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

# Development of strategies for the use of traffic models for noise mapping and action planning

***WP2: Demand and traffic flow modelling***

WP-leader: TNO

Project Co-ordinator: AEA TECHNOLOGY RAIL BV

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## EXECUTIVE SUMMARY

A first part of this report continues the efforts made in Task 2.1 to quantify the accuracy goals for traffic parameters, in order to produce noise maps with a well-defined accuracy. The accuracy demands depend on the magnitude of the traffic parameters, and simple criteria on individual parameters are therefore not always sufficient. Hence, this report focuses on combined effects and accuracy issues in a realistic context. Based on case-studies, traffic intensity, traffic speed and traffic composition on the major roads seemed to be of first importance for strategic noise mapping purposes for major roads. For noise mapping of urban roads, the use of acceleration and deceleration data, in addition to the firstly mentioned traffic parameters, lead to further improvements. Correction factors can be used in case the traffic model is not capable to provide this data. The importance of low flow roads in urban context depends on the required accuracy at lower exposure levels. Further improvements in the accuracy of noise mapping of both major and urban roads may come from including speed distribution, and from accounting for long term (or diurnal) variations in flow patterns.

It is often hard to obtain the needed accuracy with common traffic models, even for the traffic parameters that are of first importance. Therefore, some major shortcomings are addressed, and some guidance is provided to improve the traffic model outcomes. Recommendations and references to dedicated literature are provided specifically for demand modelling, traffic composition modelling, intersection modelling and the problem of low flow roads. Modelled speed is treated briefly. Taken into account its large influence on the accuracy of the noise map, and the problems involved (or lack of information on its accuracy) with traffic modelling, this will be an important issue to be covered in task 2.4 on additional data collection.

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# 1 Introduction

## 1.1 Background

For the production of strategic noise maps as required under the EU Directive 2002/49/EC, improved assessment methods for environmental noise will be required. Noise from any major noise source, be it major roads, railways, airports or industrial activities in agglomerations, needs to be included in the noise mapping. For road and rail, improved methods have been developed in the 5th framework HARMONOISE project (see www.harmonoise.org). These methods will be adapted for aircraft and industrial noise in the IMAGINE project. Noise source databases which are being developed in IMAGINE for road and rail sources will allow a quick and easy implementation of the methods in all member states. The IMAGINE project develops guidelines for noise mapping that will make it easy and straightforward to assess the efficiency of noise action plans.
IMAGINE will provide the link between HARMONOISE and the practical process of producing noise maps and action plans.

The objective of WP2 of the IMAGINE-project is to provide guidelines and examples for an efficient link between traffic modelling (including the modelling of traffic demand and traffic management measures) on the one hand and noise mapping and action planning on the other. To this end, the partners in this work package study the incorporation of road traffic flow modelling in noise emission modelling, and develop practical solutions for the combination of the two disciplines, including recommendations for additional data collection.

## 1.2 Purpose of task 2.3 and this report

The main purpose is to give guidelines and recommendations for the modelling of traffic in order to produce a sufficiently accurate noise map. The final guidelines will contain in first place a list of traffic variables that are needed for the road noise source model. Distinction is made between traffic parameters that are required, and those that are less important. It is further indicated which traffic parameters are most important in the context of noise mapping and noise action planning, or stated otherwise, how uncertainty in these parameters influences uncertainty in the noise calculations. Other aspects of traffic modelling, important in the context of noise mapping and action planning, are assessed. A main purpose of this report is providing guidance on available options (in the near future) to improve traffic models, their input and (the aggregation of) their output. Also, an indication of the efforts involved to improve traffic models is assessed.

Different uses of the harmonised noise model can be strategic mapping (major roads and all roads in agglomerations), local action planning and detailed calculations at the unit level. Where possible, we will cover these different uses, but the focus of the guidelines will be on noise mapping and, to a lesser extent, on noise action planning. The guidelines will be based on the research on accuracies and improvements to traffic models, presented in this report.

## 1.3 Outline of this report

In a first chapter, the influence of the accuracy of traffic parameters on the accuracy of noise mapping is investigated. The dominant traffic parameters, i.e. those that influence the accuracy of noise maps the most, must receive special attention and are assessed. An overview is given of the desired accuracy of individual traffic parameters. In practice, one is faced with a combination of traffic parameters, each with their typical ranges of uncertainties. First, these ranges for a number of macroscopic traffic parameters are assessed, and next, the resulting combination of these parameters as concerns noise emissions are estimated with Monte Carlo Simulations. A case-study in a suburban area allows investigating the (spatial) importance of microscopic traffic parameters in a realistic situation (so including detailed propagation of sound). In a next part, the required temporal resolution for traffic data is investigated. The purpose is to balance the temporal resolution of traffic intensity against the error on $L_{den}$ values. A number of case-studies allow assessing the importance of daily, weekly, seasonal and year-by-year variation in some traffic parameters. The problems related to modelling low intensity roads, demand modelling, intersection modelling and speed modelling are summarized.

In a second chapter, strategies to improve traffic modelling in the context of noise mapping are presented. Demand modelling, fleet composition, and low flow roads are treated in detail. The problem of intersection modelling is studied thoroughly based on literature review and a case-study. A methodology to derive (spatial) correction factors near intersections is developed.

In a third chapter, traffic modelling for the purpose of noise action planning is specifically addressed. Recommendations concerning a good choice of the type of traffic model for assessing the effect of specific measures are given, and a number of problems that can be expected are pointed out.

In a last chapter, conclusions are drawn and recommendations are made, and some aspects of the additional data collection problem are addressed.

# 2 Influence of the accuracy of traffic modelling on the accuracy of noise mapping

In this Chapter, the requirements with respect to the accuracy of the traffic parameters for noise mapping is treated. Traffic models usually do not produce the desired traffic parameters in the right units of measurement, with the desired level of accuracy.

A first question is therefore what the maximum uncertainty in traffic parameters may be. This is discussed in sections 2.1 and 2.2.1, for individual and combined errors respectively. Two fundamental questions may be posed in consideration of the impacts of traffic modelling on noise mapping. These questions are:

- What are the expected errors or uncertainties associated with output parameters from traffic modelling?
- Given an imprecision or uncertainty in traffic model parameters, what will be the expected accuracy and range of uncertainties for noise mapping produced by using those parameters?

Both of questions above may be couched in terms of “what are the parameters, and their imprecisions and uncertainties, as available now from current best practice?” or in terms of “if we need to achieve a certain standard how uncertain can we be in our future modelling and what assumptions may we make?” Much effort has already been taken to answer the questions from either approach. Examples of the former include WG-AEN’s “Good Practice Guide” [1] for use with Interim Computational methods or IMAGINE WP1 work on the Harmonoise model. Examples of the latter include the work of Shilton *et. al.* [2][3]or Trow and Shilton [4]. Eventually the two approaches must be reconciled to further inform future best practice. Note that the distinction between an imprecision and an uncertainty with relation to noise mapping has been made by De Muer and Botteldooren [5], namely that: *“Uncertain information can be characterised by partial knowledge of the true value of a statement. Imprecise information is linked to approximate information or not exact information”.*

In the remainder of this Chapter, some other limitations imposed by the traffic models are treated. These can be subdivided in two categories:

- **Inaccuracy caused by the intrinsic characteristics of traffic models:**
    - Which traffic parameters, as used in the road noise source model, are 'part of the model': All traffic models produce intensities and speeds; however, speed distributions and acceleration are not always part of the output. What errors are introduced because of this? This is discussed in Sections 2.2.2 and 2.2.3. Also, not all models make a distinction between vehicle types. It is obvious that the errors caused by that are large, so further investigation in this area is not performed.
    - Spatial aspects (e.g. network representation and detail): what errors can be expected when the network is not as detailed as desired? A case study considering a small region is used for this analysis in Section 2.2.4.

- Temporal aspects: what errors can be expected when certain assumptions are made concerning the variation in time of specific traffic parameters ? This topic is treated in Section 2.3.

- **Uncertainties caused by traffic model input uncertainty:**

  Uncertainty in input data propagates through the traffic model: does the uncertainty increase or decrease? In other words: if an uncertainty of x% is expected in input data, to what uncertainty in the output data will this lead? This is not treated in this report. More information can be found e.g. in Ref. [6].

In addition to these inaccuracies or uncertainties, there are some aspects of traffic modelling that require extra attention when traffic models are used for noise mapping and noise action planning. These are discussed in Sections 2.4 and 2.5. We do not go into uncertainty in measured traffic data (measured data can be used for noise mapping, in theory, but not for action planning).

## 2.1 Desired accuracy of individual traffic parameters

In this section, the sensitivity of the output of the traffic flow noise source model to the traffic input parameters is studied. In each of the following subparagraphs the accuracy for each parameter needed to establish a maximum deviation of 1 dB(A) – plus or minus – in the calculated road noise source level is given.

It is important to realise that the stated accuracy requirements are calculated independently. A certain accuracy level for one parameter is only valid if the other parameters are 100% accurate. So, in order to fulfil an <u>overall</u> accuracy of 1 dB(A), it is <u>not</u> enough to establish each of the given accuracies separately; the total deviation of the result could be as high as the sum of each separate deviation, being 3 dB in total. This is, however, “worst-case”: the effects of inaccuracy in traffic parameters could also cancel each other out. The effect of combining inaccuracies is treated in detail in Section 2.2.

The results given here are a summary of a separate report on this subject. For more details, the reader is advised to [7]. Details on powered two-wheelers cannot be found in this report; research on this subject is still ongoing, though the first results are incorporated here.

### 2.1.1 Intensity

For long-time equivalent noise levels, the dependence on the number of vehicles passing is simply logarithmic. Therefore a doubling of the total traffic intensity, given a constant average speed and fleet composition, results in an increase of 3 dB. An accuracy of ± 1 dB in the final result requires the total intensity to be accurate within ± 25%.

### 2.1.2 Speed

The noise emission of a single vehicle increases with its speed in a rather complicated manner, since the speed dependence of rolling noise is different from that of propulsion noise. Above 40 km/h the sound exposure level (equivalent noise level) increases approximately linear with 1 dB(A) per 10 km/h average vehicle speed. Below 40 km/h a non-linear relation is found, caused by the fact that a slower vehicle produces noise at a specific receiver position for a longer time than a fast vehicle. From 15 to 40 km/h, the change in noise level is less than 1 dB(A) per 10 km/h; below 15 km/h, the dependence is 1 dB(A) per 5 km/h, increasing with lower speeds.

These values are approximately the same for light and heavy motor vehicles. For powered two-wheelers, the dependence is approximately 1 dB(A) per 5 km/h over the entire speed range.

### 2.1.3 Speed distribution

The term “speed distribution” refers to the fact that not all vehicles in each vehicle class drive at the same speed; the distribution of vehicle speeds is a percentage of the vehicle flow driving at a certain speed range, i.e. 40-50 km/h, 50-60 km/h, etc.

If the dependence of the vehicle noise emission on speed were strictly linear, than the distribution of vehicle speeds within the flow would not have an effect on the noise calculation as long as its mean value is correct, but unfortunately this is not the case. However, the requirements for the speed distribution are not very stringent. The resolution of the vehicle speed classes is not very important; speed ranges as wide as 20 km/h (0-20, 20-40, 40-60, etc.) are fine enough. The actual shape of the distribution is more important. A broader speed distribution, with 50%-80% more vehicles in the lower and higher speed ranges instead of in the middle ranges, may have an increase of 0.5 dB(A) on the overall level, though the average speed is the same.

### 2.1.4 Acceleration/deceleration

The dependence of the noise emission of a road vehicle on acceleration (the term "acceleration" also includes negative values, thus "deceleration") is rather complicated. It is i) non-linear, ii) dependent on the vehicle speed and iii) different for each vehicle class. Summarizing the results, a maximum deviation of ± 1 dB(A) in the Sound Exposure Level requires an accuracy of:

- 0.3 m/s$^2$ for light motor vehicles and powered two-wheelers at 20 km/h when accelerating, and 0.6 m/s$^2$ when decelerating;
- 0.2 m/s$^2$ for a (medium) heavy motor vehicle at 20 km/h when accelerating, and 0.4 m/s$^2$ when decelerating;
- at 80 km/h, the required accuracy for light motor vehicles is relaxed to 0.6 m/s$^2$ / 2.5 m/s$^2$ when accelerating / decelerating respectively;
- for (medium) heavy vehicles and powered two-wheelers, there is hardly any relaxation of the requirements at higher speeds.

Values of ± 2 m/s$^2$ are hardly ever exceeded in real traffic, with the exception of two-wheelers and sports cars.

### 2.1.5 Fleet composition

Heavy and medium heavy motor vehicles make more noise than light motor vehicles, and may thus dominate the overall noise level even if the number of trucks is low. If the percentage of heavy + medium heavy vehicles is 20% or less, than the exact percentage should be known within ± 5% of the total vehicle flow (i.e. the % of trucks should be within 5 to 10%, or 15 to 20%), in order to have a maximum deviation of 1 dB(A) in the noise emission. If the total percentage of these vehicles is more than 20%, than the requirement relaxes to ± 10% per dB(A).

Within the total number of trucks, the number of medium heavy vehicles (light trucks) should be known with an accuracy of ± 25%.

For powered two-wheelers, there is not enough data yet to correctly estimate their influence on the overall noise emission. So far, the overall levels of powered two-wheelers seem to lie only slightly above those for passenger cars. However, powered two-wheelers may become dominant in certain frequency bands (imagine the typical "humming" noise of mopeds). It is expected that the percentage of PTW in the total flow will be important mainly for inner-city traffic in Southern European countries.

## 2.2 Effects of combined errors

This part is organized as follows. In Section 2.2.1, focus is on macroscopic traffic parameters. The imprecisions and uncertainties in these types of traffic parameters from traffic models are first identified. In a second part, the magnitude of uncertainty by combining these individual uncertainties is estimated by Monte-Carlo simulations. In Section 2.2.2, focus is on the combination of noise emission and (detailed) sound propagation for some micro-simulation traffic parameters, and their importance is assessed by comparing noise maps for a small study-area. The noise emission as predicted by the micro-simulation model and the HARMONOISE emission module are validated experimentally for this study area in Section 2.2.3. In Section 2.2.4, an idea is given of the impact of increasing detail in traffic modelling for this same study area, and results are condensed by looking at the distribution of exposed people over 5-dB classes.

### 2.2.1 Macroscopic traffic parameters

This section is structured into two main sub-sections. The first section attempts to identify imprecisions and uncertainties in parameters from traffic models by examining current best practice in modelling. The second section attempts to address the question of the magnitude of uncertainties in noise mapping by examining the range of emissions arising from the use of the Harmonise vehicle source model. Analysis of the uncertainties is performed through the use of Monte-Carlo Simulation (MCS) techniques. The macroscopic parameters of traffic flow intensity, mean link speed and vehicle classifications have been explored in depth.

The primary macroscopic traffic characteristics which need to be assessed in terms of their errors and uncertainties with respect to the Harmonise vehicle source model are:

- Traffic intensity (flow level);
- Mean vehicle speeds;
- Vehicle classifications or fleet proportions.

As reported in Deliverable 2.2 of the IMAGINE project [8], these three parameters are relatively available from all types of traffic model. However, the Harmonoise road source model also allows the introduction of gradient and acceleration parameters to influence emissions. Both of these parameters are used to correcting the power train emission level. They are not included in the MCS analysis. Whilst gradient is not usually available within static assignment models, it may be taken into consideration in certain cases. Acceleration is available from micro-simulation models, as are individual vehicle speeds.

#### *2.2.1.a Calibration and Validation of Traffic Models*

Any traffic model should undergo extensive calibration and validation before being accepted as fit-for-purpose, though the extents of these tasks will vary given a specific modelling scenario. For example validation of a static model used for regional planning purposes may have different criteria than a micro-simulation model used to assess the effects of a specific, localised action plan.

### *Flow and mean speeds*

For a static assignment model, modelled traffic flows at cordon screen-lines and on key links, along with journey times on key routes will typically be checked against real-world observations for the selected periods of the day. Dynamic models should also include validation of these parameters across the entire modelling period. The UK Highways Agency provides a series of expected criteria for macroscopic traffic parameters in the *"Design Manual for Roads and Bridges"* (DMRB) when validating traffic assignment models for scheme appraisals. Table 1 shows these assessment criteria.

**Table 1. Traffic Assignment Validation : Acceptability Guidelines (Source: HA [9])**

| Criteria and Measures | Acceptability Guidelines |
|---|---|
| **Assigned hourly flows vs. observed flows** | |
| 1. Individual flows within 15% for flows between 700 and 2,700 veh/h | >85% of cases |
| 2. Individual flows within 100 veh/h for flows < 700 veh/h | >85% of cases |
| 3. Individual flows within 400 veh/h for flows > 2,700 veh/h | >85% of cases |
| 4. Total screen-line flows (normally >5 links) to be within 5% | All (or nearly all) screen-lines |
| 5. GEH Statistic(1): | |
| i ) Individual flows GEH < 5 | >85% of cases |
| ii ) Screen-lines + Totals GEH < 4 | All (or nearly all) screen-lines |
| **Modelled journey times** | |
| 6. Times within 15% (or 1 min if higher) | >85% of cases |

(1) The GEH statistic is a form of Chi-squared statistic, which compares a modelled value against an observed value.

The GEH is computed thus:

$$GEH = \sqrt{\frac{(M-O)^2}{(M+O)/2}}$$

where 'M' is the modelled value of flow and 'O' is the observed value of flow.

Whilst the criteria in Table 1 were initially intended for the validation of static traffic models, they have also been applied to micro-simulation models and currently form part of the US Federal Highways Administration (FHWA) guidelines contained within the *"Traffic Analysis Toolbox Volume III – Guidelines for Applying Micro-simulation Modelling Software"* [10].

Figure 1 plots the expected variation in modelled flows for a given mean flow level in order to be within the assessment criteria in Table 1, with one minor difference. Note that in Table 1 the acceptability criteria is given at the 85% level, in Figure 1 the values have been reinterpreted to give the expected range of 95% of cases.

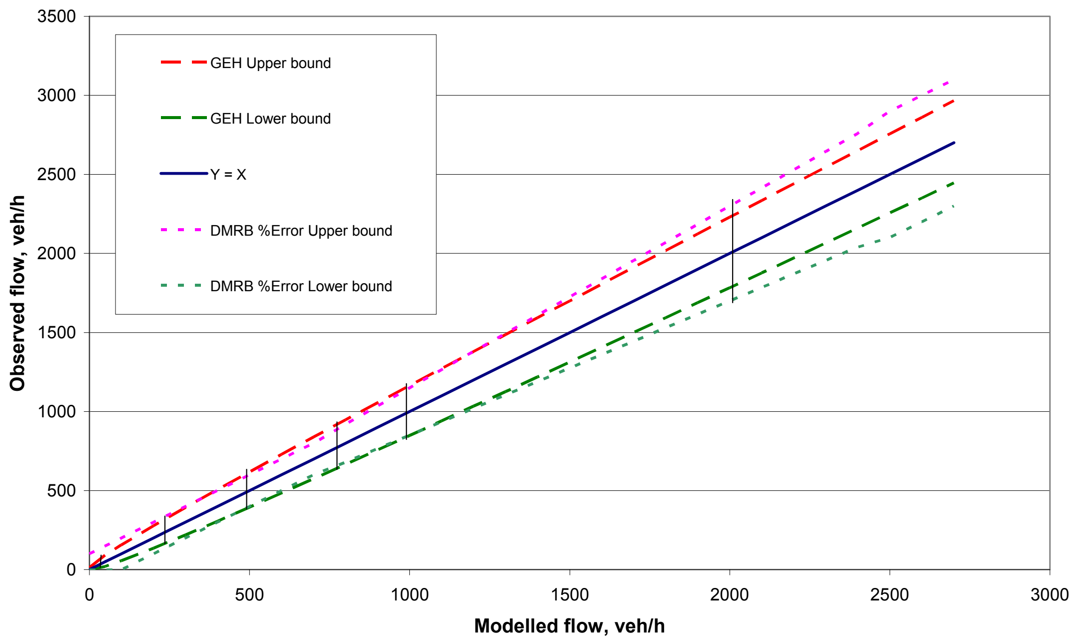



**Figure 1. Expected variations in flow levels from traffic modelling based on UK Highways Agency guidelines (based on HA [9])**

The vertical lines on Figure 1 show the flow levels used in testing uncertainties arising in the road traffic source model (see Section 2.2.1.b).

