and heavy motor vehicles as depicted in figure 13, corresponding to traffic decelerating from 1 km/h to the speed limit of 50 km/h,
- an acceleration distribution ranging approximately from 0 to -2 m/s^2 which includes a trend for fast vehicles to decelerate more.

Figure 14 shows the vehicle speed/acceleration distribution of the randomly generated vehicle values.

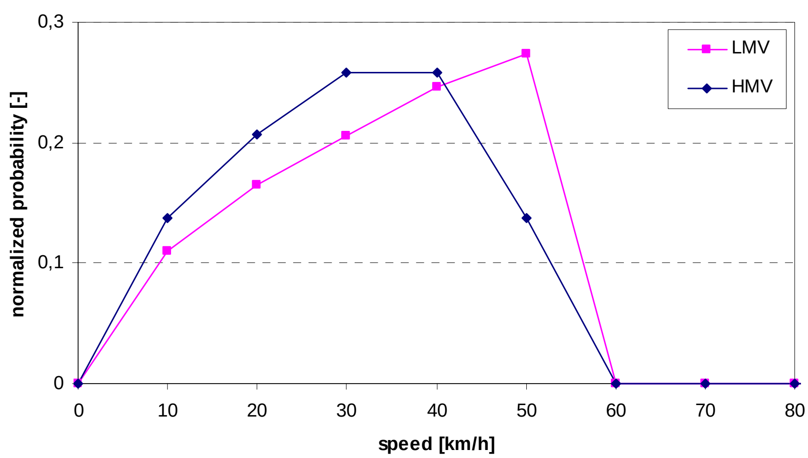


figure 13: Input speed distribution for intersection upstream decelerating traffic

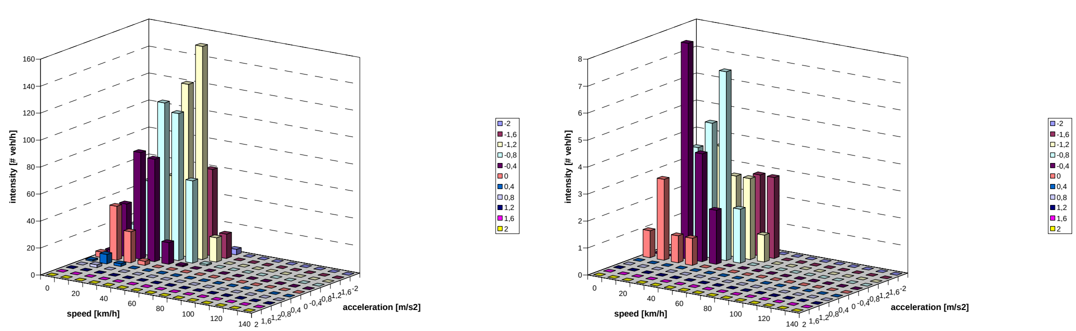


figure 14: Distributions of generated random vehicle speed and acceleration values for light motor vehicles (left) and heavy motor vehicles (right) upstream of an intersection

5.2 Analysis of typical traffic situations

5.2.1 Motorway traffic

table II: Calculated $L_{W,line,eq}$ in dB(A) from the four calculation methods, for a motorway situation

	less detail ← → more detail			
	A	B	C	D
$L_{W,line,eq,1}$	122,99	123,19	123,26	123,21
$L_{W,line,eq,2}$	112,52	112,71	112,79	112,70
$L_{W,line,eq,3}$	117,13	117,31	117,43	117,34
$L_{W,line,eq}$	124,29	124,49	124,57	124,51

In table II, the $L_{W,line,eq}$ values calculated for each calculation method, as presented in paragraph 4.2, are given. It should be noted that the resulting $L_{W,line,eq}$ is probably not as accurate as two decimals, but these are given here only because some values are very alike.

The $L_{W,line,eq}$ for method D is calculated by taking the $L_{W,line,eq,i}$ of each separate vehicle and adding these values energetically and is thus most representative of the actual situation. This value is therefore regarded as the reference. It can be seen from the other values that:

- the least detailed method (A) produces the largest deviation the maximum error of 0,2 dB(A) below the reference; this model includes only the average speed and intensity for each vehicle category;
- the difference between methods B (including a speed distribution) and C (including also an acceleration distribution) models is negligible; both values correspond within 0,1 dB(A) with method D.

It is concluded from this analysis that the simplest model, with only the average speed and vehicle intensity, is already quite close to the reference result. The dominating parameters for a highway situation are thus the average speed and vehicle intensity, and also the percentage of heavy motor vehicles. However, the error of 0,2 dB(A) could be eliminated by the incorporation of a rough speed distribution with a resolution of 10 km/h, i.e. speed ranges of 10-20, 20-30, etc. The B method result shows no significant deviation from the reference model.

The incorporation of an acceleration distribution does not increase the accuracy of the results for the motorway situation. This is mainly explained by the fact that the propulsion noise contribution, and thus the influence of acceleration, is negligible at these high vehicle speeds. It can be seen that the inclusion of a vehicle speed distribution does increase the accuracy.

5.2.2 Urban traffic

table III: Calculated $L_{W,line,eq}$ in dB(A) from the four calculation methods, for an urban road situation

	less detail ← → more detail			
	A	B	C	D
$L_{W,line,eq,1}$	109,94	110,29	110,74	110,63
$L_{W,line,eq,2}$	102,12	102,34	102,50	102,43

$L_{W,line,eq,3}$	100,99	101,26	102,18	102,09
$L_{W,line,eq}$	111,06	111,38	111,84	111,74

In table III, the calculated sound levels for the four calculation methods applied to a typical urban road situation are given. From these values, it may be concluded that:

- the methods C and D agree within 0,1 dB(A),
- the $L_{W,line,eq}$ from the simplest model (A) is 0,7 dB(A) lower, and that from method B is 0,4 dB(A) lower, than that from the reference model D.

As can be seen from these results, the influence of the acceleration on the $L_{W,line,eq}$ is larger than for the motorway situation, which explains the larger error made by the B method. Although an error of 0,7 dB(A) may seem relatively small, it cannot be ignored; 0,7 dB(A), for instance, equals an error in the total vehicle intensity of 18%, which is considerable.

This difference with the highway situation is due to the lower average vehicle speed, which means the rolling noise will become relatively less important and the acceleration correction factor will be more dominant. Furthermore, the actual acceleration values at these lower vehicle speeds are higher than on a highway situation. Thus, the incorporation of the acceleration has a considerable positive influence on the accuracy of the resulting $L_{W,line,eq}$. Here, a division into acceleration value ranges of 0 – 0,4 – 0,8 – etc. already gives a large improvement.

5.2.3 Intersection modelling

table IV: Calculated $L_{W,line,eq}$ in dB(A) from the four calculation methods, for the acceleration and deceleration area of an intersection

acceleration area				
	A	B	C	D
$L_{W,line,eq,1}$	105,86	106,62	109,59	110,40
$L_{W,line,eq,2}$	98,36	99,10	103,02	103,28
$L_{W,line,eq,3}$	98,04	98,18	102,93	103,98
$L_{W,line,eq}$	107,14	107,82	111,16	111,93
deceleration area				
	A	B	C	D
$L_{W,line,eq,1}$	106,79	107,42	106,01	106,25
$L_{W,line,eq,2}$	98,72	99,25	97,08	97,18
$L_{W,line,eq,3}$	98,15	98,51	95,26	95,15
$L_{W,line,eq}$	107,90	108,50	106,84	107,04

In table IV, the results for each of the four calculation methods are shown for the acceleration and deceleration section of an urban intersection. From these values, it can be seen that the variations are relatively large, compared to motorway and urban traffic situations:

- for the acceleration area, the difference between methods A/B and methods C/D is more than 3 dB(A); the difference between methods C and D is approximately 0,8 dB(A);

- the result from method C is still 0,7 dB(A) lower than that from method D;
- for the deceleration area, the values of all methods correspond within 1,1 dB(A) to the most detailed method D.

Apparently, for the acceleration section of the intersection, the inclusion of an acceleration correction seems to be essential. Furthermore, an analysis of the acceleration within ranges of 0,4 m/s^2 does not yet provide very accurate results. In chapter 6 the sensitivity of the model for the ‘resolution’ of speed and acceleration ranges is investigated further.

5.2.4 Additional remarks about congestion

Congested traffic is a situation receiving a lot of attention due to the negative effects, such as increased travel times and increased air pollution. Congestion is, however, from a noise point of view, relatively unimportant. This is because the average vehicle speed is generally much lower than for free-flowing traffic, therefore the rolling noise levels are relatively low. Due to higher vehicle acceleration the propulsion noise levels may however be much higher than for free-flowing traffic. From the comparison of paragraphs 5.2.2 and 5.2.3, however, it can be concluded that even if most of the traffic is accelerating at the same time (as was the case downstream of the intersection), the noise levels are still not higher than those of the free-flowing traffic, driving at higher speeds.