The magnitude or distribution of errors in a given static assignment model may also depend on the specific scenario under consideration. It is possible for sections of a modelled network that have been deemed important to a given scenario to undergo extensive calibration and validation, whilst more distant areas, or less trafficked sections receive less attention and hence possibly subject to greater discrepancies. Indeed, some models such as SATURN, specifically allow for a less detailed network description to be used in such areas. Therefore care must be taken to ascertain if traffic information has been obtained from a detailed (simulation) or less detailed (buffer) network location.

### *Fleet proportions on Links*

It is generally assumed that there will be a greater tendency for category 2 (light good) vehicles to be misrepresented in the modelling process as category 3 (heavy good) vehicles or vice versa than for category 1 (passenger) vehicles to be misrepresented as either category 2 or 3 vehicles.
As an example, inclusion of 20% category 3 vehicles in the calculation of total hourly emissions for an urban motorway scenario (see Table 2) increases the overall sound power level by 3.5 dB(A) over that calculated for 100% category 1 vehicles, whilst inclusion of 10% category 2 and 10% category 3 vehicles increases the level by 2.9 dB(A).

***Daily, Seasonal and Annual Traffic Variations***

This type of uncertainty is treated separately in Section 2.3.

***Road Gradients***

Road gradients may be applied in the context of road traffic models in the initial development of flow-cost curves in static or dynamic assignment models, or in the calculation of desired speeds on links in micro-simulation models. The introduction of a gradient parameter as a traffic modelling input will usually affect the calculated capacity of a road, and have an increasing effect with increasing and increasing proportion of heavy vehicles in the traffic composition. An example of using gradients in traffic modelling may be found in the speed curves provided by the UK Highways Agency document on Cost-Benefit Analysis (COBA) of road schemes [11]. These separate vehicles into two categories, light and heavy vehicles, with gradient having a proportionally greater effect on the speed of heavy vehicles. A better understanding of the effects of gradient and uncertainty in gradient, inclusion of such data in the traffic modelling process, and their overall effect on Harmonoise predictions are still outstanding.

***Road surface***

Road surface parameters are not typically included in any form of traffic model and hence have not been considered in this analysis. In the absence of additional information subsequent analyses in Section 2.2.1.b assume the Harmonoise reference surface [12]. There will be some benefit in reducing gross errors by including surface parameters into GIS system and road infrastructure databases for noise mapping purposes. This subject is covered by IMAGINE work package 1.

#### *2.2.1.b Uncertainty and Error Propagation Analysis of Harmonise Road-Traffic Emissions*

This section examines the use of Monte-Carlo Simulation to explore the ranges and magnitudes of uncertainties produced in source emission levels by the Harmonoise model.

***The Harmonoise Road Traffic Model***

The Harmonoise source model provides emission levels for a single vehicle, fundamentally based on the classification of that vehicle and its speed. Two emission levels are calculated, a rolling noise emission being a logarithmic function of speed, and a power train level being a linear function of speed. These emission levels are initially calculated in 1/3$^{rd}$ octave band values. The emissions from individual vehicles of different classes are then to be scaled by the traffic flow and combined to provide line source emission values. It is expected that three line sources will be used:

1. A source at 0.01m height calculated from an 80% weighting of combined rolling noise emission levels and 20% power train emission levels;
2. A source at 0.3m height calculated from an 80% weighting of the power train level and 20% weighting of the rolling level from cars only, and;
3. A source at 0.75m height, calculated as for the second source, but using data for heavy vehicles.

Analysis of uncertainties and the propagation of errors was undertaken using Monte Carlo Simulation (MCS) implemented within the University of Leeds' proprietary noise modelling software. MCS has previously been successfully employed to study uncertainties associated with both the interim computational method for road traffic noise [2][3], and the Harmonoise methodology [4]. The work presented in this section both complements and develops the work contained within both papers. The MCS implementation was made using the C/C++ programming language, with all output generated as individual text files for subsequent analysis.

Whilst the MCS has been initially implemented as a single, stand-alone dialog within the software and its outputs relate to noise emissions alone, there is no reason why MCS methodology could not be directly implemented as input to the point-to-point propagation process required for mapping. However, such an approach would, at the time of writing, potentially lead to unacceptably long computation times. Therefore, techniques for generating uncertainty values other than MCS should be considered for implementation in mapping software, for example *fuzzy-set* techniques [13][14]. See also IMAGINE work package 1 for more information on this subject.

***Definition of Uncertainty and Percentage Uncertainty***

The definition of uncertainty used in the MCS is that of the *standard uncertainty 'u'*, which is considered equivalent to the *standard deviation* of the output results. The standard deviation has been calculated using the well known formula, using the unbiased estimator from a given sample:

$$u = S.D. = \sqrt{\frac{\sum\left(x - \bar{x}\right)^2}{n-1}}$$

Where '$x$' is the output from an individual run, '$\bar{x}$' is the arithmetic mean of all samples and '*n*' is the number of samples.

The percentage uncertainty is considered to be:

$$u\% = 100\frac{u}{\bar{x}}$$

Note that Shilton *et. al.* [2][3] used a definition of uncertainty based on 3 standard deviations of the mean (99.8% confidence level), hence results are not directly comparable, though general trends in results will remain similar.

***Monte Carlo Simulation***

MCS is defined as a numerical analysis technique which employs a statistical simulation methodology to explore a given system. The statistical simulation employs a sequence, or sequences, of randomly generated numbers to select input parameters from defined probability density functions (p.d.f's). The simulation is run multiple times using differing randomly selected input parameters. The output from each run may then be analysed statistically, for example histograms of output values may be plotted, and means and standard deviations of output calculated [2][3].

Figure 2 outlines the general process of MCS [2][3].

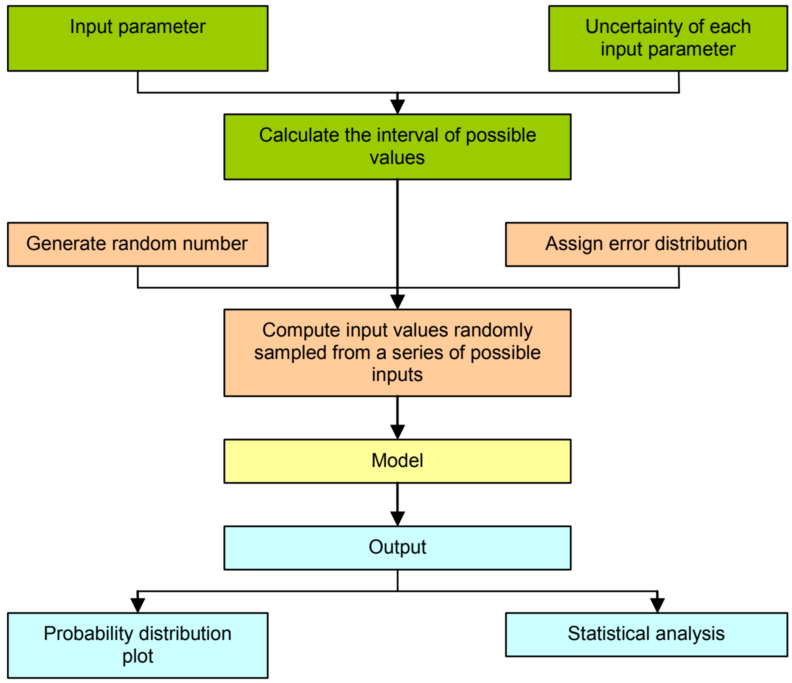



**Figure 2. Process workflow for Monte Carlo Simulation (Source in [2][3])**

The exact number of simulation runs required in order to give statistically valid results, may be considered as a function of the variance of the output parameter. Consideration must be given to the fact that computers cannot actually produce completely random numbers, only *pseudo-random* ones, where the same sequence of numbers is generated based on an initial seed value. A by-product of pseudo-random nature of the RNG is that the use of the same seed number within the RNG allows for complete repeatability in MCS results. A Random Number Generator (RNG) should be selected that has appropriate properties for the MCS, typically that the *period* of the RNG is sufficiently large compared to the number of random numbers actually selected from a given sequence [15]. The exact implementation of the RNG used in the MCS (Park-Miller method with Bays-Durham shuffle) may be found in “Numerical Recipes in C++” [16].

***Input Parameters and Parameter P.D.F’s***

The p.d.f’s of the input parameters for the MCS are assumed to describe the parameter outputs and the expected ranges of outputs obtained from a variety of traffic models. Each set of inputs describes traffic on a single small section of road, over which the parameters do not vary.

Individual p.d.f’s may be supplied for:

- Hourly flow (by vehicle class);
- Traffic speed (by vehicle class);
- Gradient of the link (note: *not strictly an output of a traffic model – applied globally to all vehicle classes*);
- Acceleration of vehicles, (by vehicle class).

For the distributions of flows and speeds, uncertainties were input as percentage values. For gradient and acceleration absolute values were used. Assuming that particular type of road link (e.g. 2-lane urban motorways subject to a 100km/h speed limit) has been modelled correctly (i.e. no gross errors in demand flow, capacity or speed parameters) a large number of times in the given range of traffic models then, it has been assumed that the above input parameters will be normally distributed around their mean values, for that particular class of road.

The classes of road tested were based on those suggested in the technical manual for the French MITHRA noise modelling software [17]. Table 2 presents the assumed traffic parameter values from that document, used as a basis for the MCS analysis. Note that the initial analysis of Trow and Shilton was also based on a far higher flow of 4400 veh/h. The values in Table 2 are based on flows *per traffic lane*.

**Table 2. Default traffic parameters by road class (Source : Mithra 4.0 Technical Manual [17])**

| | **Flow in veh/h per lane** | **%age of Heavy Vehicles** | **Mean speed in km/h** |
|---|---|---|---|
| **Highway and urban motorway** | 1000 | 20 | 105 |
| **Highway and urban motorway** | 800 | 15 | 100 / 75 (1) |
| **Main road** | 500 | 9 | 47 |
| **Primary artery** | 250 | 3 | 40 |
| **Secondary artery** | 50 | 0 (20 (3)) | 32 |
| **Minor road (1)** | 1000 | 20 | 105 |

(1) Original speed of 100km/h in [17], Additional speed of 75km/h used in analysis to provide a mid-range point

(2) Road class not in original document – added for this analysis

(3) 0% used for minor road without bus lane, 20% Medium Heavy Vehicles used for suburban road with frequent bus service – see below.

Note that the Mithra software operates using only two vehicle classes, whilst the Harmonoise model uses five main classes, subdivided into 18 sub-classes [12]. In the absence of additional information, the 3 Harmonoise classes have been used in the MCS. As an additional simplification, it has been assumed in the MCS that all Heavy Vehicles possess 4 axles – requiring no axle correction to their rolling noise levels.

Analysis of initial results, using the input data in Table 2 suggested that the main road results assuming a mean speed of 100 km/h were superfluous, being similar to the urban motorway results. It was therefore decided to lower the tested speeds on main roads to 75km/h to provide a mid-point scenario between the urban motorway and primary artery scenarios.

Table 3 shows expected percentage uncertainty levels in flow for the link classes in Table 2, based on the DMRB criteria presented in Table 1 and Figure 1. The uncertainty values for flow are consistent with the uncertainties on link flows reported by Zhao and Kockelman [18] or de Jong et. al. [6]. Unfortunately, reviews of literature on uncertainty propagation in traffic modelling, such as that contained within de Jong et. al. [6] have failed to highlight any analyses of mean link speeds, rather being concentrated on higher level parameters, such as journey time or network delay information. It may be possible for future work to infer some estimate of speed uncertainties in assignment models based on analysis of the distribution of volume to capacity ratios (V/C) ratios, given link classification information and speed/cost/capacity curves such as those found in COBA [11].

**Table 3. Suggested upper bounds on uncertainty levels associated with modelled traffic flows and speeds by road type(1)**

| | %Uncertainty, based on fixed value or %age of flow from HA(2) | %Uncertainty, based on DMRB GEH statistic <5 from HA(2) | Uncertainty in speed(3) |
|---|---|---|---|
| **Highway and urban motorway (1000 veh/h/lane)** | 11% | 10% | 20% |
| **Main road** | 10% | 12% | 20% |
| **Primary artery** | 13% | 15% | 30% |
| **Secondary artery** | 27% | 22% | 30% |
| **Minor road (0% Class 2 veh)** | 119% | 42% | 30% |
| **Minor road 20% Class 2 veh)** | 119% | 42% | 30% |

(1) Assumes HA [9] could be applied to lanes of traffic, as per Table 2

(2) Value is an approximate value based on converting 85% confidence level as suggested in HA [9] to 68% confidence level (1 S.D.) for standard uncertainty. This ignores the non-normality of the GEH statistic range.

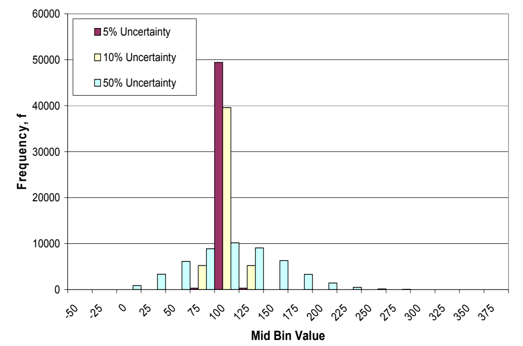
(3) In the absence of additional information 20% has been assumed for high speed roads and 30% for lower speed roads. During peak periods on heavily congested roads values may be larger.

Table 3 illustrates the expectation that minor roads will be expected have flows modelled with less accuracy than more major routes – consistent with the strategic goals of most static models. Also visible is the divergence between the fixed flow and percentage based criteria and the GEH criteria for minor roads.

Figure 3a shows the effect of varying uncertainty on a set of 50,000 random deviates drawn from a normal distribution with mean set to 100. The precise implementation of normal deviate generation used by the MCS is based on the Box-Muller [19] method. Certain parameters may not allow the generation of variates with values outside of a certain range, most notably neither vehicle flow nor vehicle speed can be negative. Therefore input parameters to the MCS have been selected using two approaches:

- Truncation of the distribution at certain limit values – the distribution is re-sampled until a variate is obtained within the limit values;
- Clamping of a variate outside of the limit range to the limit value.

Figure 3b shows three distributions, generated using the same seed value, one with no range limit, one with truncation and re-sampling for values < 0, and one with negative values clamped to zero. Alternate analyses, for example that of Zhao and Kockelman [18].



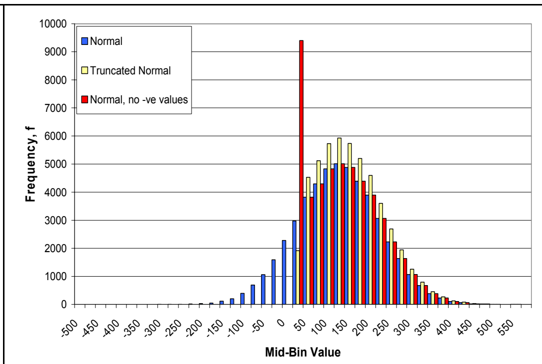




**Figure 3**

***a. Effects of varying input uncertainty on normally distributed parameter input (mean = 100)***

**b. Effects of use of truncation or range clamping on normally distributed input parameter (mean 100, uncertainty 100%)**

Note that both truncation and clamping significantly alter the mean value and standard deviation of the latter two distributions (truncated dist. mean = 128.6 SD = 79.13, clamped dist. Mean = 108.6 SD = 86.27). This has significant implications on the accuracy of the MCS when input parameters are assigned large uncertainty values, as there will be a tendency for calculated mean noise emission levels to drift, and the overall magnitude of uncertainties will be suppressed.

Additionally, MCS generally assumes that all input parameters are independent of one another. However, it is understood that traffic parameters are interlinked (e.g. speed of a particular class of vehicle on a link depends on flow and gradient) and that such links may be present in the traffic model, and hence it's output. Also, within the Harmonise emission model, vehicle speed is used both in the initial generation of emission levels, and in the correction of point source to line source levels (i.e correction by a factor of 10 $\log_{10}$ (Q/v)).

Therefore, two MCS variations have been considered and tested:

1. MCS assuming completely independent input p.d.f.'s for all input parameters;
2. An MCS with independent selection of flow and speed parameters, with vehicle mix assigned as fixed percentages of the input flow;

For the first model variation it was assumed that for a given run, the overall uncertainty in the total flow was constant. Percentage uncertainties were then applied to the individual distributions of flow for each vehicle category based on the following assumption:

$$\frac{\mu_{C1}}{\mu_{Overall}}\sigma_{C1}{}^2 + \frac{\mu_{C2}}{\mu_{Overall}}\sigma_{C2}{}^2 + \frac{\mu_{C3}}{\mu_{Overall}}\sigma_{C3}{}^2 = \sigma_{Overall}{}^2$$

Where $'\mu_{C1}','\mu_{C2}','\mu_{C3}' and '\mu_{Overall}'$ are the input distribution means for each vehicle category and the overall sum of the means, $'\sigma_{C1}{}^2','\sigma_{C2}{}^2','\sigma_{C3}{}^2'$ are the assigned variances to the vehicle class distributions, and $'\sigma_{Overall}{}^2'$ is the initially assigned variance to the overall flow distribution.

The preliminary runs of the MCS were done using 10,000 iterations within each run. Subsequent analysis suggested that, depending on the magnitude of the initial input uncertainties, between

2,000 and 10,000 were sufficient for stability in the 2nd decimal place of output. Trow and Shilton [4] reported that using 2,500 iterations were sufficient – and this number of iterations was subsequently adopted in this analysis. Figure 4 shows an extreme example (based on the highway and urban motorway case at 100% uncertainty in both speed and flow) of the effect of the number of iterations on statistical parameter stability. The values are based on the difference between the mean and uncertainty parameters obtained for a given number of iteration compared to those obtained for 500,000 iterations.

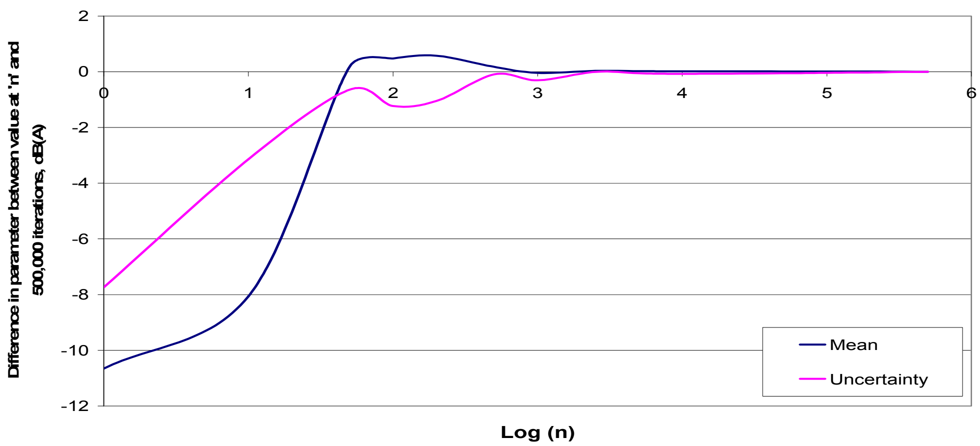



**Figure 4. Example of parameter Stability versus number of iterations**

***Initial Results from MCS analysis – No uncertainties assigned***

Table 4 shows the base emission levels recorded from the MCS for each road category when the flow distribution and speed distributions were assigned with 0% uncertainty (i.e assumed that mean flow and speeds are known).

**Table 4. Base noise emissions in dB(A)/m/lane, by Harmonoise source, with 0% uncertainty in flow and speed**

| | Source 1 Low noise source (0.01m high) | Source 2 Mid noise source (0.3m high) | Source 3 Hi noise source (0.75m high) | Combined level from all sources |
|---|---|---|---|---|
| **Highway and urban motorway (1000 veh/h/lane)** | 84.83 | 77.97 | 83.45 | 87.69 |
| **Main road** | 82.98 | 76.84 | 80.85 | 85.66 |
| **Primary artery** | 74.36 | 70.62 | 73.51 | 77.87 |
| **Secondary artery** | 69.14 | 67.48 | 65.61 | 72.42 |
| **Minor road (0% LGV)** | 59.87 | 60.36 | N/A | 63.13 |
| **Minor road 20% LGV)** | 62.68 | 59.40 | 64.86 | 67.62 |

The final column in Table 4 shows the energetic sum of contributions from the other three sources. It is provided for indicative purposes only, given that the Harmonoise model specifies the use of two point sources per vehicle. It has been assumed that ground and propagation effects will make little overall change to broadband, A-weighted uncertainty values.