A second effect that further weakens the importance of congested traffic for noise maps is the fact that noise levels are calculated as long-term average values. Since congested traffic only occurs for a few hours each day, the equivalent noise levels will be dominated by the free-flowing traffic. Congested traffic will therefore not be regarded as a special situation requiring extra attention in WP2.

6 Model sensitivity and accuracy

In this paragraph, the sensitivity of the output of the noise source model for the traffic flow to the traffic input parameters is regarded. This analysis gives insight regarding the accuracy of traffic flow data that is needed to reach a certain level of accuracy for the resulting noise levels.

6.1 Vehicle intensity and traffic composition

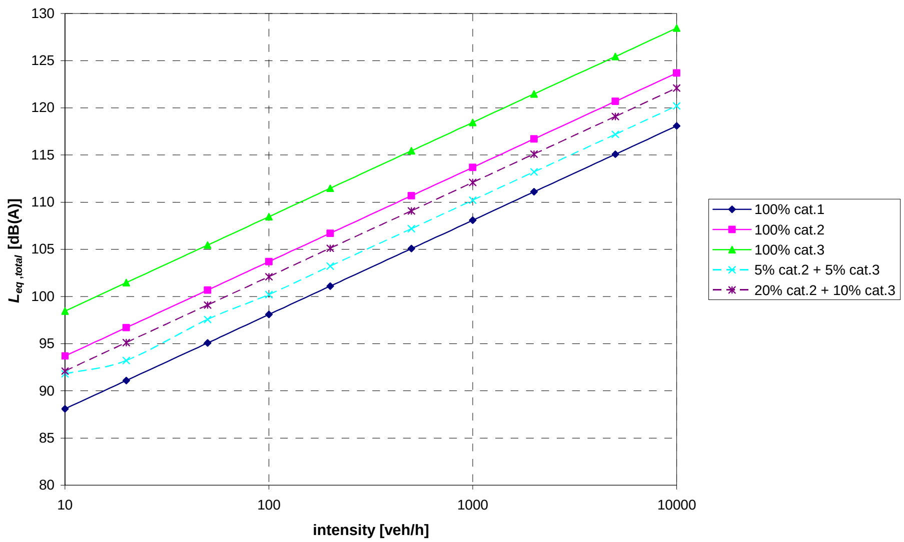


figure 15: Calculated $L_{W,line,eq}$ as a function of traffic flow intensity, for various compositions of categories at 50 km/h and no acceleration

First, the $L_{W,line,eq}$ is calculated for a vehicle flow as a function of its intensity. The calculation is done using method A, thus no random distribution of vehicles is used. The $L_{W,line,eq}$ is shown in figure 15 as a function of the (logarithmic) traffic intensity, using different ratios of light, medium heavy and heavy vehicles. From this figure, it can be seen that for any composition of traffic flow, the $L_{W,line,eq}$ increases linearly with the logarithm of the total intensity. This can also be seen from the underlying equation (4.1). A doubling of the intensity at the same vehicle speed (no congestion) causes the traffic density to double, and thus an increase of 3 dB(A) in equivalent noise level. Or, alternatively, to achieve an accuracy of 1 dB(A) in the final result, an accuracy of 25% is needed for the traffic intensity.

In figure 16, the $L_{W,line,eq}$ is given as a function of the percentage of heavy motor vehicles. Here, an equal ratio of category 2 and category 3 vehicles is assumed for each percentage. The graph shows multiple series, for 50 and 80 km/h and for acceleration values of -1, 0 and +1 m/s^2. From this graph, it can be concluded that the influence of the percentage of heavy motor vehicles is larger if the propulsion noise is more dominant, for instance for accelerating traffic. At 80 km/h and -1 m/s^2, the $L_{W,line,eq}$ increases with only 4 dB(A) with the % heavy motor vehicles (HMV) increasing from 0 to 50%, whereas at 80 km/h and +1 m/s^2 the increase is 8,5 dB(A).

Furthermore, due to the logarithmic influence of the intensity, the sensitivity for errors in the % HMV is larger if the actual number of HMV is low (less than 10%). In general, these conclusions are stronger for the category 3 (heavy) vehicles than for the category 2 (medium heavy) vehicles.

Concluding, it can be roughly stated that an accuracy of ±1 dB(A) in the final result requires the % of HMV to be known within ± 5%.

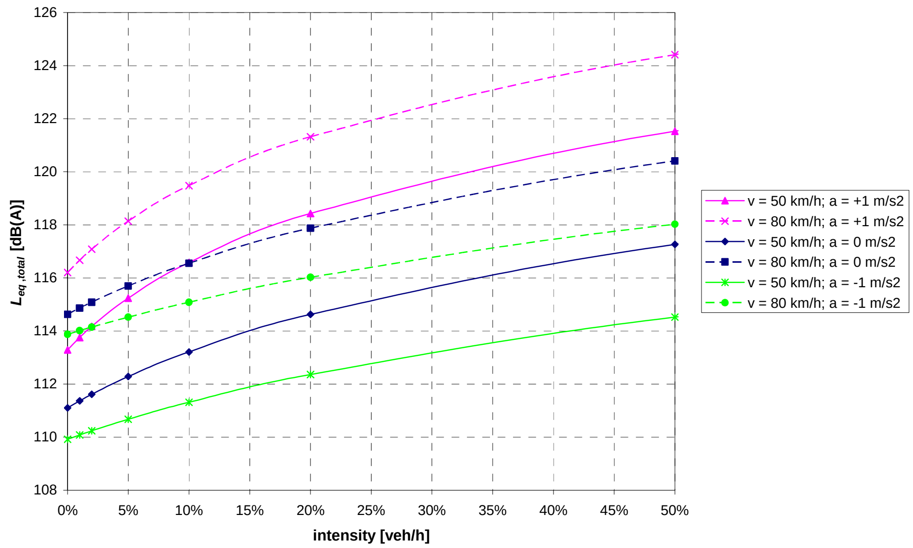


figure 16: Calculated $L_{W,line,eq}$ as a function of the % of heavy motor vehicles, of which 50% is medium heavy, for an intensity of 2000 veh/h at 50 and 80 km/h and acceleration varying from -1 to +1 m/s^2

6.2 Average speed

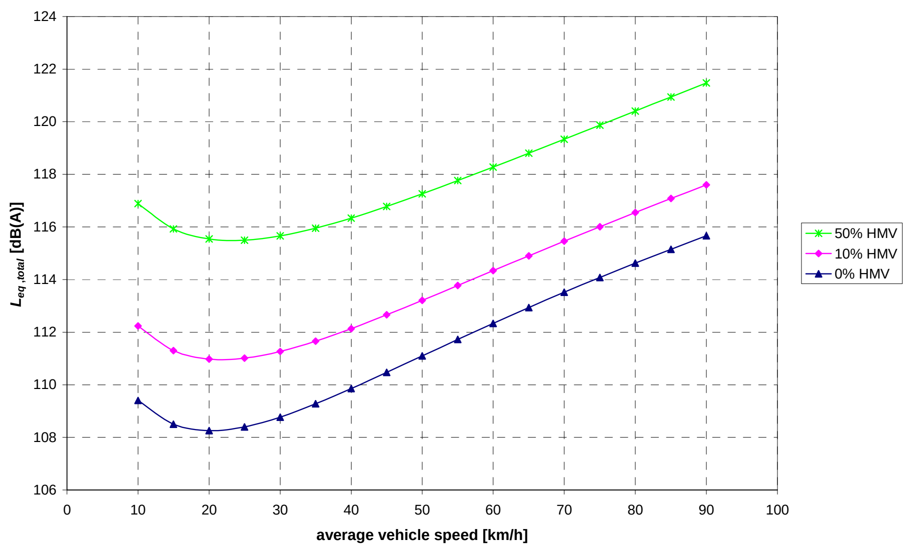


figure 17: Calculated $L_{W,line,eq}$ as a function of the average vehicle speed, for a traffic intensity of 2000 veh/h with 0%, 10% and 50% heavy motor vehicles

In figure 17, the $L_{W,line,eq}$ of a steady vehicle flow of 2000 veh/h is shown as a function of the average vehicle speed. It can be concluded from this graph that above 40 km/h, the equivalent sound level increases approximately linear with the vehicle speed, and an error of 10 km/h in the average vehicle speed causes an error in the $L_{W,line,eq}$ of approximately 1 dB(A).

It is also clear from this graph that below 40 km/h, the relation is no longer linear. There is a minimum in the curve at 20 km/h, below which the sound level increases with decreasing vehicle speed. This is caused by the correction of $10 \cdot \log(Q/v)$, which expresses the effect that a slower vehicle causes more equivalent noise since it is in the neighbourhood for a longer time; it may also be explained by the fact that the vehicle density is generally larger at lower vehicle speeds.