***Initial Results from MCS analysis – Variation in emission uncertainty with changes in individual parameters***

***Changes in flow mean and percentage uncertainty in flow***

As reported by Trow and Shilton [4], uncertainties in emissions from the Harmonise model show a constant sensitivity to relative uncertainty across the range of mean flow values. If the relative uncertainty in flow was increased in linear steps, then uncertainty in noise emission level increased in approximately linear fashion. This holds true for any component of noise source (rolling or power train for any vehicle class), for any frequency band or broadband level, for un-weighted or A-weighted levels. This is due to uncertainty only propagating through the flow density ($10\log_{10}(Q/V)$) correction term.

When selecting flows from the truncated normal distribution some drift in mean emission levels was noted, these drifts often became statistically significant at the 5% level for values beyond a percentage uncertainty of 20 - 40% for all categories of links. Figure 5 shows an example of the behaviours of uncertainty in emission level, and calculated mean emissions, with increasing percentage of uncertainty in flow.

The situation for increased uncertainty in mean speeds is more complex than that for flows, given that the speed parameter is present in the initial calculation of rolling noise (logarithmic relationship), power train noise (linear relationship) and the flow density correction term (logarithmic relationship).

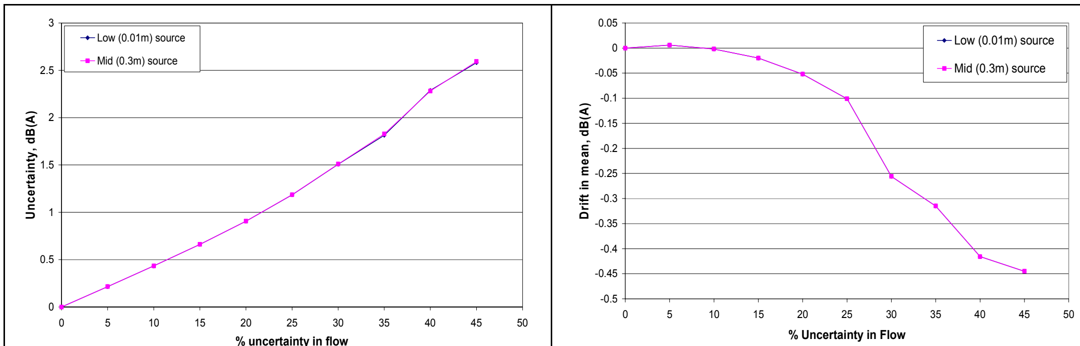


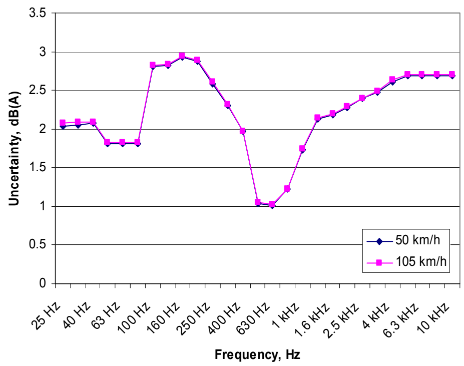

**Figure 5**

**a. Behaviour of source uncertainty with increasing uncertainty in flow**

**b. Drift of mean value with increasing uncertainty of flow**

Initially the behaviour of uncertainties across the 1/3$^{rd}$ octave bands was examined for differing mean speeds, both in terms of rolling and propulsion noise for each vehicle category, and in terms of the three Harmonoise sources. The magnitude of the emission uncertainty in a given 1/3$^{rd}$ octave band depends on the exact '$b_r$' and '$b_p$' speed sensitivity parameters in the rolling and power train calculations respectively. The results of an example test are shown in Figure 6a and

Figure 6b, (all category 1 vehicles, 1000veh/h, 0% uncertainty in flow, speeds of 50km/h or 105km/h, 20% uncertainty in speed).



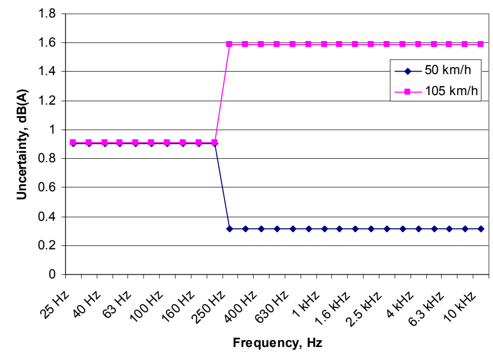




**Figure 6**

**a. Behaviour of rolling noise uncertainty with varying speed, vehicle class 1, flow 1000veh/h uncertainty 0%, speed uncertainty 20%**

**b. Behaviour of propulsion noise uncertainty with varying speed, vehicle class 1, flow 1000veh/h uncertainty 0%, speed uncertainty 20%**

Figure 6a shows that for the magnitude of the uncertainties by frequency band for rolling noise are primarily dependent on the '$b_r$' parameter values, little sensitivity to increasing mean speed is shown (some variation of <0.1dB(A) was found). Figure 6b demonstrates that for power train noise at frequencies below 250Hz, uncertainties are not sensitive to variations in mean speed. The magnitude of uncertainty for the 250Hz band and above relate to the combination of uncertainty in the speed correction term in the propulsion noise calculation with the uncertainties in the flow density correction. This combination can produce a step change in the magnitude of uncertainties between the lower and upper range of frequencies.

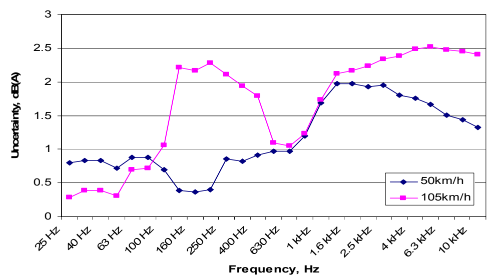
The Harmonise source model then combines the relative strengths of the rolling and propulsion noise sources to give the contributions of the vehicle class to the different source lines. Therefore the propagation of the uncertainties in rolling and propulsion noise emissions depends on the relative strength of the sources in a given 1/3$^{rd}$ octave band at a given speed. Figure 7 gives an example of the uncertainties generated through the combination of the rolling and propulsion emission level for the three vehicle classes, assuming a flow of 1000 veh/h, all of the given class. The figures reflect the findings of Trow and Shilton [4], who noted that uncertainties of differing magnitudes could be produced at the same relative uncertainty in speed, for differing mean speeds. It can be fairly readily seen that the resulting uncertainties in Figure 7 are associated with various combinations of the uncertainties of those of the form shown in Figure 6a and Figure 6b.

As reported by Trow and Shilton [4], the behaviour of uncertainties in the individual category contributions, across 1/3$^{rd}$ octave bands or broadband levels, to each of the Harmonoise sources displayed linear increases in emission uncertainty with linear increases in relative uncertainty with speed. An example of this behaviour is shown in Figure 8a-c. Again as with Trow and Shilton [4] no surface corrections have been made to the data.

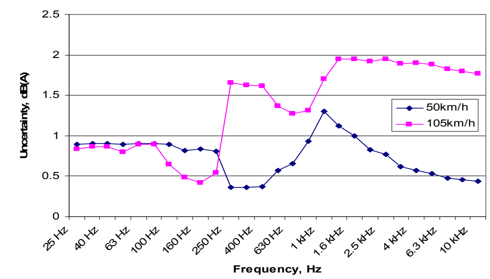
The calculated broadband uncertainty for any source lies within the overall range of the 1/3$^{rd}$ octave band uncertainties. Generally, for a fixed flow level of a given vehicle class, it was noted that the uncertainties in rolling emissions (and hence Harmonoise source 1 emissions) were of a greater magnitude than those uncertainties associated with propulsion (and hence source 2 and 3 emissions), though the difference between source uncertainties reduced with increasing speeds (see Figure 7 – noting the differing shape of the distributions of rolling noise levels at a mean speed of 50km/h, compared to 105km/h).

Trow and Shilton [4] note that *"the application of the A-weighting curve biases the uncertainties in the mid-frequencies towards the overall A-weighted value. This means that parameters which yield greater uncertainty in the mid-frequencies will contribute more uncertainty to the overall level".*

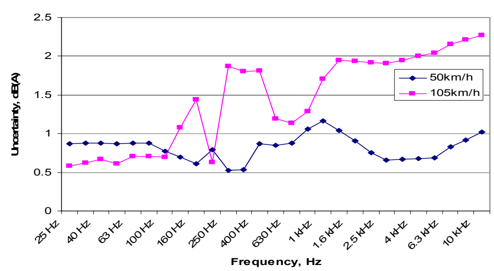
*Vehicle Class 1*



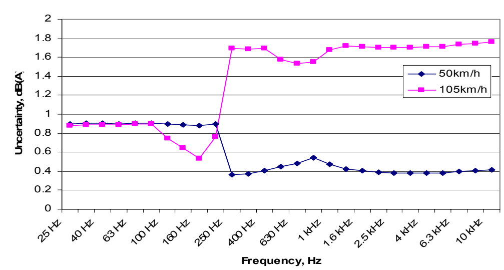

*Vehicle Class 1*



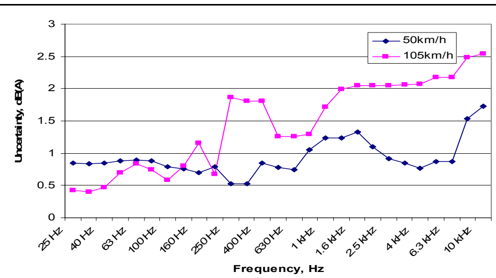

*Vehicle Class 2*



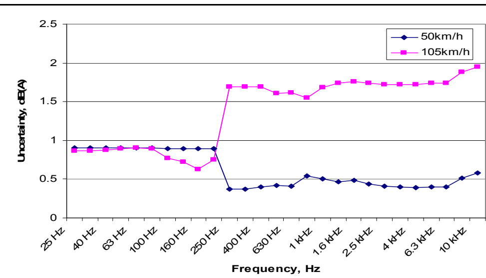

*Vehicle Class 2*




*Vehicle Class 3*




*Vehicle Class 3*

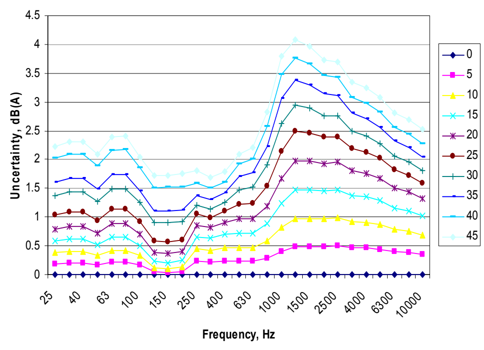



**Behaviour of uncertainty in source 1 with varying speed (speed uncertainty 20%), flow set to 1000 veh/h (flow uncertainty 0%)**

**Behaviour of uncertainty in sources 2 (top) and 3 (middle and bottom figures) with varying speed (speed uncertainty 20%), flow set to 1000 veh/h (flow uncertainty 0%)**

**Figure 7a-f. Behaviour of uncertainties in Harmonoise source emissions at differing speeds**

Figure 8 presents the uncertainty results by frequency band for Harmonoise sources 1 and 2 (low source at 0.01m height and mid source at 0.3m height respectively) for a link with a mean flow of 1000veh/h and mean speed of 50km/h. As would be expected, given that the sources are composites, features from Figure 7a and Figure 7b are present in both Figure 8a and Figure 8b (e.g. relatively low uncertainty contributions for bands between 100Hz and 250Hz in rolling noise source are present in source 1).



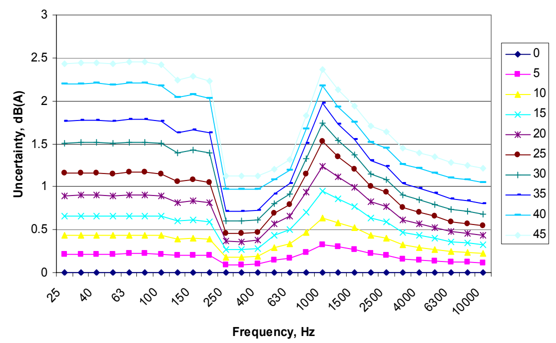




**Figure 8**

**a. Behavior of source 1 uncertainties with increasing percentage uncertainty in vehicle speeds (1000 veh/h, 0% uncertainty in flow, cars only)**

**b. Behavior of source 2 uncertainties with increasing percentage uncertainty in vehicle speeds (1000 veh/h, 0% uncertainty in flow, cars only)**

***Initial Results from MCS analysis – Combined effect of flow and (mean) speed uncertainties***

Figure 9 and Figure 10 and shows an example of the effect of combined percentage uncertainties in flow levels and speeds, on the broadband, A-weighted distributions of emissions from the various component sources. For the example the flow was set to 1000 veh/h, 10% uncertainty, speed was set to either 50 km/h or 105 km/h with 20% uncertainty. The traffic composition was assumed to be 80% Category 1, 10% Category 2, 10% Category 3 with no uncertainty applied.

Note the change in shape of the distributions in Figure 9 and Figure 10 with increasing mean speed. At a mean speed of 50km/h the rolling noise contributions from each vehicle class show a far greater overall range (and hence uncertainty) than those at a mean speed of 105km/h. Indeed, at 105km/h the rolling and propulsion noise distributions appear broadly similar. Also worthy of note are the changing positions of the distributions, demonstrating the increasing importance of rolling noise over propulsion noise. In both cases source 2, dominated by category 1 vehicle propulsion noise, has the lowest mean value.

The figures illustrate that the final, overall uncertainty obtained from combining of all sources is not a simple addition of the uncertainties from the individual sources, given:

- That the individual source distributions are not independent from each other, being made of combinations of the rolling and propulsion noise components. These in turn contain non-independent combinations of uncertainties in each frequency band which are dependent on the original flow and speed distributions;
- The distributions are of logarithmic values (i.e. decibels) and therefore distributions containing higher values have a relatively higher contribution to overall uncertainty.

Given that at lower speeds, propulsion noise dominates overall sound, and that propulsion noise exhibits lower uncertainties relative to rolling noise, it would be expected that for minor roads, flow and fleet composition (%age class 1 and 2 vehicles) would be more influential on overall uncertainty and hence need to be the focus of accurate modelling. Conversely for higher speed roads, overall uncertainty depends more on the rolling noise contributions, and hence more on accurate determination of speeds and fleet compositions.

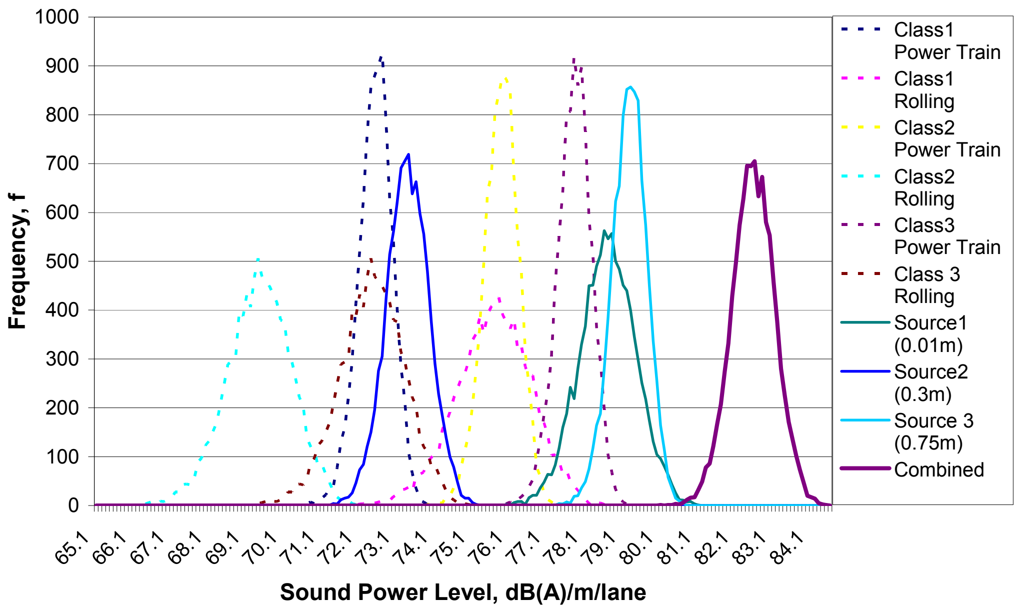



**Figure 9. Sample output histograms from Monte-Carlo Simulation, Mean Flow 1000veh/h, Uncertainty 10%, Mean Speed 50km/h, Uncertainty 20%.**

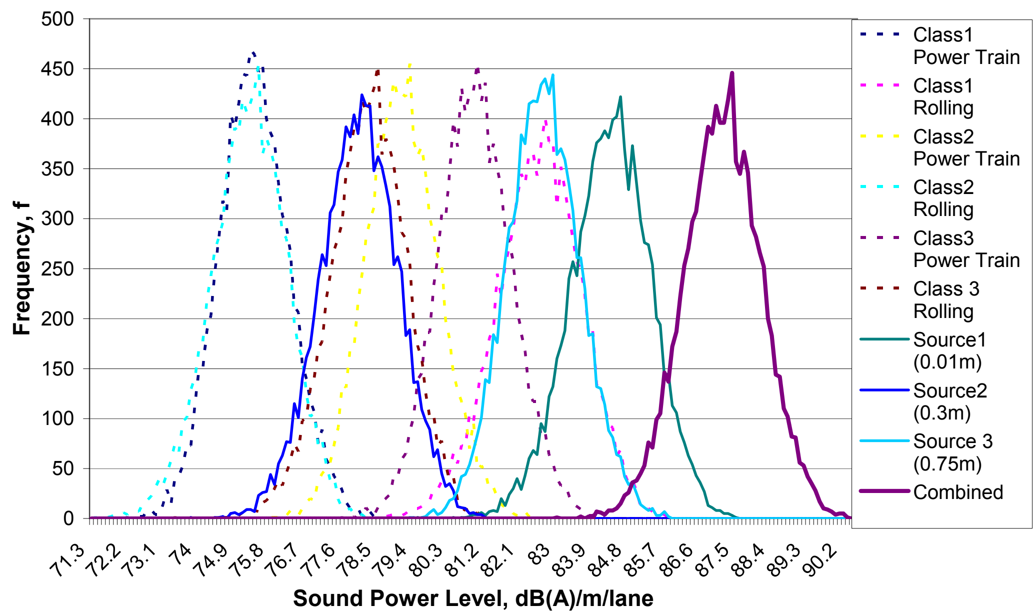



**Figure 10. Sample output histograms from Monte-Carlo Simulation, Mean Flow 1000veh/h, Uncertainty 10%, Mean Speed 105km/h, Uncertainty 20%.**

Work by Shilton *et. al.* whilst quantifying the effects of WG-AEN Toolkit recommendations on accuracy of Interim methods, lead to the specification of "group" references for input dataset, which allowed classification of datasets regarding their effect on expected errors in calculations. These groups are outlined below, and the group boundary values have been adopted as contour values in the MCS analysis:

- Group A defines very accurate and precise input data, leading to uncertainties of less than 0.5 dB(A);
- Group B defines input data that will produce results within the "best" standard for END noise maps, with uncertainties of less than 1.0dB(A);
- Group C defines input data aimed at a "good" standard of noise maps, with uncertainties of less than 2dB(A);
- Group D defines data aimed at a "pass" standard of noise maps, with uncertainties of less than 5dB(A), and;
- Group E defines data that will produce results with uncertainties outside of Groups A-D above. Shilton *et. al.* remark that under such circumstances new input data should be obtained either by direct collection, or through the use of a WG-AEN toolkit. It is expected that other IMAGINE work-packages will provide supplementary information for use with the Harmonise model.

For reference, the uncertainty results of each source and all sources combined from the MCS have been contoured in accordance with the above bands. Note however that as the above groups refer to the quality of *noise maps,* and hence subject to the propagation of uncertainties through both emission and propagation calculation components, as well as assumptions made regarding conversion to long-term annual average parameter values.

Figure 47, Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52 in Appendix A.2 show a sample of the MCS results, based on the urban motorway scenario (mean flow of 1000veh/h/lane, mean speed of 105 km/h). Axes have been labelled with the abbreviations '%U(F)' for 'Percentage uncertainty in flow' and '%U(S)' for 'Percentage uncertainty in speed'. The red surface in the figures represents the results obtained when assuming that the flow is 100% Category 1 vehicles, whilst the blue surface represents the results obtained when assuming 80% Category 1 and 20% Category 3 vehicles. Figures for all MCS runs have not been included in this document for reasons of space.

#### *2.2.1.c Conclusions*

From the analysis of all MCS results, the following conclusions were drawn:

1. Standard uncertainties for a given source, or at a specific frequency bands may be far greater than the overall standard uncertainty obtained by combining frequency band contributions, or complete sources. This is consistent with the analysis of Trow and Shilton [4].
2. The overall A-weighted standard uncertainty lies between the minimum and maximum uncertainties obtained in the contributing sources. For uncertainties of 100% in both flow and speed, the maximum overall uncertainty in sound power level obtained was 7.7 dB(A) for the urban motorway scenario. For the minor road scenario the equivalent value was 5.1 dB(A). All other scenarios produced standard uncertainties that lay between these two ranges. These values may be considered upper bounds on uncertainties as it

is unlikely that a traffic model producing such results would be accepted in common practice.

3. Generally, the introduction of category 2 or category 3 vehicles into the scenario reduces overall uncertainty by an amount which increases with increasing uncertainty in flow and speed. The maximum observed magnitude of this effect is of the order of up to 2 dB(A) with the tested parameters. This decrease is thought due to the magnitude of the propulsion noise contribution these vehicles make to overall levels and the relative insensitivity to speed. The exception to the above is for the case of scenarios assuming a distribution of heavy vehicles, where for low uncertainties of speed (<10%) and flow (<40%) the modelled uncertainties exceeded those for flow composition of cars alone.
4. Increasing uncertainties in speed beyond 50% gives rise to substantial increases in the mean sound power level calculated for each source, when compared to the sound power level at 0% uncertainty in flow / 0% uncertainty in speed. For flow compositions of 100% class 1 vehicles (cars) the observed drift was up to 2 dB(A). Including heavy vehicles, by assuming a fixed percentage composition of the input flow, compounded the drift by up to a further 1 dB(A). When, assuming a distribution of heavy vehicles, the drift in mean was even further compounded, with a maximum recorded of just under 6 dB(A).
5. A slight negative drift in mean power level of the order of 0.1dB(A) was noted with increasing uncertainty of flow up to the 50% level for scenarios assuming fixed percentages for link compositions. Scenarios using a distribution heavy vehicles exhibited large positive drifts in mean at low uncertainty values.

The phenomena points 2-5 may be explained by the truncation of the distributions assumed for sampling input parameters. Beyond input uncertainty values of 50% in flow or speed, the truncation of the input distributions renders the MCS results increasingly invalid, given that the truncation process causes a shift in the mean value, and a decrease in the variance, of generated input parameters. The rate of increase in uncertainty becomes curtailed, leading to a plateau in the uncertainty surface; this may readily be seen in Figure 47c - Figure 52c. The effect of truncation when sampling for input flows may also be seen in point 2 above, where the generation of excessive number of heavy vehicles is possible at low uncertainty values in overall flows. It should also be noted that the maximum values for uncertainties quoted in point 1 above (and all values obtained for high uncertainties in speed), would in both traffic modelling and reality, be further curtailed by upper bounds on speed.

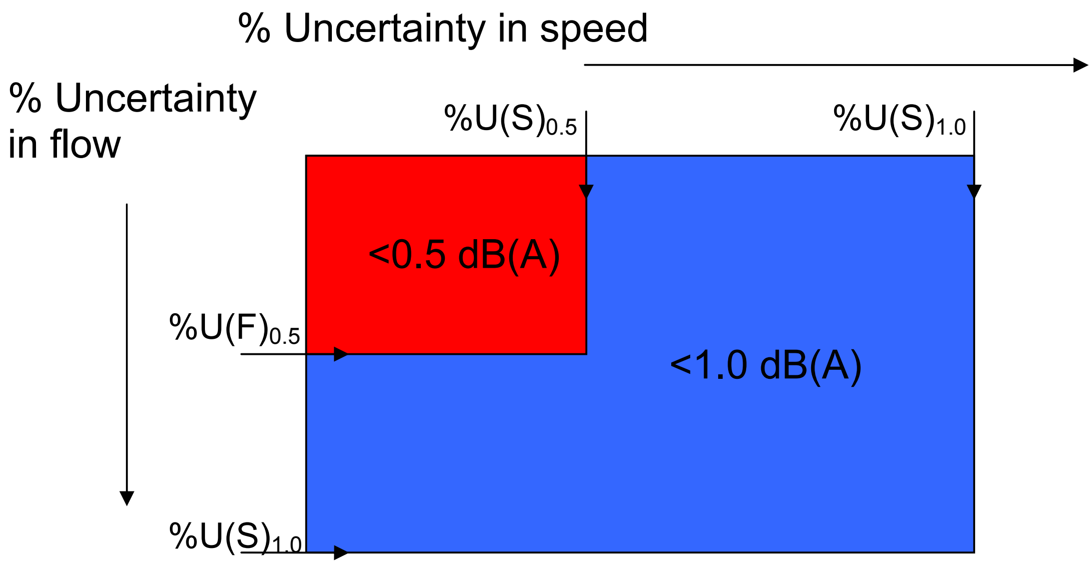
Aside from the points above, the following practical observations were made:

1. The drifts in the calculated mean sound power levels, for the bounds taken from Table 3 were generally within acceptable bounds (i.e. changes below 0.1dB(A). At levels of uncertainty in speed and flow expressed in Table 3, the size of the overall combined standard uncertainty in sound power level for all sources exceeded the drift in the mean by at least an order of magnitude.
2. At the levels of uncertainty presented in Table 3, the resulting uncertainties in sound power level were below 2.0 dB(A) for all cases, except those scenarios involving minor roads, where standard uncertainties varied from 2.2 dB(A) to over 4.0 dB(A). **It is recognised that the bounds chosen for uncertainty in speeds are essentially arbitrary. These values do not fully account for both the effects of gradient and a more realistic distribution of modelled speeds.** Analysis of the uncertainty effects of gradient, both directly through its inclusion as a parameter in the source model affecting propulsion source noise generation and indirectly through

appropriate modelling of the effects of gradient on category 2 and 3 vehicle speeds is ongoing.

3. Given the bounds in Table 3 and the traffic parameters in Table 2, adding category 2 or category 3 vehicles to the composition of vehicles reduces overall standard uncertainty by the order of 0.3 dB(A), but increases the mean power level by at least this magnitude.
4. More work is required to examine the effects of fleet proportions, gradient and acceleration on uncertainty levels. Based on the MCS analysis and the complex nature of the Harmonoise source model, the calculation of the additional uncertainty due to these extra dimensions, will not be a simple additive or multiplicative effect.
5. The output uncertainties are dependent on the input distributions used for the MCS. Independent, normally-distributed parameters were selected for both flow and speed. In reality the output of speeds from a traffic network model will be highly dependent on the volume-to-capacity ratios of the network links. Further analysis of the input parameter space is recommended – with the likely effect that overall uncertainties would be further decreased if a more realistic distribution of modelled speeds was obtained.
6. Additional attention is needed in order to estimate the effect of assumptions made when scaling the hourly values to long-term annual parameters. It is likely that whilst overnight speeds may be know with greater certainty, overnight flows will be less well understood.
7. It should be mentioned that the uncertainties in emission level do not include the effect of uncertainties in the original data used to produce the Harmonoise source model itself (i.e. uncertainties in the measurements taken to produce the coefficients in the source models).

Figure 11 summarises the approximate bounding regions in percentage standard uncertainties in both speed and flow required to achieve overall standard uncertainties for all sources combined of under 0.5 and 1.0 dB(A) for the urban motorway and minor flow road cases. The figure illustrates how the relative sensitivity of overall uncertainty changes with mean speed. Also worthy of note, is that the assumption of a fixed proportion of category 3 vehicles in the flow produces substantially different results from those produced assuming a distribution of these vehicles. It is considered that the latter results may be more realistic in representing overall uncertainties. Figure 11 combined with point 2 above suggest that a very high, though achievable, standard of traffic data collection and modelling, will be required to achieve the gold standard of noise mapping.




| Flow | Speed | %HGV | Dist. | $\%U(S)_{0.5}$ | $\%U(F)_{0.5}$ | $\%U(S)_{1.0}$ | $\%U(F)_{1.0}$ |
|---|---|---|---|---|---|---|---|
| 1000 | 105 | 0 | N/A | 5 | 10 | 10 | 22 |
| 1000 | 105 | 20 | Fixed | 5 | 11 | 12 | 22 |
| 1000 | 105 | 20 | Normal | 8 | 8 | 16 | 16 |
| 800 | 75 | 0 | N/A | 6 | 11 | 12 | 22 |
| 800 | 75 | 15 | Fixed | 7 | 11 | 16 | 22 |
| 800 | 75 | 15 | Normal | 10 | 7 | 22 | 16 |
| 500 | 47 | 0 | N/A | 9 | 11 | 20 | 22 |
| 500 | 47 | 9 | Fixed | 12 | 11 | 28 | 22 |
| 500 | 47 | 9 | Normal | 17 | 7 | 34 | 16 |
| 250 | 40 | 0 | N/A | 11 | 11 | 23 | 22 |
| 250 | 40 | 3 | Fixed | 13 | 11 | 31 | 22 |
| 250 | 40 | 3 | Normal | 16 | 7 | 34 | 16 |
| 50 | 32 | 0 | N/A | 16 | 11 | 34 | 22 |
| 50 | 32 | 20 | Fixed | 28 | 11 | 42 | 22 |
| 50 | 32 | 20 | Normal | 32 | 7 | 50 | 16 |

**Figure 11. MCS results – Approximate bounding rectangle regions for % uncertainties in flow and speed in order to achieve an overall standard uncertainty in combined source power levels of 0.5 dB(A) and 1.0 dB(A) respectively.**

### 2.2.2 Microscopic traffic parameters – urban road noise mapping

The traffic parameters speed distribution and acceleration/deceleration largely depend on the local situation, and therefore, noise mapping in a (sub)urban area is well-suited to study their importance. An accurate noise map of the region Gentbrugge (Belgium) is used. A micro-simulation traffic model was build, and was calibrated with traffic counts in this region [20]. Noise measurements at selected locations in the study area were compared to the calculations [20] . The importance of the traffic parameters under study is assessed by making noise maps, and by taking into account or neglecting certain parameters. For the reference calculations, all available data is passed to the emission module. The latter serves as a reference.

The study region Gentbrugge contains local streets with low and medium traffic volumes and a district road connecting the city of Gent (located to the north-west) with other suburban areas. The E17 highway is crossing the area in the south, and is situated on a viaduct. The area of about 1 $km^2$ has a mainly residential use; almost no industry is located in it. Road traffic and daily life of the inhabitants are the main sources of noise. Focus is on the distribution of exposed people over sound pressure levels. The same sound propagation model and emission model is used for the different calculations.

First, the influence of the traffic parameters acceleration and deceleration is studied. The difference between neglecting acceleration/deceleration data and the reference noise map is shown in Figure 12. This leads to (mostly) negative values near intersections, indicating sound pressure levels are underestimated by neglecting acceleration/deceleration. This error is at most intersections between 2 and 3 dBA.

Secondly, the importance of speed distribution data in the network is studied. Traffic is forced to drive at the speed limit in order to compare with the reference calculation (that takes actual speed distributions). Acceleration/deceleration data is neglected as well in these calculations. The difference between the latter and the reference noise map is shown in Figure 13. The main differences are observed near the large roads, especially close to the highway in the south and near the district road connecting Gentbrugge to other part of the city of Gent. Neglecting the actual speed distribution results in an increase in sound pressure level, ranging from 1 dBA to more than 3 dBA. At larger distances from these major roads, the effects are mainly caused by neglecting acceleration/deceleration data (see previous paragraph).

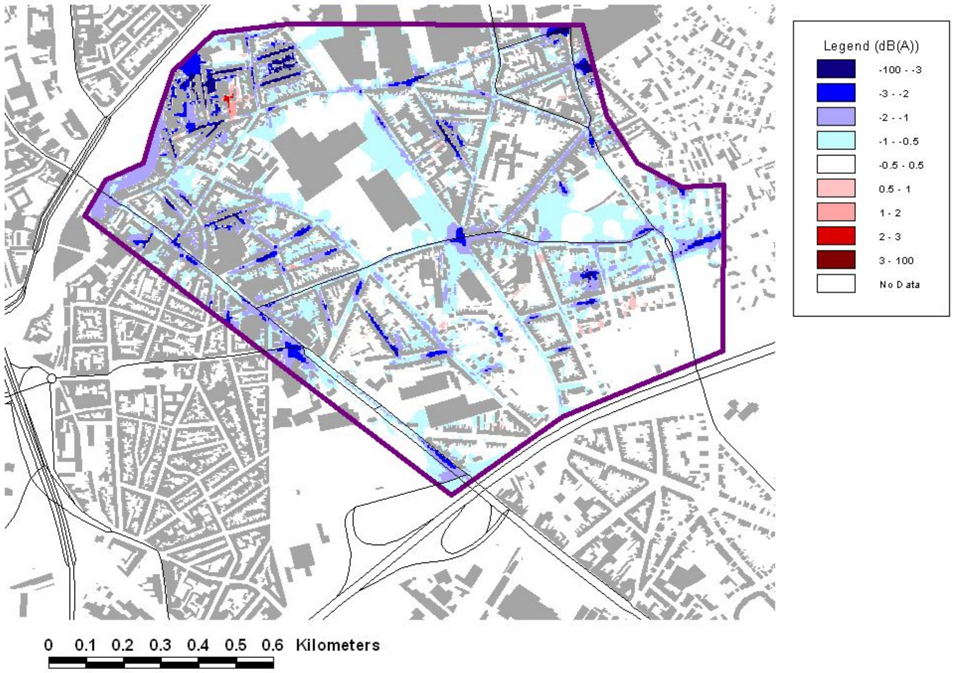



**Figure 12. Influence of neglecting acceleration/deceleration data.**

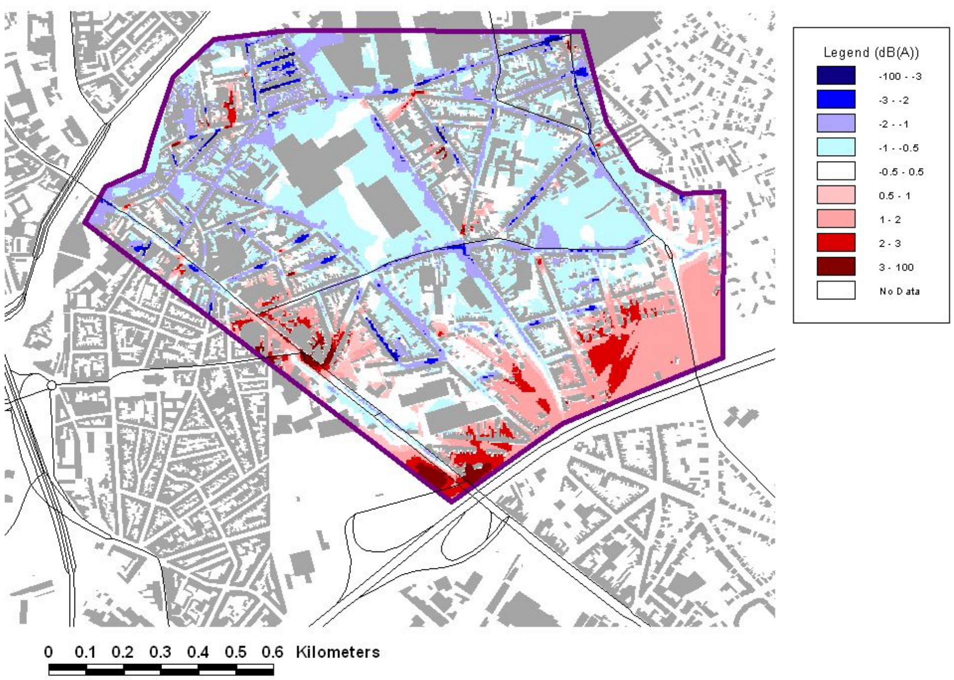



**Figure 13. Influence of neglecting speed distribution (and acceleration/deceleration data).**

The use of micro-simulation traffic parameters influences noise mapping. These type of models provide speed and acceleration data for every individual vehicle in the network. It was shown that including acceleration gives increased differentiation in noise levels, which leads to higher

prognoses of noise levels in the neighbourhood of intersections. The effect is not as local as one could think at first (especially when saturation starts to occur). A methodology to obtain (spatial) correction factors for intersections will be developed in Section 3.3 of this report, in case a macroscopic model is used that neglects intersections.
In the urban area studied, the effect of introducing individual vehicle speed is largest near the main roads and partly compensates the effect of introducing acceleration. The cumulated effect amounts up to +/- 3dBA.
This analysis shows that these (microscopic) traffic parameters, demanded by the HARMONOISE emission model, are of importance. An experiment to have an idea of the accuracy of the micro-simulation model applied to the study region, in combination with the HARMONOISE emission model, is presented in Section 2.2.3.

### 2.2.3 Accuracy of micro-simulation traffic models for emission modelling

To investigate to what extent vehicle speed, acceleration and associated noise emission can be modelled correctly using a micro-simulation model, kinetic parameters and resulting noise emission of an actual vehicle were compared with those simulated by a micro-simulation model. Since the same part of Gentbrugge was chosen as in Section 2.2.2 for this experiment, the accuracy of emission modelling/noise maps can be checked.

A number of rides through this case study area were performed. For this, a normal car was equipped with a speed meter and a GPS, which logged the instantaneous velocity and position of the car each second of the ride. Acceleration data was calculated afterwards from the speed data. Two different trajectories through the network were chosen, as shown in Figure 14. The first trajectory represents the local traffic that has its destination in the study area. The second trajectory represents the rat-run traffic through the area, from and to the city of Gent. Both trajectories were driven two times, once with a normal, relaxed driving style, and once with an aggressive driving style.


**Figure 14. Selected rides through the case study area. (a) Local destination traffic; (b) rat-run traffic.**

Using the case study micro-simulation model, the speed and acceleration data for all car vehicles driving at some moment along one of both paths was gathered. Harmonoise vehicle emission values were then calculated both for the rides and for the simulation. The emission time series of the car during the ride at various places along the path was compared with the emission of all simulated cars that pass on the same places along the path. For the roads where 70 km/h is allowed, the ride emission is most of the times within the predicted limits. For the more urban stretches of road, where only 50 km/h is allowed, several low level peaks are observed during the ride, which are not predicted by the micro-simulation model. This is shown in Figure 15. These can be explained by the fact that the car during the ride had to slow down for an obstacle, such as a person crossing the street, a car parking, or because a parked car is blocking part of the street, and one has to slow down for an oncoming car. These situations are not simulated by a micro-simulation model.