6.3 Speed distribution

table V: Influence of the resolution of the speed ranges on the $L_{W,line,eq}$ for an urban 50 km/h road

speed range resolution	$L_{W,line,eq}$ [dB(A)]
1 km/h	111,30
2 km/h	111,24
5 km/h	111,29
10 km/h	111,26
20 km/h	111,31
40 km/h	111,04

In paragraph 5.2, the distribution of speeds for methods B and C was given in ranges of 10 km/h. It was argued then that the analysis into larger or smaller ranges might influence the final $L_{W,line,eq}$. In table V, the $L_{W,line,eq}$ calculated from the data for the urban 50 km/h road (see paragraph 5.2.2) are analysed again, with different resolutions of the speed ranges, as indicated. Thus, a resolution of 1 km/h means an analysis into speed ranges of 10 – 11 – 12 – … km/h, whereas a resolution of 20 km/h means speed ranges of 0 – 20 – 40 - … km/h. From table V it can be concluded that the difference between the various resolutions is negligible up to 20 km/h. Thus, the inclusion of a speed distribution increases the accuracy of the result (see 5.2.2), even if this resolution is not very detailed.

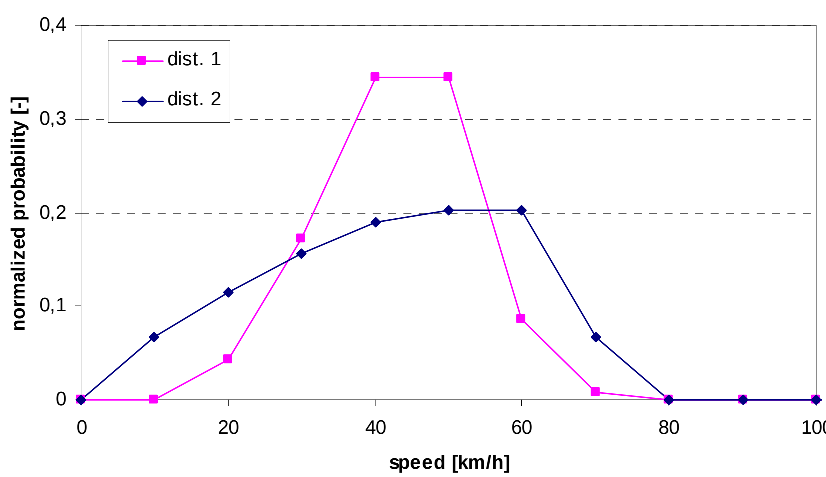


figure 18: Two different speed distributions, with the same average speed

Though the resolution of the speed distribution does not matter, the actual shape of the distribution is of greater importance. Of course, if the error in the speed distribution (the number of vehicles per speed range) is such that the *average* speed is influenced, or if the *total* number of vehicles is different, then the error to be made is evident. But even if this is not the case, the $L_{W,line,eq}$ is influenced by the actual shape of the distribution, due to the equal-energy averaging of the noise levels.

In figure 18, two speed distributions are given for an urban 50 km/h that have roughly the same average speed, but with different shapes. In table VI, the sound levels calculated from a random distribution of 2000 vehicles is given for each distribution. These levels are computed using method B (see 4.2.2), disregarding any information on acceleration. It can be seen from these values that the noise level for the broader speed distribution is 0,5 dB(A) higher, even though the average speed is slightly lower.

table VI: Influence of the shape of the speed distribution on the $L_{W,line,eq}$ for an urban 50 km/h road

	avg. speed [km/h]	$L_{W,line,eq}$ [dB(A)]
distribution 1	42,8	111,9
distribution 2	41,9	112,4