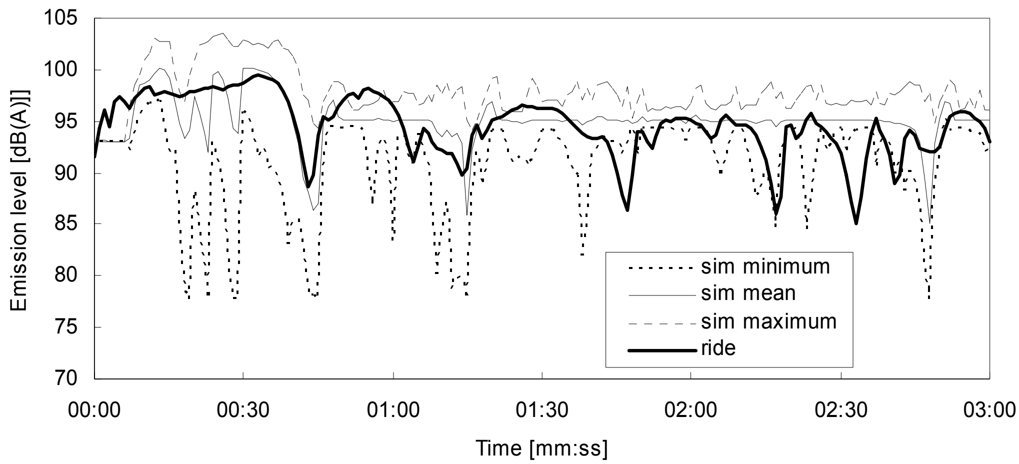
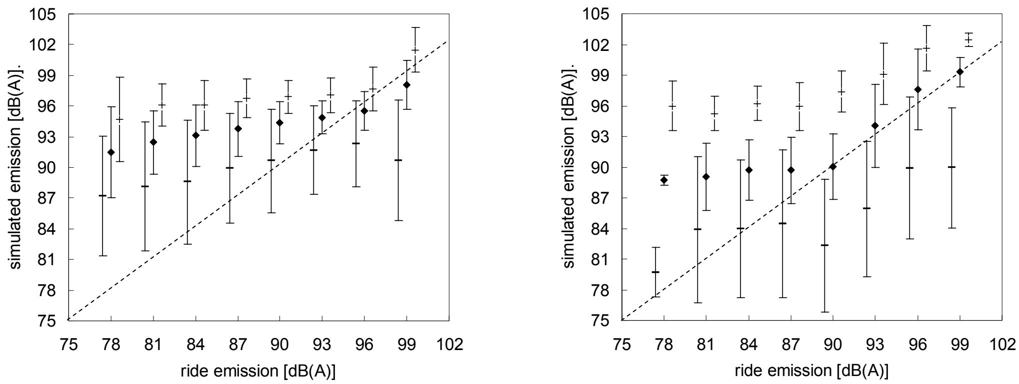



**Figure 15. Noise emission during a part of a ride (bold solid lines), compared with the mean simulated value of the emission at the same spots (thin solid line). The minimum and maximum simulated levels are also shown (dashed lines). The first 45 seconds of the ride, the vehicle was on a road with speed a limit of 70 km/h, the remaining of the ride is on roads with a speed limit of 50 km/h.**

A way to aggregate and represent the data is to analyse what level will be predicted by the micro-simulation, at all places along the paths where the ride emission had a certain level. In Figure 16, the emission data is given on a categorical scale. One can see that, for low levels on roads where 50 km/h is allowed, on average the simulated emission values are too high, but the ride emission values are still within the limit values which are predicted by the micro-simulation model. The slope of the mean simulated values is less steep than it should be. This could mean that the path of a car driving in an urban area will be more interrupted in reality than in the micro-simulation. For the roads where 70 km/h is allowed, one would expect less sporadic obstacles, but more jams, which are simulated by the micro-simulation model. The simulation mean predicts the ride emission better for the higher levels on these roads.

When looking at the emission of the car considering the whole ride, one can compare the different driving styles. It was found that on the average the emission level is about 2.5 dB higher for the aggressive driving style compared to normal driving. Accounting for the shorter duration of the ride on a path when driving aggressively, it was found that the contribution of the car passage to the equivalent noise level (or $L_{den}$) can still be more than 1 dB higher compared to a normal driving style.




(a) (b)

**Figure 16. Predicted level versus ride emission level on a categorical scale, for (a) the roads were 50 km/h is allowed and (b) were 70 km/h is allowed. The markers give the mean value of (♦) the mean predicted emission level, (+) the maximum predicted emission level and (-) the minimum predicted emission level. Standard error bars are also shown.**

In task 2.2 the accuracy of the noise immission near the edge of the road was investigated, showing that the predicted $L_{Aeq}$ is much closer to the measured $L_{Aeq}$ than one would expect on the basis of the uncertainty in noise emission of a particular car that is shown above.

### 2.2.4 Effect of traffic modelling detail on exposed population

In this section, the effect of increasing the (spatial) detail in traffic modelling is studied. Noise maps are made for a same urban area Gentbrugge, using in a first step interpolated traffic counts, in a second step a macroscopic model and in a third step a micro-simulation model. Results are condensed by looking at the distribution of the number of exposed people over 5-dB $L_{den}$ classes, the information to be provided by the member states to the European Commission. The same sound propagation model and emission model is used for the different noise maps.

**Regional map 1**. In a first noise mapping approach (see Figure 17), calculations are based on continuous traffic counts on the major roads only. This noise map is actually a zoom-in of a noise map on a much larger scale (namely the whole of Flanders, in the context of producing a “state-of-the-environment”). At the traffic counting stations (about 500 on the total area of 13 500 km$^2$ of Flanders) traffic intensity and percentage of heavy vehicles is measured every hour over the full day and year. Thus errors on diurnal and annual pattern of traffic intensity are extremely low at these locations. The error on traffic composition is slightly larger because the definition of light and heavy does not fully correspond to the definition used in the noise emission model. Traffic intensity is extrapolated spatially using a separate interpolation for highways and major roads. This very simple “traffic model” is an obvious cause of error on intensities. The vehicle speed distribution is based on nation-wide statistics of speed limits combined with data from point measurements of real driving speed distribution as a function of speed limit. For each type of road available in the GIS system (there are about 7 relevant categories) a distribution of speed limits is available. This distribution is then convoluted with the measured speed distribution for each given speed limit. The amount of heavy traffic is set constant and varies by class of road-type. The presence of the buildings is not accounted for in the propagation module. The distribution of people living in this area is based on building density (soil use map).

**Regional map 2**. This noise map is similar to the previous one. The main difference lies in the fact that a more detailed traffic model is used; the actual traffic links and local speed limits are taken into account. For the regional map 1, the speed limit is assigned based on road type only. This means that the speed limit of a major road, when running through a build-up area, will be too high. The impact on sound exposure is clearly visible in Figure 18.

**Urban map**. In a second noise mapping approach (see Figure 19), traffic data is gathered from a multimodal static assignment traffic model, owned by the city of Gent, where Gentbrugge is part of. The model is constructed to assess traffic changes due to major mobility changes in the city (prohibiting parking at certain locations, new roads, changes in public transportation, and so on). The model produces traffic data on a more detailed set of road segments than the previous approach. The traffic model topography had to be mapped to the real street topography. The automatic mapping needed to be adapted manually using field knowledge. The model however only calculates rush hour traffic intensity. Heavy traffic and passenger cars are included in OD-matrices. The extrapolation of $L_{Aeq,rush}$ to $L_{den}$ was based on noise measurement experience near similar roads. Traffic flow speed obtained from the model was too unreliable to be used in the noise emission calculation so local speed limits had to be used instead. No special effort is made to model intersections of roads. The traffic data is now spatially more detailed but less detailed in time compared to the traffic counts in the first approach. Screening of buildings is taken into account and the distribution of the population over sound pressure level classes is based upon actual buildings, distributing the population proportionally to the ground surface of the buildings.

**Local noise map**. In a third noise mapping approach (see Figure 20), a micro-simulation model is used to get detailed traffic data in the area under study [20]. All streets are now modelled, as well as individual cars. The OD-matrices are initially obtained from the previous model, but were further refined to match a set of traffic counts made in the small area. Additional origin/destination data had to be introduced to correctly predict traffic intensity on the lower level roads. Acceleration and deceleration data is available by the micro-simulation traffic models, and used in the emission module. Three vehicle types are used: passenger cars, light goods vehicles and heavy goods vehicles. The purpose of producing a noise map in this degree of detail would be neighbourhood action planning. The micro-simulation model was tuned in detail for this particular situation, and noise measurements were compared to simulation results [20].


**Figure 17. Extract for Gentbrugge from the regional noise map 1, based on interpolated traffic counts.**


**Figure 18. Extract for Gentbrugge from the regional noise map 2, with local speed limits.**

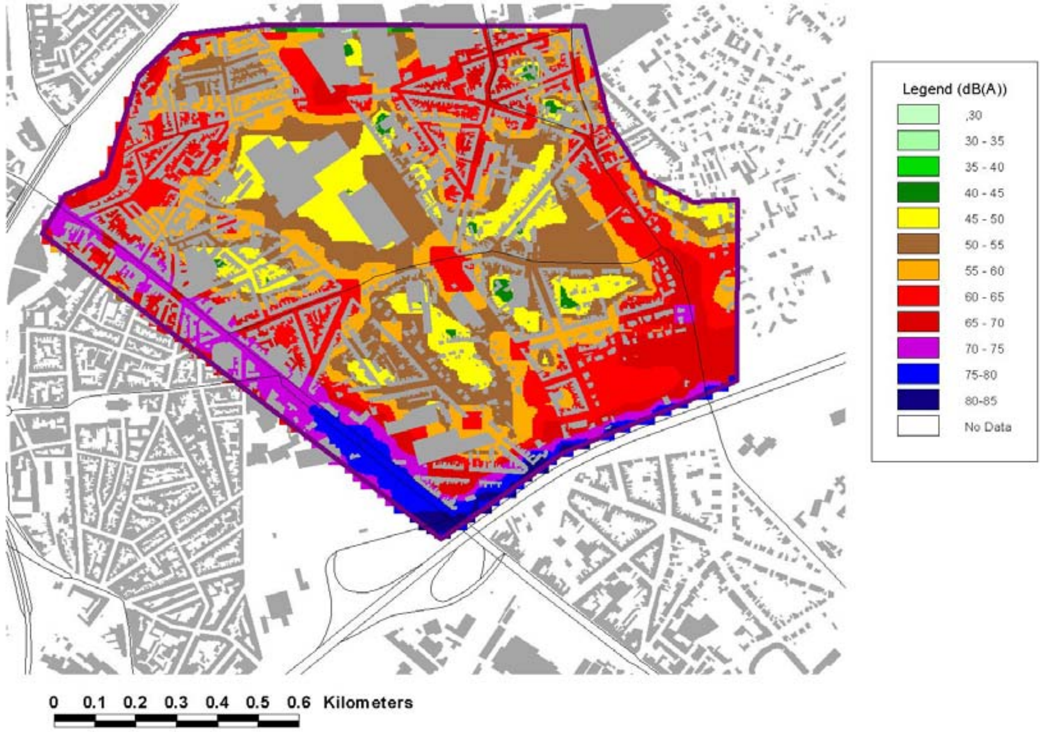



**Figure 19. Extract for Gentbrugge from the urban noise map, based on static assignment traffic model.**


**Figure 20. Local noise map of Gentbrugge, based on micro-simulation traffic model.**

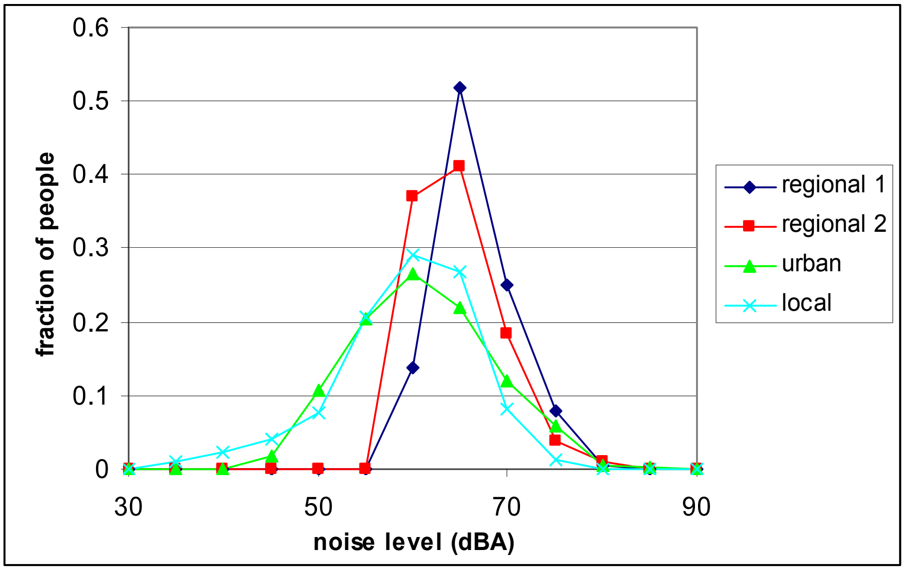



**Figure 21. Distribution of the people in Gentbrugge over a wide range of noise level classes, based on calculations with different traffic modelling approaches.**

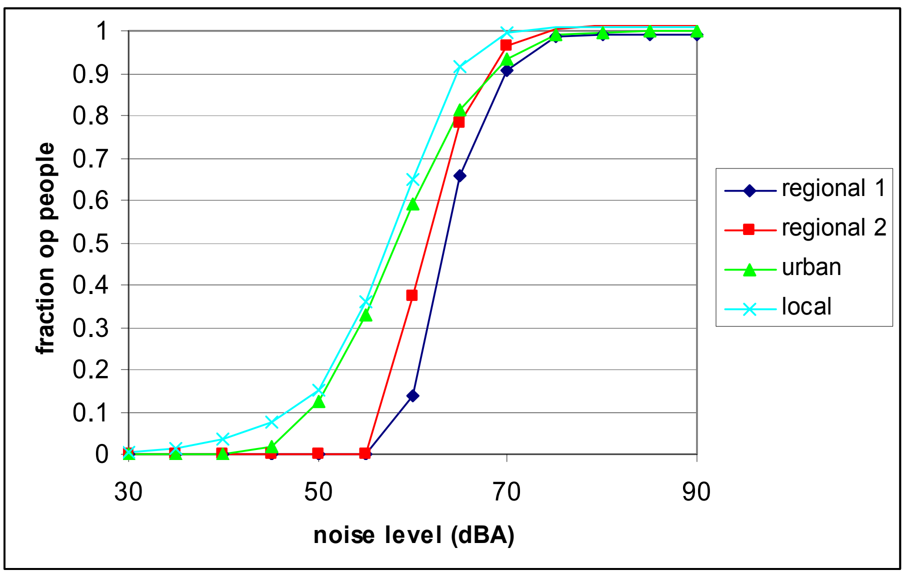



**Figure 22. Normalized, cumulative distribution plot (see Figure 21).**

In Figure 21, the distribution of the people in Gentbrugge over a wide range of sound pressure level classes (discretised per 5 dBA) is shown, based on calculations on different scales (or with different degrees of detail). In Figure 22, the corresponding, normalized cumulative distribution function is shown. In case of the regional noise maps 1 and 2, no persons are exposed to noise levels smaller than about 55 dBA. This is simply because the shielding by houses is not accounted for in the propagation module, which is of course important in an urban area. When comparing regional noise map 2 with regional noise map1, the distribution becomes wider, and the number of people exposed at noise levels larger than 65 dBA is smaller. This is caused by using more realistic (and lower) speed data in the build-up area. This gives an indication of the importance of accurate speed data. Both regional noise maps overestimate the number of exposed people at high sound pressure levels, relative to the more detailed urban and local noise maps. The shift towards higher noise levels in the distribution of the urban noise map relative to the local noise map is caused by neglecting a number of smaller roads in the network.

In the above example, it will not surprise the reader that a micro-simulation traffic model tuned in detail to a local situation results in very accurate noise maps. It is however similarly obvious that this approach can not be used at a larger scale due to both preparation time (counts) and computation time. Moreover there is always a risk of over-fitting a model to the current situation thereby jeopardising the option for calculating scenarios and evaluating the impact of measures. Using a macroscopic model allows producing traffic parameters for whole regions or countries. The example gives an idea of the impact of the detail in traffic modelling on a noise map. In terms of population exposed, the error introduced by neglecting exposure to noise of traffic on lower level roads seems of little important. Although the error that this approximation introduces in the distribution is clearly observable, it occurs mainly at lower exposure levels and thus will be of lesser importance for estimating impacts on health (and annoyance). Imprecision in the modelling of traffic on the main road on the contrary is rather important for the distribution of the population exposed to high noise levels in this example. This imprecision consists of poor estimate of vehicle speed mainly.

### 2.2.5 Conclusions

From the MCS analysis it was found that the relative error on mean speed, which is allowed to achieve a predefined accuracy in noise maps, decreases significantly with vehicle speed. The absolute error stays more or less the same, and is near 10 km/h to achieve 1-dBA accuracy. The needed accuracy for traffic intensity is rather insensitive to changes in the mean speed, and to the traffic intensity itself. The allowed error on speed and traffic intensity also depends on the prevailing percentage heavy good vehicles. An overview is given of the allowed inaccuracies of these traffic parameters to achieve an overall accuracy goal of 0.5 dBA and 1 dBA. A similar conclusion is based on a detailed, suburban area study. It was clear that the importance of accurate speed data/speed distribution is most prominent near roads where the maximum allowed speed is largest. The importance of using acceleration/deceleration data in the noise emission model was studied as well. Local errors (underestimates) near intersections in the order of maximum 2-3 dBA were observed. When saturation occurs, the errors are present up to large distances from the intersection. A spatial approach in order to formulate correction factors will be necessary.

The Harmonoise emission model, with traffic parameters provided by a micro-simulation model, gives a reasonable estimate of the emitted acoustical power. The accuracy of the emitted acoustical energy increases with increasing flow velocity. Higher emission levels are better predicted than lower levels. This gives confidence in the conclusions drawn in previous paragraph.

By comparing a selected area in noise maps with different degrees of detail (or alternatively, with different purposes), it was found that differences (errors) are mainly observed at high and low exposure levels. This analysis gave an idea of the impact of the degree of detail in a practical situation.

## 2.3 Temporal resolution

In this section, the required temporal resolution for traffic data is investigated. The purpose is to balance the temporal resolution of (mainly) traffic intensity against the error on $L_{den}$ values. Two case-studies are performed to assess the importance of daily, weekly, seasonal and yearly variations. In a first study, focus is on traffic intensity, and strictly on emission. Variation within single days and within weeks is investigated, based on a database of (yearly averaged) hourly traffic counts for each day of the week, at about 300 locations on highways in Flanders, Belgium. Weekly and daily $L_{den}$ values are calculated. In a second part, a similar study is performed, based on traffic counts in Leicester, UK. A receiver is now present very close to the centreline of the road. Year-by-year variations, seasonal variations and variations within the week are investigated, for traffic intensity and speed distribution, and for different types of roads. Yearly $L_{den}$ values are calculated.
A third part in this chapter on temporal resolution focus specifically on the correlation between diurnal emission profiles (traffic intensity) and diurnal propagation behaviour, influenced by meteorological conditions.

### 2.3.1 Daily and weekly $L_{den}$ (highways in Flanders)

In this section, the effect of the temporal detail in traffic data on $L_{w,den}$ values is studied. The latter is defined as the equivalent source power accounting for the 5 dB penalty during the evening period and the 10 dB penalty during the night period.

***Distribution of traffic intensity over day, evening and night period***

Traffic models very seldom produce traffic intensity data for representative hours of the day, evening and night. In some cases intensity is given as a 16h daytime intensity $I_d$ and night time intensity $I_n$. For $L_{w,den}$ calculations, an estimate must be made on the distribution over day period, evening period and night period. The recommendation by the Good Practice Guide (GPG) [1] is to attribute 75% of *Id* to 12 hours of the day and 25% of $I_d$ to the evening. This approach was compared to a large number of detailed traffic counts on the highways in Flanders. The error made by using the GPG assumption on $L_{w,den}$ of individual highways lies between 0.7 dBA and -1.2 dBA (see Figure 23). This error is caused by differences in diurnal fluctuations of traffic intensity between individual highways: on some highways there is significantly less traffic during the evening.

Using another distribution of $I_d$ between day and evening shifts the error but does not reduce it. Using a 85%/15% distribution (which is more appropriate in Flanders) shifts the error in such a way that the $L_{w,den}$ of about 60% of the highways falls within the a 0.25 dBA error margin, and 75% within the 0.3 dBA error margin. The above discussion applies to single day-intensities averaged over a year. No distinction is made between the days of the week.