6.4 Acceleration

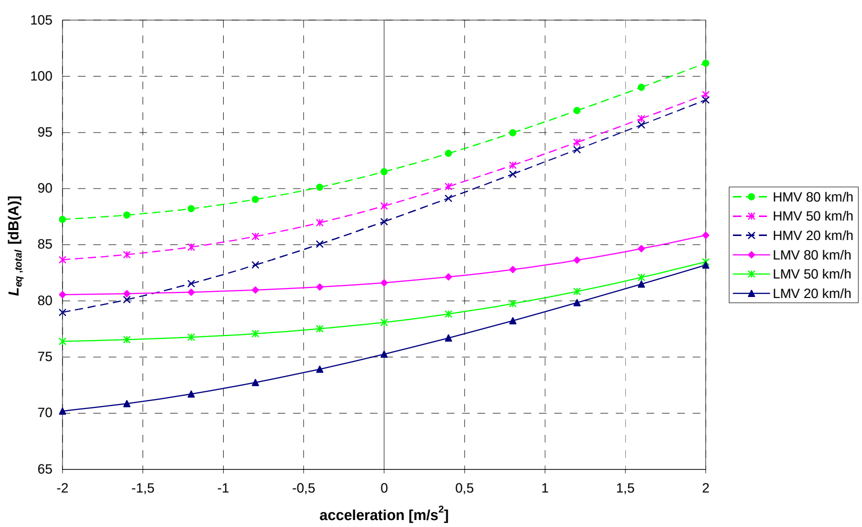


figure 19: Calculated $L_{W,line,eq}$ as a function of the vehicle acceleration, for a single light or heavy motor vehicle at 20, 50 and 80 km/h

For an entire stream of vehicles, it is not representative to analyse its ‘average acceleration’, since the acceleration will be quite different for each vehicle; calculating the noise level of 2000 vehicles all at the same speed and accelerating at the same time with 1 m/s^2 does not seem to be very realistic. In figure 19, therefore, the $L_{W,line,eq}$ of a single light or heavy (cat. 3) motor vehicle is given as a function of the acceleration, for different vehicle speeds.

From this figure, it can be seen that:

- in general, the noise emission of heavy motor vehicles is more sensitive to acceleration than light motor vehicles;
- in general, the noise emission of a vehicle is more sensitive to the error in the acceleration if it is accelerating than if it is decelerating; this is due to the rolling noise becoming dominant for negative acceleration values;

- for an accelerating light motor vehicle, an accuracy of approximately 0,3 m/s^2 is needed for a maximum error in $L_{W,line,eq}$ of 1 dB(A); for a heavy motor vehicle, this is approximately 0,2 m/s^2
- for an decelerating light motor vehicle, an accuracy of approximately 0,6 m/s^2 is needed for a maximum error in $L_{W,line,eq}$ of 1 dB(A); for a heavy motor vehicle, this is approximately 0,4 m/s^2.

table VII: Influence of the resolution of the acceleration ranges on the $L_{W,line,eq}$ for an urban 50 km/h road

acceleration range resolution	$L_{W,line,eq}$ [dB(A)]
1 m/s^2	111,8
0,5 m/s^2	112,0
0,2 m/s^2	111,9
0,1 m/s^2	111,9
0,05 m/s^2	111,9
0,02 m/s^2	111,9

Like the speed distribution, the resolution of the acceleration ranges may influence the calculation of the $L_{W,line,eq}$. In table VII, the $L_{W,line,eq}$ is given for various resolutions of the acceleration ranges. Here, the sound levels are calculated using method C from paragraph 4.2.

From this table, it may be concluded that the acceleration ranges may be as coarse as 0,2 m/s^2 to give an accuracy of the $L_{W,line,eq}$ of roughly 0,1 dB(A). Again, this is only the influence of the range resolution, the actual shape of the acceleration distribution may have a larger influence.

6.5 Accuracy

In the Description of Work for the HARMONOISE project, it is stated that the required accuracy is still to be discussed, as well as the exact definition of 'accuracy'. However, a preliminary statement about accuracy is given as follows:

> *For the latter [the computational methods] the following ambition levels can be defined (order of magnitude):*
>
> - *up to 1 dB standard deviation for distances up to 100 m between source and receiver,*
> - *up to 2 dB s.d. for distances up to 2000 m in flat surroundings,*
> - *up to 5 dB s.d. for distances up to 2000 m in hilly surroundings,*
> - *and up to 5 dB in urban areas.*

The total accuracy of the final traffic noise model is dependant on the accuracy of i) the noise source model, ii) the traffic flow model and iii) the propagation model. Currently, there is no accurate information on the accuracy of each part, but it may be stated already that the ambition levels above are quite demanding, if feasible at all. More details on the required accuracy for the traffic flow model and its feasibility should follow in the course of the IMAGINE project.

7 Action plans

In addition to providing data for noise mapping, traffic models will also be used to provide data for noise action planning, which is required when noise levels exceed limits. This paragraph discusses briefly what is expected of action plans: what sort of measures can be expected to be included in action plans, and on what geographical scale are they likely to be deployed? Together, this results in (additional) requirements for traffic models.

7.1 Categories of action plans

The final goal of the IMAGINE project is to support the creation of noise maps, and, when necessary, *action plans* for noise abatement. For road traffic noise, action plans may include various types and levels of noise reduction measures, a large number of which has been listed in the State-of-the-Art report [6]. In this report, noise action plans are divided into two categories: source noise reduction and traffic volume reduction. The well-known category of noise propagation measures (e.g. noise screens) is not regarded here, the focus is on *source* noise measures.