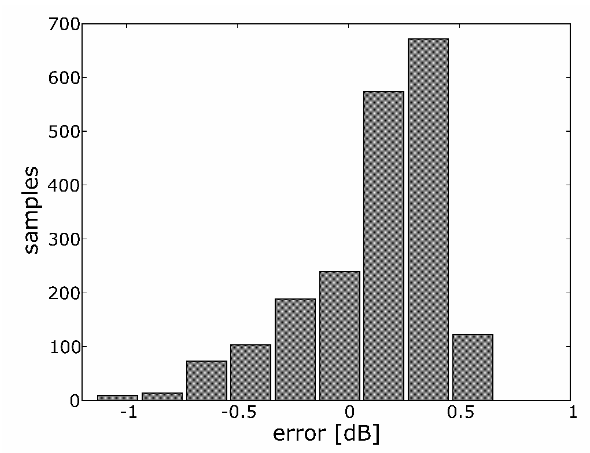



**Figure 23. Distribution of the difference on $L_{w,den}$ calculated with hourly traffic counts and using the WG-AEN method for subdividing 16h traffic, over individual highways in Flanders.**

### *Variation over the day of the week*

The average ratio of daytime traffic intensity and night-time intensity over a year at 300 locations on highways in Flanders changes during the course of a week as shown in Figure 24. Every day of the working week can serve as a representative sample for the other days of the working week as regards daytime/night-time traffic intensity ratio. During the weekend on the other hand, the share of daytime traffic decreases. Using the weekday distribution for the days during the weekend yields an error of about 0.3 dBA during the weekend.

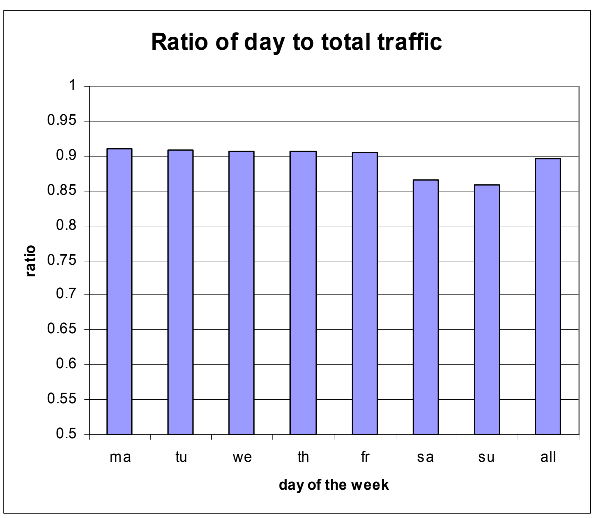



**Figure 24. Averaged ratio of traffic intensity during day time relative to total traffic intensity, over the week for highways in Flanders.**

If traffic counts (or traffic modelling) are performed for one day only and then evenly distributed among the other days, including the weekend, the expected error is about 0.5dBA on the weekly averaged $L_{w,den}$. This assumes that there is no preference for the day of the week to perform the traffic counts. The individual differences between days are of the order of 0.2dBA during day and night and up to 0.95dBA in the evening period caused by the Friday evening. If the Friday is excluded then the expected error is 0.1dBA and 0.5dBA respectively, totalling 0.2dBA on the weekly $L_{w,den}$.

**Table 5 Estimated error on average weekly $L_{Wden}$ by different simplifications in traffic model.**

| Approximation | 95% confidence interval (assuming normal distribution) for the errors on weekly $L_{Wden}$ introduced by the approximation (in dBA) |
|---|---|
| $I_{24h}$ on weekday from traffic model (GPG : 70 % day, 20 % evening, 10 % night) | [-0.58, 1.00] |
| $I_{de}$ (16h) (GPG : 75 % day, 25 % evening) and $I_n$ on weekday from traffic model | [-0.30, 0.63] |
| $I_{1h}$ on weekday from traffic model | [-0.28, 0.54] |
| $I_{1h}$ on weekday and weekend day from traffic model | [-0.22, 0.05] |
| $I_{1h}$ for every day of the week from traffic model | reference |

Table 5 gives an overview of the (combined) error introduced by limiting the traffic simulation to shorter periods. This estimate is based on the situation in a particular region (Flanders) and for highway traffic only. As a reference, the weekly $L_{den}$ is calculated based on hourly countings $I_{1h}$ on (a yearly averaged) Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday. In a second approach, hourly countings on a certain day of the working week are taken representative for the other days of the working week, and hourly counting on a weekend day is taken representative for the other day of the weekend. In a third approach, hourly countings on a day during the working week is taken representative for all other days of the week, including days during weekend. For the lesser detailed approaches, hourly countings are not available anymore. In a first approach, the total 16-hour traffic intensity $I_{de}$ on a certain weekday is taken representative for all other days of the week (including weekends). The share between daytime and evening-time intensity is made following the GPG, while the total 8-hour traffic intensity at night $I_n$ is assumed to be known. The approach with the smallest amount of detail in our example has a (total) 24-hour traffic intensity $I_{24h}$ of a day during the working week. The distribution over the 3 periods D/E/N follows the recommendations of the GPG. It is clear that with decreasing detail, the 95% confidence intervals increase.

The 300 locations near highways to obtain the data in Table 5 cover busy highways near Brussels capital region, as well as more remote and less used stretches. These results are not necessarily applicable to all situations in Europe. Nevertheless it gives some insight in the order of magnitude of the error introduced. In Section 2.3.2, a similar exercise is performed, at which seasonal and yearly variation are addressed as well. It is however limited to 8 types of roads in one city. Variation in speed distribution over time is considered in this case-study.

### 2.3.2 Yearly $L_{den}$ (city roads in Leicester)

#### *Annual variations*

The END specifies that the $L_{DEN}$ and $L_{night}$ noise levels should be expressed as *long-term annual average* values. It is also stated that the usual period between successive rounds of noise mapping should be 5 years. It may be considered reasonable that the traffic used as input into the noise mapping exercise is representative of an average year within that period. Historically traffic models have been developed only to study the most congested periods, i.e. weekday daytime traffic. Therefore some consideration should be given to the uncertainties arising from the scaling of modelled traffic flows to cover entire days, daily variation in levels, seasonal variation in levels and year-on-year traffic growth. Suitable year-on-year growth may be potentially found in national literature, or from traffic digest information kept by relevant local authorities. National growth may be distinct from regional growth for a specific agglomeration.

If it is assumed that annual growth in traffic does not affect speeds, is independent of road type, is uniformly distributed throughout the day and any effects of aging of road surface on noise are ignored, then a simple correction to the annual level may be applied:

$$Correction = 10\log_{10}\left(1+\frac{x\%}{100}\right) \text{ dB(A)}$$

The above equation gives an increase in noise level of +0.04 dB(A) per annum for 1% traffic growth. This, in turn, suggests that a prediction of average parameter values for a five-year period, based on a traffic forecast for the initial year would need to be corrected by approximately +0.09 dB(A).

Regarding micro-simulation, a particular node, or group of nodes in a micro-simulation may operate successfully a given demand, but produce instabilities, leading to excessive queues and delays at a marginally higher demand level. Therefore, application of growth factors to demand levels in micro-simulation models has the potential to give divergent results between individual model runs. This necessitates further runs to obtain statistically sound parameter values. The *"Traffic Analysis Toolbox Volume III"* [10] recommends testing micro-simulation networks for sensitivity to demand at a variety of multiples of the base demand level.

***Seasonal variations***

It is recognised that traffic patterns are subject to seasonal variations within the year, for example a general lull in urban traffic levels during the summer holiday periods, with a corresponding increase in inter-urban traffic at the same period. Some months may be considered to be '*traffic neutral*', where the monthly flow may be considered to be representative of the annual flow. It is generally typical for traffic models to be calibrated and validated against data collected during such a neutral month.

In order to study the effects of seasonal variations, traffic pattern data from the city of Leicester, UK was examined. Figure 25 shows the seasonal variation data, by particular classifications of road obtained from the City Council. Seven categories of road were defined: Motorway, Inbound and outbound radial roads, with two categories for each, two categories of ring-road and local/sub-urban roads.

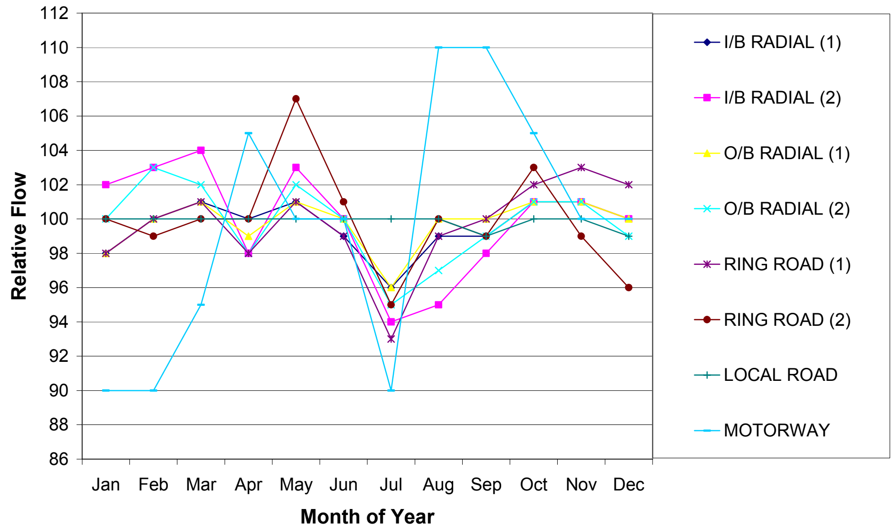



**Figure 25. Seasonal Variations in traffic pattern used to study long-term annual parameter values (NB I/B stands for inbound traffic and O/B stands for outbound traffic)**

$L_{day}$, $L_{evening}$, $L_{night}$ and $L_{DEN}$ parameters were calculated for a single roads using the Harmonoise source model, see Section 2.2.1b, over the period of a month, based on additional traffic data from the City Council (see *Daily Variations* below), using the assumptions made by Watts *et. al.* [21] in converting sound power levels to sound pressure levels. All values are calculated for a point 10 m from the source line. Due to this small distance from the source, meteorological influences on sound propagation is not considered. It was assumed that a year was comprised of 12 months of equal duration. A flow correction was then applied to each month in the same format of the annual correction outlined above (i.e. assuming no change in speed with flow variation) and new parameter values calculated. The base profile was assumed to be one with no correction applied to each month.

Table 6 shows the results of using the different seasonal road profiles on a link assumed to have an AADT flow of 24000 veh/day, at a mean speed of 105km/h. Note that the application of the seasonal variation parameters makes little difference to the overall calculated annual parameter values, with variations generally being in the second decimal place. Given that the flow variations were applied based on normalised profiles not affecting speed, the same results are obtained for links with differing AADT flow levels and speeds.

**Table 6. Results of analysis of effect of seasonal flow variation on annual parameter values in dB(A)**

| Seasonal Profile | $L_{Day}$ | $L_{Evening}$ | $L_{Night}$ | $L_{DEN}$ |
|---|---|---|---|---|
| **Base** | 78.24 | 76.78 | 74.87 | 82.06 |
| **Motorway** | 78.22 | 76.76 | 74.85 | 82.04 |
| **I Radial (1)** | 78.22 | 76.76 | 74.85 | 82.04 |
| **O Radial (1)** | 78.23 | 76.77 | 74.86 | 82.05 |
| **I Radial (2)** | 78.24 | 76.78 | 74.86 | 82.06 |
| **O Radial (2)** | 78.23 | 76.78 | 74.87 | 82.06 |
| **Ring Road (1)** | 78.24 | 76.78 | 74.86 | 82.06 |
| **Ring Road (2)** | 78.24 | 76.78 | 74.86 | 82.06 |
| **Local Road** | 78.23 | 76.77 | 74.86 | 82.05 |

***Daily variations***

Additional data on daily traffic variations and vehicle speeds was obtained from Leicester City Council on daily variations of traffic for the road types mentioned above. The data obtained gave:

- Hourly variations in vehicle flows, by road class for four categories of day: Weekdays, Fridays, Saturdays and Sundays.
- Hourly speed data from all signalised intersection for the year 2001, from the cities' Urban Traffic Control (UTC) system.

The former data was normalised and used to scale AADT flow values to provide hourly link flows for the day types. The latter data was disaggregated by road class, speed limit and day, and used to calculate normalised average speed profiles. Unfortunately no speed information was obtained for the 'motorway' road class – being outside the UTC system. Speed profile information also only spanned the hours in which the UTC system was in operation, 07:00 – 00:00. For speeds outside of this period it was assumed that vehicles would travel at the speed limit. Finally no time-varying information on vehicle classifications was obtained.

Figure 26 displays the relative flow volumes for each of the four days, averaged across road types. Figure 27 shows the hourly profiles for weekdays by road type.

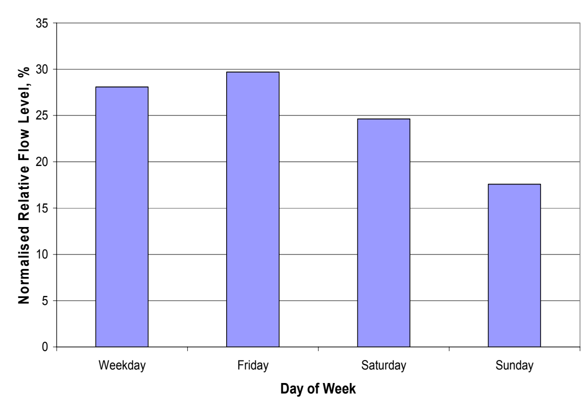



**Figure 26. Relative flow volumes by day**

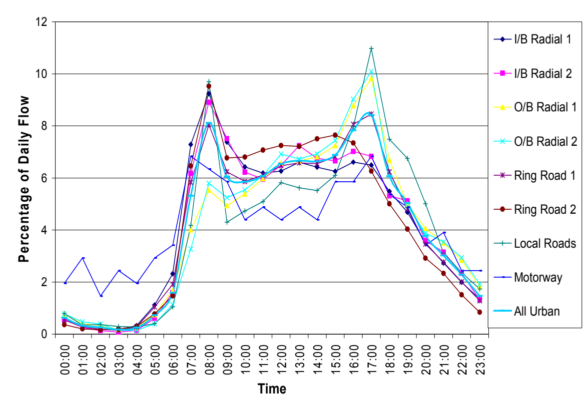



**Figure 27. Weekday hourly flow profiles by road type**

Figure 28 shows the relative percentages of daily flow totals, by road type for the day, evening and night periods for weekdays. Note the profile from WG-AEN Toolkit 1, Tool 2, which assumes 70% of flow during the day, 20% during the evening and 10% during the night was included in the analysis. The day, evening and night proportions of the WG-AEN profile fall between the profile taken from Leicester motorway data, which has a substantial (20%) night component and the general Leicester urban profiles (average flow distribution of 80.5% during the day, 14.1% during the evening and 5.4% during the night). Figure 29 gives a sample calculated average annual speed profile for an inbound radial road for weekdays. Generally the profiles used give daytime speeds of 70% to 80% of the base values, with evening speeds in the order of 85% - 95% of base values.

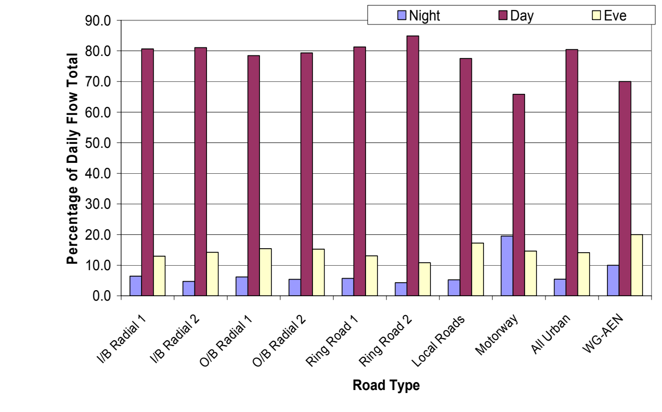



**Figure 28. Weekday relative flow volumes by road class and period of the day**

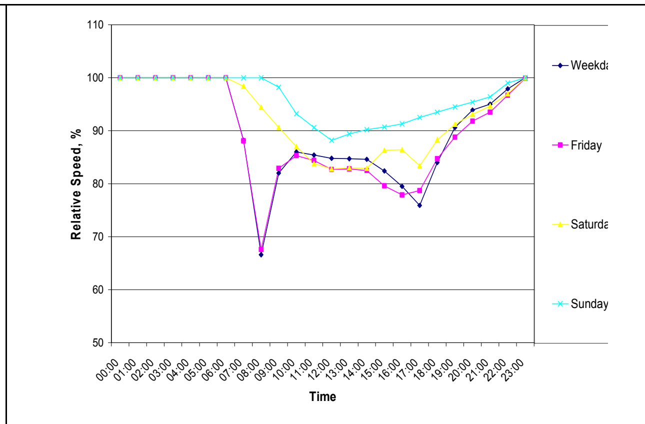



**Figure 29. Sample weekday hourly flow profile for inboun radial roads**

For analysis, $L_{day}$, $L_{evening}$, $L_{night}$ and $L_{DEN}$ were calculated for a selection links, based on the following AADT flows, speeds and compositions.

**Table 7. Default traffic parameters used to study daily variations**

| AADT Flow | %age of Category 2 (LGV) vehicles | %age of Category 3 (HGV) vehicles | Mean flow speed, km/h |
|---|---|---|---|
| 24000 | 0 | 20 | 105 |
| 12000 | 4.5 | 4.5 | 47 |
| 6000 | 1.5 | 1.5 | 40 |
| 1200 | 0 | 0 | 32 |

The following combinations of profiles were used for calculations:

1. Use flow and speed profiles for each road type, for all four days. Weight daily results to give weekly parameter values, and assume no seasonal variations, i.e. annual parameter values = weekly parameter values.
2. Use flow and speed profiles for each road type, for weekdays only. Assume that annual parameter values = weekday parameter values.
3. Use the flow profile for each road type, for all four days. Annual parameters calculated as for 1. above.
4. Use the flow profile for each road type, for weekdays only. Annual parameters calculated as for 2. above. The results of using WG-AEN Toolkit 1, Tool 2 were included in this section.

Table 8, Table 9, Table 10 and Table 11 show the results of using the different combinations of profiles for the first set of parameter values in Table 7.

From the tabulated results, it may be seen that the exclusion of the speed profile has the greatest effect, giving a change of over 1 dB(A) in the calculated $L_{DEN}$ level, (>2dB(A) change in $L_{day}$ levels and >1.5 dB(A) change in $L_{evening}$ levels). A smaller change is noted in the $L_{night}$ level, given the use of the base speed value for the majority of that period. For the other link flow and speed combinations tested, the inclusion or exclusion of the speed profile had a lesser effect, in the range of 0.5 - 0.7 dB(A) for $L_{day}$, 0.4 - 0.6 dB(A) for $L_{evening}$, 0.1 dB(A) for $L_{night}$ and 0.3 - 0.5 dB(A) for $L_{DEN}$.