The first category are measures to reduce the noise production of each single vehicle, which can be divided into:

- measures at the road level: application of silent road types, maintenance;
- measures at the tyre level: application of silent tyre types;
- measures at the driveline level: silent engines, outlets, aerodynamic noise reduction.

The second category are measures to reduce the noise production of the entire traffic flow by influencing the traffic parameters:

- the total traffic intensity;
- the traffic composition, i.e. reduction of the number of heavy and/or noisy vehicles;
- the average speed;
- reduction of acceleration/deceleration or stop-and-go traffic.

7.2 Geographical scale

Besides the general type of the action plans, or the level at which it intervenes, a division may be also be based on the geographical scale that is affected by it. The geographical scale of action plans may range anywhere from

- national, or even European level,
- regional (i.e. province or county) level,
- city level,
- street level, and
- intersection level.

National or supranational measures usually have a legal character, i.e. a new law adaptation, or an economic character, which may be the promotion of public transport, or the introduction and adaptation of fees or subsidies. The regional level mainly concerns the motorway and/or highway infrastructure and city-to-city traffic. The city level includes the structure of the urban road network, and land use planning, but may also be legal or economic measures at a local (municipality) scale. Finally, the city may take decisions at the *street* or *intersection* level.

For source noise reduction, driveline noise and tyre design measures are usually taken at the (supra)national level (type approvals, maintenance requirements, etc.). The application of silent road types may be at the regional level for highways, or at the street level for urban roads. Traffic flow reduction action plans may be applied at any level: at the (supra)national level for legal or economic measures, at the regional level for highways, at the city level for both the design of the urban road network and specific legal or economic measures at a local scale, and at the street or intersection level for local traffic flow measures, i.e. traffic signalling, road signs, and intersection design.

7.3 Requirements for the traffic model

The evaluation of action plans may require specific requirements for the traffic model that is to be used. Each combination of the types of action plans from 7.1 and the geographical scales from 7.2 has different requirements for the traffic model. A detailed microsimulation model that gives all traffic parameters may be suitable or even indispensable for traffic flow measures at the street or intersection level, but it is not realistic to apply such a model to the national highway network.

In general, the requirements for the traffic model are defined by the i) the required level of detail of the traffic output parameters, as demonstrated in the previous analyses, and ii) the required geographical scale and complexity of the road network under study, and iii) the type of measure proposed.

8 Conclusions and future work

For the creation of long-term average noise maps for road traffic noise, the road noise source model developed within the HARMONOISE project, which calculates the instantaneous sound power level of one single vehicle, has to be combined with a traffic flow model in order to produce data for traffic flows over a certain period of time. In this report, the requirements for the traffic flow model output have been assessed in terms of the desired level of detail for an accurate calculation of noise levels.

8.1 Conclusions

With respect to the various levels of detail available, it can be concluded that:

- the minimum amount of information to allow the calculation of the sound power level of a certain road segment is
    - the traffic intensity for each of the main vehicle categories,
    - the average speed of the vehicles within each category;
- to calculate the yearly averaged noise indicators L_{den} and L_{night}, these values should be known
    - per day, evening and night period, and
    - if possible, for each separate road lane and driving direction;
- further information which could enhance the accuracy and representativeness of the results is:
    - the distribution of vehicle speeds, i.e. the number of vehicles within each speed range,
    - the distribution of acceleration values;
- the highest level of detail is to have the vehicle category, speed and acceleration for each vehicle at each road lane segment, at any time of day.

With respect to the theoretical exercise of assessing the noise levels for a number of typical traffic situations, it is concluded that:

- for a motorway situation, characterised by high vehicle speeds and little acceleration:
    - using only the traffic intensity and average speed results in a minor error of 0,2 dB(A);
    - inclusion of a rough speed distribution gives an improvement, but the use of acceleration values shows no further positive influence;
- for an urban 50 km/h road situation, characterised by lower vehicle speeds and considerable acceleration:
    - the inclusion of a distribution of acceleration values is desirable; the inclusion of acceleration data has a substantial impact on the overall noise level;
- for the modelling of a road intersection:
    - detailed modelling of the area of accelerating traffic, characterised by mostly accelerating vehicles at very low speeds, is more important than the deceleration area, due to the dominance of high propulsion noise levels;
    - the inclusion of acceleration values seems to be very important: neglecting acceleration resulted in a deviation of > 3 dB(A) for the acceleration area;
    - the use of individual vehicle data is advisable; in the example given this was needed to reduce the error to a value below 0,8 dB(A);

  - the intersection modelled here was a 'stop sign' crossing; the difference with free-flowing traffic will be somewhat less for intersection types where traffic does not (always) come to a full stop, for instance at traffic lights, roundabouts, etc.
- in general:
  - situations with low vehicle speeds and high acceleration values demand more detailed information;
  - the level of detail is particularly important for intersection modelling. This is an item for further research in WP2;
  - congested traffic is relatively unimportant for noise mapping, due to the low average vehicle speeds and the limited periods in which it occurs.

With respect to the sensitivity of the noise source model for the various traffic parameters, it may be concluded that:

- doubling the vehicle intensity results in a change of (only) 3 dB(A);
- the influence of the traffic composition, i.e. the percentage of heavy motor vehicles, has a large influence especially for accelerating traffic (up to 15 dB(A) from 0% to 100%); the sensitivity of errors for this percentage is larger if the total number of HMV is low;
- a deviation in the average vehicle speed of 10 km/h causes an change in the equivalent noise level of approximately 1 dB(A); this change is somewhat lower for vehicle speeds below 40 km/h, because the influence of a higher vehicle speed is partially cancelled by the increase of the vehicle density;
- the inclusion of a vehicle speed and/or acceleration distribution may have a significant positive influence on the results, but the resolution of these distributions is not very important: using distributions of 20 km/h and 0,2 m/s^2 still results in an change of < 0,1 dB(A); the actual shape of these distributions, however, is more important.

Roughly speaking, it may be concluded that an error of 1 dB(A) in the final equivalent sound power level requires an accuracy of:

- 25% in the total vehicle intensity,
- 5% in the share of heavy motor vehicles,
- 10 km/h in the average vehicle speed,
- 0,3 m/s^2 in the acceleration for an accelerating vehicle, and 0,8 m/s^2 for a decelerating vehicle.

The conclusions above imply that accuracy in traffic parameters is more important than the level of detail for urban and highway situations. This means that, given the required accuracy, which is likely to be in the order of 1 dB, information should be provided about the accuracy that can be expected from the output of traffic models (intensities, speeds, etc.), and what to do if this information is not accurate enough.

For intersection modelling, the level of detail is more demanding and should receive separate attention. But within the development of calculation strategies for urban and highway situations, the appropriate level of detail of modelling should receive attention as well. However, if the traffic parameters (intensities, speeds, percentages of heavy motor vehicles) cannot be modelled accurately enough, there is no point in increasing the level of detail in the input data, i.e. it is more important to accurately estimate the percentage of heavy motor vehicles than to put extra effort into obtaining the acceleration distribution of traffic.

8.2 Recommendations for future tasks

This document has provided more insight into the requirements for the data that are to be provided by the traffic models. Continuing from here, tasks 2.2 and 2.3 of Work Package 2 should pay attention to:

- possible methods for aggregation from the instantaneous, single vehicle sound power level to the equivalent sound power levels for an entire traffic flow;
- information on the realistic accuracy of the traffic model output and the availability of data in the Member States;
- more detailed strategies for the actual calculations of traffic flow source noise levels in practice: which models should be applied in which situations, and which typical traffic situations need which level of detail in the modelling. The exercises in the report already showed that intersections should receive special attention. Intersection modelling requires more detailed data than more flowing traffic. It may, however, be much too demanding for the end-users to develop these detailed models for their entire research areas. A solution may be to develop a database of standard intersections with speed/acceleration profiles, or to generate a parameter model for intersections based on their type, number of exits and road lanes, posted speed, etcetera. These strategies should be developed in Task 2.3.

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[2] HAR1TR-021204-SP03, “To evaluate the Sound Power Level from the measured L_{eq} of a passing vehicle”;
[3] HAR21MO020204TNO01, “Calculation of traffic noise levels – revised concept”;
[4] HAR21MO020204TNO02, “Calculation of traffic noise levels near the driving line”;
[5] HAR32TR-030715-DGMR04, “Engineering method for road traffic and railway noise”, draft version 4, 25-02-2004;
[6] IMA10TR-040402-AEA01, “IMAGINE – State of the Art”, deliverable 2 of the IMAGINE project, final version, 23-04-2004;
[7] Directive 2002/49/EC of the European Parliament and of the Council, relating to the assessment and management of environmental noise (END – European Noise Directive), 25 June 2002.

[7] All the HARMONOISE documents are available for download trough the *private area* of the website http://www.harmonoise.org