**Table 8. Annual parameter values calculated using hourly flow and speed profiles for all days**

| Daily Profile | $L_{Day}$ | $L_{Evening}$ | $L_{Night}$ | $L_{DEN}$ |
|---|---|---|---|---|
| **I Radial (1)** | 77.73 | 75.65 | 70.37 | 79.31 |
| **O Radial (1)** | 77.57 | 76.31 | 70.41 | 79.44 |
| **I Radial (2)** | 76.66 | 75.11 | 68.98 | 78.24 |
| **O Radial (2)** | 76.51 | 75.35 | 69.83 | 78.61 |
| **Ring Road (1)** | 76.19 | 73.68 | 69.20 | 77.84 |
| **Ring Road (2)** | 77.85 | 74.26 | 68.50 | 78.33 |
| **Local Road** | 75.17 | 74.14 | 69.45 | 77.75 |
| **Average** | **76.81** | **74.93** | **69.53** | **78.50** |
| **St.Dev.** | **0.974** | **0.937** | **0.713** | **0.664** |

**Table 9. Parameter values calculated using hourly flow and speed profiles for weekdays only**

| Daily Profile | $L_{Day}$ | $L_{Evening}$ | $L_{Night}$ | $L_{DEN}$ |
|---|---|---|---|---|
| **I Radial (1)** | 77.96 | 75.74 | 70.25 | 79.36 |
| **O Radial (1)** | 77.80 | 76.52 | 70.06 | 79.42 |
| **I Radial (2)** | 76.93 | 75.26 | 68.76 | 78.29 |
| **O Radial (2)** | 76.72 | 75.52 | 69.23 | 78.47 |
| **Ring Road (1)** | 76.48 | 73.89 | 69.12 | 77.95 |
| **Ring Road (2)** | 78.32 | 74.59 | 68.56 | 78.64 |
| **Local Road** | 75.15 | 74.41 | 68.38 | 77.32 |
| **Average** | **77.05** | **75.13** | **69.19** | **78.49** |
| **St.Dev.** | **1.085** | **0.896** | **0.722** | **0.747** |
| **Diff. from** Table 8 | **0.24** | **0.20** | **-0.34** | **-0.01** |

**Table 10. Parameter values calculated using hourly flow profiles for all days, but assuming base speed**

| Daily Profile | $L_{Day}$ | $L_{Evening}$ | $L_{Night}$ | $L_{DEN}$ |
|---|---|---|---|---|
| **Motorway** | 78.24 | 76.78 | 74.87 | 82.06 |
| **I Radial (1)** | 79.13 | 76.21 | 70.38 | 79.97 |
| **O Radial (1)** | 79.01 | 76.84 | 70.41 | 80.08 |
| **I Radial (2)** | 79.14 | 76.64 | 69.22 | 79.7 |
| **O Radial (2)** | 79.03 | 76.87 | 70.08 | 79.98 |
| **Ring Road (1)** | 79.18 | 76.15 | 69.80 | 79.78 |
| **Ring Road (2)** | 79.38 | 75.37 | 68.68 | 79.35 |
| **Local Road** | 78.98 | 77.11 | 70.13 | 80.04 |
| **Average**[a] | **79.12** | **76.46** | **69.81** | **79.84** |
| **St.Dev.** [a] | **0.136** | **0.594** | **0.644** | **0.257** |
| **Diff. from** Table 8[a] | **2.31** | **1.53** | **0.28** | **1.34** |

(a) Values excludes motorway profile results.

**Table 11. Parameter values calculated using hourly flow profiles for weekdays only, assuming base speed**

| Daily Profile | $L_{Day}$ | $L_{Evening}$ | $L_{Night}$ | $L_{DEN}$ |
|---|---|---|---|---|
| **WG-AEN** | **78.58** | **77.91** | **71.89** | **80.80** |
| **Motorway** | 78.45 | 76.69 | 74.93 | 82.13 |
| **I Radial (1)** | 79.47 | 76.30 | 70.25 | 80.09 |
| **O Radial (1)** | 79.34 | 77.05 | 70.06 | 80.15 |
| **I Radial (2)** | 79.62 | 76.83 | 69.02 | 79.9 |
| **O Radial (2)** | 79.45 | 77.07 | 69.52 | 80.03 |
| **Ring Road (1)** | 79.82 | 76.65 | 70.03 | 80.25 |
| **Ring Road (2)** | 79.92 | 75.74 | 68.75 | 79.72 |
| **Local Road** | 79.10 | 77.35 | 69.17 | 79.86 |
| **Average**[a] | **79.53** | **76.71** | **69.54** | **80.00** |
| **St.Dev.** [a] | **0.281** | **0.545** | **0.584** | **0.183** |
| **Diff. from** Table 8[a] | **2.72** | **1.78** | **0.01** | **1.50** |

(a) Values exclude motorway and WG-AEN profile results.

When using both flow and speed profiles, calculating annual parameters by using weekday data only, as opposed to using data from the four day types made little change in the $L_{DEN}$ level, in the order of 0.1 dB(A), with increases in $L_{day}$ and $L_{evening}$ values associated with work traffic, being cancelled out by decreases in $L_{night}$ levels that associated with leisure traffic during the weekend. Exclusion of speed profile information compounds the exaggerating effects of using weekday data only when calculating annual $L_{day}$ and $L_{evening}$ levels.

As expected, the use of both flow and speed profile information increased the variation (standard deviation) of the results over using flow profile information alone. For the example in Table 8-Table 11, at a mean speed of 105 km/h, variation in the speed profiles has a major contribution to the variation in calculated parameters, hence the variation in $L_{day}$ levels exceeds that for $L_{evening}$ or $L_{night.}$ For lower speeds, or if speed profile information is ignored completely, variation in flow profiles leads to greater variation in $L_{evening}$ and $L_{night}$ levels. In all of the tested combinations, using the different profile information for the urban road categories (i.e. non-motorway and WG-AEN), gave standard deviations in $L_{DEN}$ levels of <0.7 dB(A).

Using the WG-AEN Toolkit 1, Tool 2 profile gave a lower $L_{day}$ level, but higher $L_{evening,}$ $L_{night}$ levels and overall $L_{DEN}$ levels, in the order of approximately 1 dB(A), when compared to using the Leicester urban flow profiles. Using the Leicester motorway profile, with its high night time flow levels decreased $L_{day}$ values by approximately 1 dB(A), but increased $L_{night}$ levels by over 3 dB(A), for a net increase in $L_{DEN}$ of the order of 2 dB(A). The results therefore suggest that, in this instance it could be considered important to distinguish between the motorway and other classes of urban roads. It must be borne in mind however that the results obtained using the motorway profile could have been somewhat mitigated if an appropriate daytime speed profile had been available. However, the $L_{night}$ level would be further increased if diurnal changes in fleet proportions were also considered – given that the relative proportion of class 2 and 3 vehicles increases during the night on major inter-urban roads.

### 2.3.3 Correlation between diurnal traffic intensity and propagation conditions

Traffic intensity is strongly linked to the period of the day, as is clear from typical intensity profiles. On the other hand, it is known that favourable and unfavourable sound propagation conditions are linked to different periods of a day as well. At night and in the early morning, temperature inversion often occurs and this results in increased sound pressure levels at distant receivers. During the day, there is usually an unstable atmosphere, resulting in upward refraction of sound and decreased sound pressure levels at distant receivers. In this section, it is studied how the above described dependencies interact.

#### *Hourly attenuation calculations*

Detailed hourly attenuation calculations are made. The Harmonoise reference model is used namely the (axisymmetric) Parabolic Equation method (to represent a point source).

Refraction of sound by wind speed gradients and temperature gradients are taken into account by using the effective sound speed approximation. Detailed meteo-observations on a tower in Meppen (Germany) were available from the Harmonoise project. The dataset consisted of one-minute measurements of wind direction, profiles of temperature (at 6 heights) and profiles of wind speed (at 8 heights) and relative humidity near the ground (or alternatively the dew-point temperature) during two periods of the year (May and December). Hourly averaged meteo data is used. The interpolation to continuous vertical profiles is performed using the log-linear relationship between height and effective sound speed, as proposed in the Harmonoise project (see also [22]). The meteo data consisted of about 20 full days in both periods. Relative humidity data and temperature data were used to calculate atmospheric absorption.

A constant, effective sound speed profile is assumed during propagation between source and receiver. As an example, the hourly sound speed profiles over a full day are shown in Figure 30. The ground is modelled by a complex, frequency-dependent impedance with the one-parameter model of Delany and Bazley [23]. A value for the flow resistivity of 200 kPa s/m$^2$ is appropriate to model grassland. The source height was taken at 0.5 m, while the receiver height was 2 m. Calculations were done up to 100 m, 500 m, 1000 m and 2000m from the point source, in 8 directions (with an interval of 45 degrees).

For upwind sound propagation, sound pressure levels relative to free field are limited at -25 dB [12][22], in order to account for unrealistic large attenuations, since turbulent scattering in the acoustic shadow zone is not accounted for.

These simulations resulted in hourly averaged attenuation data, taking into account geometrical divergence, atmospheric absorption, ground effect and refraction of sound by gradients in wind speed and temperature.

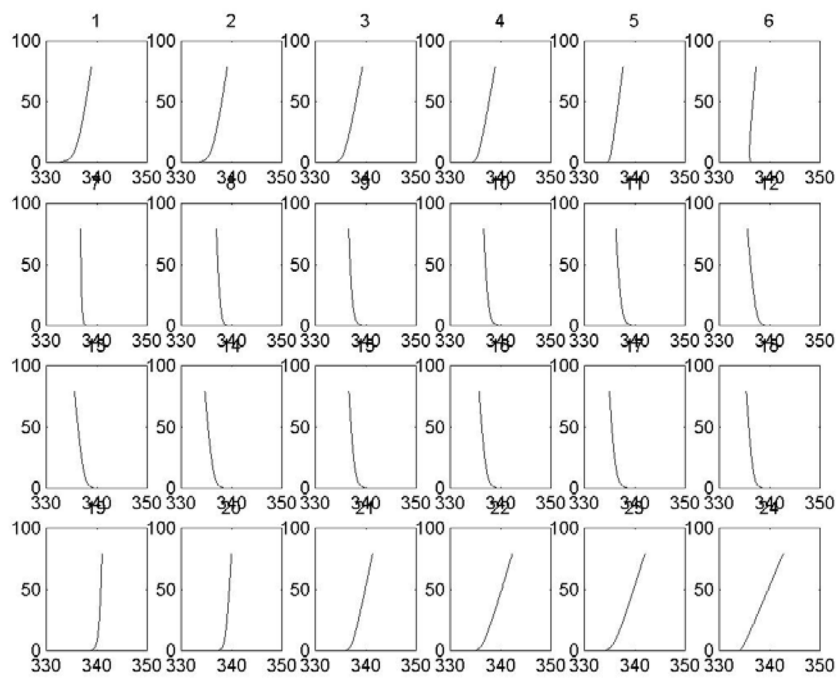


**Figure 30. Effective sound speed profiles (combination of wind and temperature effect) during a 24 hour-period in May, for a certain direction. On the horizontal axis, the effective speed of sound (in m/s) is shown, on the vertical axis the height (in m).**

***Linking emission and attenuation***

The most accurate 1-day $L_{den}$ values are based on calculations that combine the emission at a certain hour with the corresponding attenuation for this same hour. In this way, the coupling between emission of a traffic stream and noise attenuation is accounted for to a large extent. These calculations serve as a reference (1) for less accurate estimations of $L_{den}$. A first estimate considers the three periods of the day separately by combining $L_{Wday}$, $L_{Wevening}$, and $L_{Wnight}$ with the attenuations $A_{day}$, $A_{evening}$, and $A_{night}$ respectively (2). These attenuation values are calculated by energetically averaging the hourly attenuations in the relevant periods. The second estimate combines a single (energetically averaged) attenuation for the full day with $L_{Wden}$ (3).

As a summary, we compare, written down in formulas:

(1) $$L_{den,hourly} = 10\log_{10}\left(\frac{12}{24}10^{L_{day}/10} + \frac{4}{24}10^{(L_{ev}+5)/10} + \frac{8}{24}10^{(L_{night}+10)/10}\right),$$

with

$$L_{day} = 10\log_{10}\left(\frac{1}{12}\sum_{i=7}^{19}10^{(L_{Wi}-Ai)}\right), L_{ev} = 10\log_{10}\left(\frac{1}{4}\sum_{i=20}^{23}10^{(L_{Wi}-Ai)}\right), L_{night} = 10\log_{10}\left(\frac{1}{8}\sum_{i=23}^{6}10^{(L_{Wi}-Ai)}\right).$$

(2) $$L_{den,den} = 10\log_{10}\left(\frac{12}{24}10^{L_{day}/10} + \frac{4}{24}10^{(L_{ev}+5)/10} + \frac{8}{24}10^{(L_{night}+10)/10}\right)$$

with

$$L_{day} = L_{W_{day}} - A_{day}, L_{ev} = L_{W_{ev}} - A_{ev}, L_{night} = L_{W_{night}} - A_{night}.$$

(3) $$L_{den,24} = L_{W_{den}} - A_{24}.$$

The influence of temporal resolution of traffic data on $L_{night}$ is considered separately. Now two approaches are possible, namely accounting for the link between attenuation and emission every night hour (analogous to (1)), and using a global night emission and a global night attenuation (analogous to (3)).

A typical traffic intensity profile was chosen from a database (highways in Flanders) of hourly traffic counts during the working week (averaged over all workdays over one year). The traffic intensity profile (see Figure 31) shows a morning and evening peak, corresponding to rush hours, and a limited amount of vehicles during the night.

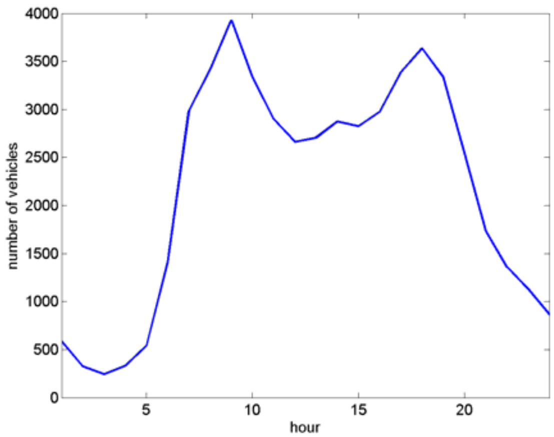



**Figure 31. Traffic intensity profile used for the analysis in this paper.**

As an example, the difference between $L_{den}$ calculated with 3 degrees of temporal resolution at 1000 m from the source in December, over 20 days, can be found in Figure 32. The 8 directions considered in the calculations are shown. The combination of source and attenuation data, hour per hour, is used as a reference. It is observed that the differences may range up to 5 dB at specific days.

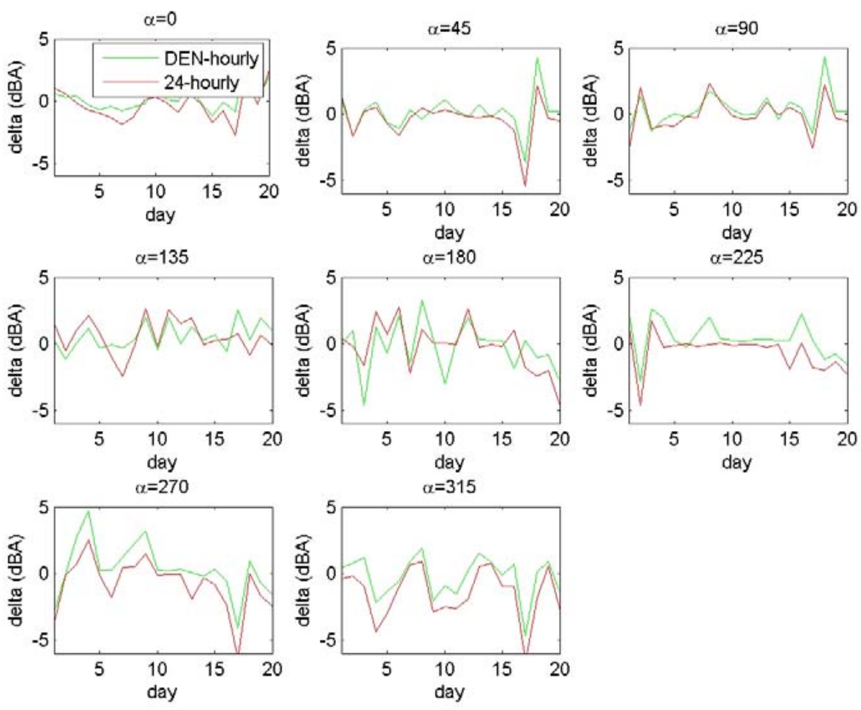



**Figure 32. Difference in $L_{den}$ using 3 periods per day and 1 period per day, relative to $L_{den}$ calculated with hourly data (respectively "den-hourly" and "24-hourly") for the 8 directions considered, for 20 days, at 2000 m from the source (May).**

A more general view is given in Figure 33 and Figure 34, for $L_{den}$ and $L_{night}$ respectively. Results are energetically averaged out in each 20-day period, and averaged out (linearly) over the 8 directions of propagation in a next step. It is observed that with increasing distance, the error by neglecting the correlation between noise emission and attenuation increases. The maximum, average error at 2000 m stays however below 1 dBA for $L_{den}$ values, and is about 0.5 dBA for $L_{night}$ values considered separately. Considering 3 periods a day (day, evening and night) is more accurate than just considering one period a day for $L_{den}$ calculations. It seems that during spring (May), the correlation is more pronounced, both for $L_{den}$ and $L_{night}$.

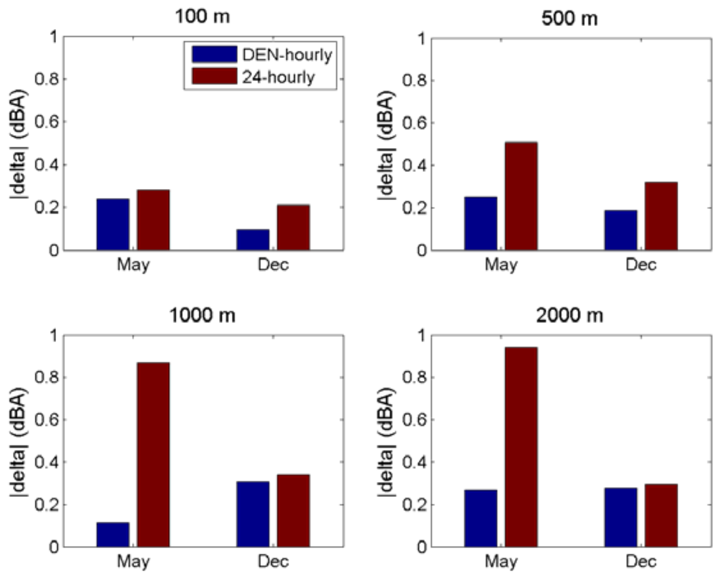



**Figure 33. Average difference in $L_{den}$ using 3 periods per day and 1 period per day, relative to $L_{den}$ calculated with hourly data (respectively "den-hourly" and "24-hourly"). $L_{den}$ values of 20 days and 8 directions are considered.**

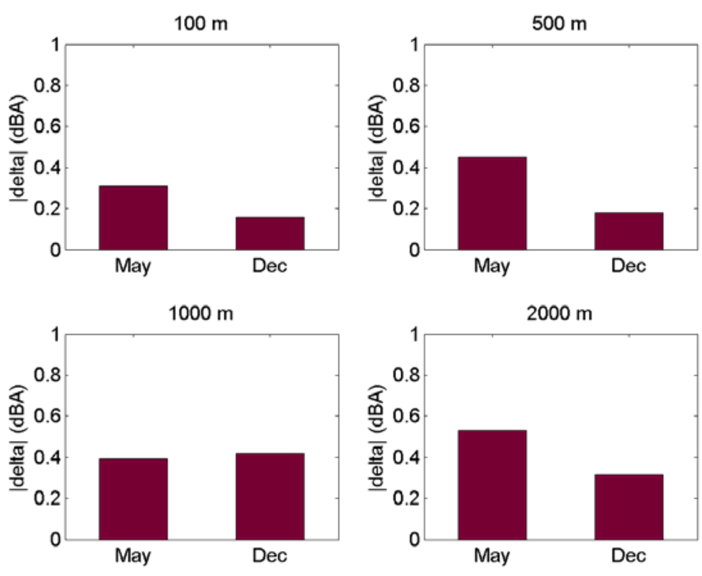



**Figure 34. Average difference in $L_{night}$ considering the night as a single period, relative to $L_{night}$ calculated with hourly data. $L_{night}$ values of 20 days and 8 directions are considered.**

### 2.3.4 Conclusions

In this Chapter, an assessment is made of the importance to take care of the variation in time (annual, seasonal, weekly, daily) of some selected traffic parameters for $L_{den}$ calculations. In a first part, the effect of diurnal variations and variations over the week of traffic intensity is studied. The least detailed input dataset, consisting of a single (total) 24-h traffic count, and using the GPG recommendations to distribute intensity over the different periods, lead to a 95 % confidence interval (samples = about 300 different locations on highways in Flanders) of the error on weekly $L_{w,den}$ ranging from -0.6 and +1 dBA. In the latter, variations over the different days of the week are disregarded.

For larger integration times, as was clear from the Leceister study (samples = 8 types of city roads), (extrapolated) annual changes and seasonal changes in traffic intensity seemed of no importance for yearly $L_{den}$ calculations (at the source). City roads like ring-roads and local roads were considered here. Use of weekday profiles alone, as opposed to specific weekday, Friday, Saturday and Sunday profiles also had a relatively minor (sub-decibel) effect on long term parameter values. In this same study, the error by neglecting specific flow and speed profiles was investigated as well, and was more important (ranged up to 2 dBA).

The correlation between typical daily traffic intensity profiles and typical daily propagation conditions for distances larger than 100 m was investigated in a next part. It could be concluded that using traffic intensity data on a low temporal resolution (e.g. traffic intensities expressed per day) results in average errors on $L_{den}$ values smaller than 1 dBA, and for $L_{night}$ up to 0.5 dBA. When looking at specific, daily $L_{den}$ values, errors up to 5 dBA are nevertheless possible when neglecting the link between emission and attenuation. It seems that, although the correlation between traffic intensity and the point in time is strong, and although the correlation between attenuation of sound and the point in time is strong, the interaction between both is rather limited when looking at equivalent sound pressure levels over long periods. Traffic intensity data is less demanding as regards temporal resolution than it is for attenuation data.

It can be concluded in general that the importance of temporal resolution decreases when the integration period increases. When looking e.g. at yearly $L_{den}$ values, the influence of temporal resolution as concerns traffic intensity will be limited. On the other hand, variation in speed profiles with time might be more important.

## 2.4 Requirements for low flow roads

To strictly apply the END, all major roads and all roads in agglomerations have to be mapped. This includes therefore roads on which traffic volumes are (very) low. When traffic models are used to calculate the flows on these roads, three problems occur:

- networks in traffic models generally leave out low flow or minor roads, since they are not very interesting from a traffic modelling point of view (capacity is not a problem, travel times are not influenced by congestion) and including all of these roads would lead to much longer run times of the models;
- the accuracy of flows calculated by the traffic models is always relatively poor for the lowest scale level roads;
- measurements of speeds and flows to calibrate the model with are scarce; from a transport planning point of view it is more interesting to measure on busier roads.

But how important is it to obtain accurate traffic estimates for low flow roads? Because of the low flows, noise levels will not be very high. An error of e.g. 2 dBA has a totally different consequence when it occurs at exposure levels over 70 dBA or at exposure levels around 50 dBA. For low flow roads the accuracy requirement can thus not easily be expressed in terms of dBA difference between calculated and exact (measured) $L_{den}$. Indeed, Noise policy targets and goals will often be expressed in terms of reducing the number of people exposed to the highest noise levels. Thus it seems reasonable to tolerate larger errors at low exposure.

There is a second reason why one could consider putting less effort in calculating exposure to noise produced by traffic on low flow roads: exposure effect correlation is much less well proven for this type of exposure. Indeed, most exposure-effect relationships (e.g. for annoyance, sleep disturbance, blood pressure increase, etc.) have been extracted for roads with considerable traffic intensity. Low $L_{den}$ (or $L_{night}$) in that case corresponds to large distance to the road. The scarce exposure annoyance relationships that can be found for noise from traffic on low flow roads indicate that the effect is lower than what would be expected for high intensity roads for the same $L_{den}$.

Based on the observations above, one could decide to ignore low flow roads as soon as the façade $L_{den}$ for flanking dwellings that they produce drops on average below 60, 65, or 70 dBA depending on the application envisaged and the policy goals in effect.

Exactly how the above stated accuracy requirements for low flow roads translate to traffic intensities that can be ignored, depends on many factors: the distance from the road to the facades, the driving speed, the fleet composition, traffic dynamics, to name just a few. Nevertheless it seems useful to derive some guideline for deciding which roads to include in the traffic model. Such an estimate can be based on noise measurements at a representative set of sampled locations or it can be based on the harmonised noise emission for individual cars combined with a best estimate for the parameters mentioned. In Figure 21 measured noise levels at the façade of over 200 randomly chosen dwellings are shown as a function of traffic intensity of the road in front of the dwelling. Situations where other sources contribute significantly to the noise level are removed.

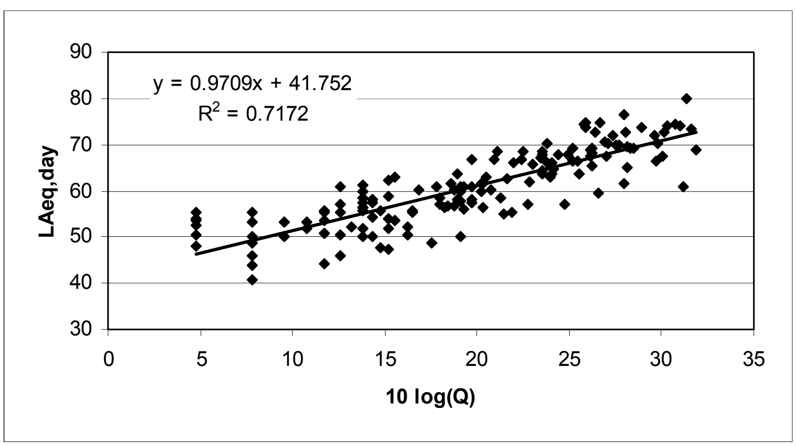



**Figure 35. Measured facade level LAeq during the day at over 200 randomly chosen dwellings in Flanders as a function of traffic intensity, Q, in vehicles per hour.**

From these curves, one can deduct that tolerating neglecting contributions of 60, 65, or 70 dBA respectively correspond to omitting road segments with approximately 100, 300, and 1000 vehicles per hour in the traffic model.

## 2.5 Inaccuracies in the traffic modelling process

In addition to the topics discussed in the previous sections, other inaccuracies can be introduced by the use of traffic models. These have to do with:

- Demand modelling
- Intersections
- Modelled speeds

A short problem analysis can be found in the remainder of this section. A more detailed description on these aspects (and strategies for improvements) can be found in the respective sections in Chapter 3. Some aspects of validation and calibration of macroscopic traffic models can be found in Section 2.2.1a.

### 2.5.1 Demand modelling

All traffic models start, in some form, with the application of a demand model, which produces the origin-destination table (OD-table, number of trips between zones). Some models have separate OD-tables for different vehicles types, other only have one OD-table for all vehicles types. To run the demand model, the following information is generally needed:

- socio-economic data: land use (number of household/inhabitants, jobs, schools, etc.), income, car ownership, travel and parking costs, etc.;
- road network representation;
- travel data for the periods modelled (for noise, that would be day, evening and night, ideally).

When the OD-table has been determined, the trips can be assigned to the network. Calibration and validation data (measured traffic volumes and speeds) is then used to check the accuracy of the traffic estimates.

If no reliable data is available, it is not possible to produce a realistic OD-table. Here, it is important to consider some of the dilemmas that traffic modellers face: the level of detail of the data vs. computation time, the false sense of accuracy that a high level of detail might introduce, the efforts to obtain the necessary data (which has to be of good quality and thus is likely to be costly to collect) vs. the expected improvement in accuracy in traffic estimates and thus, in the end, of the noise calculations.

### 2.5.2 Intersections

When traffic flows at a steady speed, acceleration/deceleration data is not necessary to produce accurate noise estimations. However, for road sections at or near intersections, it is desirable to know how much traffic decelerates and accelerates, and what share of the traffic needs to slow down or make a full stop. This can vary considerable for different types of intersections (e.g. a roundabout vs. an intersection with traffic lights which may be turned off at night) and different traffic flow patterns. Some traffic models include intersection models, others don't. For those models in which intersections are not modelled, it would be useful to know what increase in noise production can be expected at or near intersections.

### 2.5.3 Modelled speeds

For noise modelling, accuracy of speeds is more important than accuracy of traffic flows (see Section 2.1). When using speeds as produced by traffic models, it has to be kept in mind that traffic models were not designed specifically to produce accurate speeds. Reliable travel times and traffic flows are more important. This means that the reliability of modelled speeds should be checked for the various types of traffic models. For instance, speeds may be underestimated when travel times are used to calculate average speeds. In models that do not include intersection modelling, the delays experienced at an intersection have to be incorporated into the time spent on a link (leading to or away from an intersection).

# 3 Strategies to improve traffic modelling in the context of noise mapping

A strategy is needed if the wish to calculate something is not matched by the possibilities of the available models. Or the models are able to calculate the desired output, but the results are not accurate enough. In theory, it is possible to put the strategies in a matrix, as in the diagram in Figure 36 below.

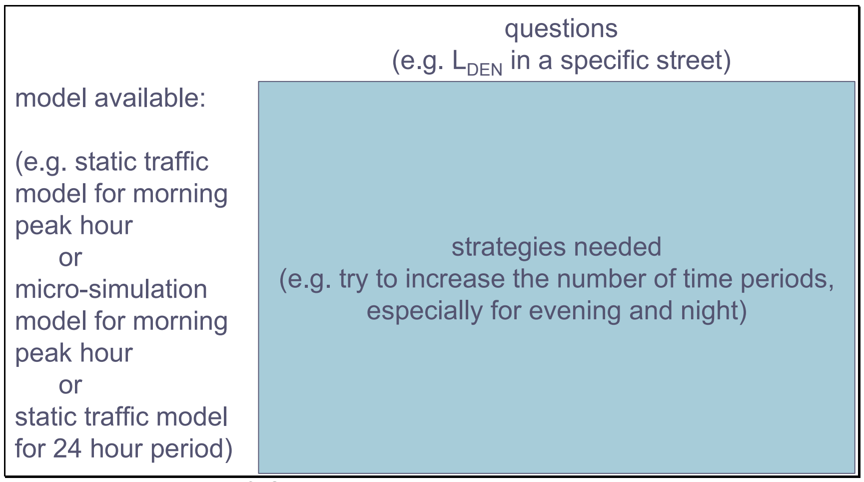



**Figure 36. Example of "Strategy matrix"**

The columns contain possible questions that traffic modellers can be asked when they calculate traffic flows for noise mapping. The rows contain the of model configurations that could be available. For each combination of a question and an available model, a strategy is possible, or maybe needed. If the model is perfectly suitable to answer the question, the strategy will be simple: use this model to answer the question. If the available model is unfit to answer the specific question, a strategy could be to improve the model, or use another model. Three types of situations with respect to model suitability can be distinguished:

1. No model is available. Solutions to this problem are:
    a. to purchase a model;
    b. to estimate (not calculate with a model) the indicators needed (traffic volumes, speeds, etc.).
2. A traffic model is available, but has deficiencies. In that case, two approaches are possible:
    c. devise strategies to get around the deficiencies of the model (by assuming values when they cannot be calculated);
    d. solve the deficiencies (the model is adapted to deal with the specific questions of noise mapping and noise action planning).
3. The model is (nearly) perfect.

In this report, the focus is on situation 2. Strategies will be developed to either solve the model deficiencies or to get around them. Obviously, for situation 3, the model that is (nearly) perfect, the strategy is just to use them.

This report does not provide extensive strategies for the situation that measurements or estimates have to be used. Some guidance is given, and such strategies can also be found in the Good Practice Guide [1].

The following sections describe, for each aspect for which strategies have been developed:

- the context: A strategy is needed because... (you can't calculate something at all, or the tools offer some possibilities but are not yet adequate/can be improved) -- example: macroscopic models don't always model intersections and if they do, do you get the info you need?
- the problem analysis: what problem do you want to solve exactly -- example: we know that at intersections there may be more noise because the effect of acceleration can compensate the effect of speed reduction, but how do we know what acceleration to expect for certain types of intersections?
- the strategies: how can the problem be dealt with.

The strategies are based on literature, expert judgment, and case studies. They consist of descriptions of what can be done and references to reports/websites on which more information can be found.

## 3.1 Demand modelling

***Context***

Traffic network models rely on the output of transport demand models [8]. The quality of this output has a large influence on the accuracy of traffic network models, and thus also on the quality of the noise models. Demand modelling is a large area of research where different approaches en ad hoc methods are developed (e.g. four step approach, activity based models, econometric logit models, …). This wide range of methods is an important factor in the overall poor quality of the results. The major weaknesses of current transport demand models are:

- the focus in current practice on peak periods,
- the focus on reproducing data. Determining demand patterns for areas and periods outside of data surveys remains very difficult.
- the poor representation of freight demand.

***Problem analysis***

The question is how the weakest points in transport demand models can be improved to increase the accuracy and quality of the calculated noise levels. The points that have the largest influence on the overall modelled noise accuracy are:

- **Poor representation of freight demand**
  The number of trucks on a road has a large influence on noise levels.
- **Poor quality of the demand pattern in urban areas**
  For highways and non-urban areas traffic volume data availability is often quite good, enabling calibration of traffic demand. Furthermore, in these cases the large volumes make it relatively easy to reconstruct a straightforward demand pattern.
  However, urban volumes are a large problem area, especially outside the area of high level roads. Transport demand is diffuse in urban areas with small volumes. This can have a large impact on noise accuracy.
- **Bad demand patterns for off-peak periods**
  The deficiencies of the demand patterns for off-peak periods stem from the difficulties that arise in the modelling of peak spreading: why do peaks exist and what is the influence of higher travel times during peak periods on people’s behaviour?

Furthermore, demand levels are lower during off-peak periods, resulting in lower relative accuracy for the same absolute uncertainty level. It should be noted that local activities and large (recurrent) events can have a large influence on traffic volumes at night and on the corresponding noise levels.

***Strategies***

The actions for the improvement of transport demand models in the context of noise mapping are best integrated in a general effort for the development of better traffic models. The improvement of transport demand models will have an impact on the use of these models for all purposes. Anyhow, the help of experienced demand modellers seems necessary to do this. The following actions can be taken:

- **Development of an accurate freight demand model**
  Freight flows in a road network can differ completely from passenger flows. This is largely due to the difference in demand pattern. Freight demand prediction is completely different from modelling passenger demand. This means that a separate freight demand model has to be developed.
  Freight demand must be modelled as the result of complex decisions within companies on their logistic process. The model can take into account: type of freight, value of time, volumes, multimodal options, and different cost aspects. Good practices on how to develop freight demand models can be found in Ref. [24].
- **Improvement of statistical input for transport demand models**
  The accuracy of the modelled demand pattern can be improved by focussing on the driving forces of transport demand. Gathering additional data on the following socio-economic topics can drastically improve the demand model: number and age of inhabitants, number of workplaces, vehicle ownership rates, location of schools, income distribution, …
- **Collect information on the demand pattern**
  Data can also be collected on the demand pattern itself. It can be used to:
    - Calibrate and validate the demand model.
    - Construct a demand pattern when no demand model is available.

  Two types of demand data can be distinguished:
    - Floating car data (based on the movements of cars over time using e.g. mobile phone or GPS sensors) can help to improve knowledge on the demand pattern in urban areas, even for off-peak periods. Floating car data is also convenient for freight demand patterns.
    - Surveys can help in gathering information on activity patterns of typical inhabitants for the area and period under study. Surveys within logistic companies are also suitable to gain insight in the freight demand patterns. This will help to construct a demand pattern for urban areas.

Furthermore it is important to know which reference period is modelled in the transport demand model. Noise maps are based on annual traffic levels, and therefore it is necessary to know how representative the modelled day is for the whole year. A lot of demand models do not explicitly mention the modelled period, which is a meaningful indicator for its accuracy. In general we can assume that a modelled peak period represents the 80 percentile heaviest traffic day in a year.

## 3.2 Traffic Composition

***Context***

For noise mapping and noise action plans, it is important to discriminate between vehicle types that have different noise emission. Next to the passenger car, it is very useful to know more about the volumes and speeds of heavy trucks and motorized two-wheelers. It was shown in Section 2.1.5 that a good estimate of the share of heavy traffic (less than 5% deviation) is of major importance.

Most traffic models distinguish only one type of traffic: the passenger car, or the passenger car equivalent. For traffic analysers, this is enough to predict travel costs and congestion levels. Simulation models contain more traffic types in most cases, but the demand data is often poorly estimated (see Section 3.1), which can lead to inaccurate flows and modelled speeds.

***Problem analysis***

The main question is: how to predict the volumes and speeds of (heavy) trucks and motorized two-wheelers at network links, by improving the possible available traffic models, or get around their limitations.

For *heavy vehicles*, the strategy needed will mainly depend on whether the model available is based on a single or multi user class demand model and traffic assignment (i.e. all vehicle types are lumped together or there are separate user classes for different vehicle types, e.g. passenger cars, light trucks and heavy trucks). If the model uses a separate truck O/D-matrix, and the assignment is multi user class based, the truck volumes on individual network links can be predicted. However, if the demand model and/or the assignment model are single user class based, estimations have to be made for the share of heavy vehicles on a link [1].

For *motorized two-wheelers*, the effect on $L_{den}$ is not clear. Research into the noise emission of two-wheelers is carried out in the IMAGINE project (but no results are available yet). Another problem is that motorized two-wheelers are hardly ever available as a separate user class in traffic model results. The reason for that is that most traffic models are capacity models and motorcycles are not considered to be very important in that respect, because their travel times are not influenced by congestion, and their presence on the road (usually) does not influence travel times of other road users. However, if large volumes of two-wheelers are expected and/or their noise emissions are relatively high, it may be necessary to incorporate motorized two-wheelers in traffic models. On the other hand, although annoyance from individual motorcycles and mopeds is often reported, the noise levels in $L_{den}$ are based on considerable averages (yearly) in which the contribution of individual vehicles is small.

***Strategies***

To calculate heavy vehicle volumes, there are several possible strategies. Which one should/can be chosen depends on how much data is available per user class (and thus whether a MUC approach is possible). Table 12 shows several strategies.

**Table 12. Strategies to obtain traffic data by vehicle class.**

| **Approach** | | **Strategy** |
|---|---|---|
| MUC demand data available | MUC assignment model available | **MUC assignment gives output per vehicle class**<br>If the demand model is multi user class, and the assignment is multi user class, it should be possible to obtain an O/D-matrix from the demand model that contains data on several user classes (e.g. passenger cars, light and heavy trucks) and use this O/D-matrix in the assignment. The output (e.g. traffic volumes and speeds per network link) will then be given separately for each user class, i.e. each vehicle type.<br>For more information on MUC approaches, see below. |
| | MUC assignment model *not* available | **Option 1: Adapt model to include MUC assignment**<br>An option is to include MUC assignment in the traffic model available. Also, several traffic models commercially available can work with MUC assignment, from static models to micro-simulation models. See below.<br>**Option 2: Single User Class (SUC) assignment**<br>If the demand model is multi user class, but the assignment is not, the various O/D-matrices (of each vehicle class) have to be added up for the assignment. For instance the truck matrix will be added up to the O/D-matrix of passenger cars, and the resulting O/D-matrix will be assigned as a single user class (which means that trucks routes will not differ from passenger car routes). In order to obtain differentiated traffic flows per vehicle class for each network link, estimations of the share of each vehicle type are necessary. This can be done in different ways – see below (paragraph on *Estimations of the share of each vehicle type*). Alternatively, a separate (all-or-nothing) assignment can be carried out for each vehicle class, to determine the expected routes for that vehicle type. Note that in that case, more detailed data can be obtained per user class, but if the network is congested, adding up the volumes obtained by each assignment could lead to volumes (far) exceeding the capacity of a road and thus unreliable traffic data. |
| No MUC demand data available | | **Estimate shares of vehicle types**<br>If both demand model and assignment are single user class, estimations of the share of each vehicle type have to be made. There are several options for this; see below. |

**Multi-user class O/D-matrix and assignment**

Multi-user class O/D-matrix and assignment is not very common yet in traffic models (except for micro-simulation models) and it is not easy to find literature on the subject. Below, a few starting points are given:

- Chapters in advanced books on modeling transport

- o Motorway Traffic Analysis: New Methodologies and Recent Empirical Findings, Bovy, P.
- o http://search.barnesandnoble.com/booksearch/isbninquiry.asp?ean=9789040716515&displayonly=TOC
- o Modelling for Transportation Systems Planning: New Approaches and Applications, Bovy P., Remmelt, T.
- o http://search.barnesandnoble.com/booksearch/isbninquiry.asp?ean=9789040722745&displayonly=TOC

- Dissertations:
  - o Bliemer, M., *Analytical dynamic traffic assignment with interacting user-classes: theoretical advances and applications using a variational inequality approach*, Ph.D. thesis, Faculty of Civil Engineering and Geosciences, TU Delft, Delft, The Netherlands, 2001.
  - o Wynter, L., *Advances in the theory and application of the multi-class traffic assignment problem*, PhD thesis, Ecole Nationale des Ponts et Chaussées (ENPC), Paris, France, 1995.

Table 13 below gives an overview of some of the commercially available multi user class traffic models.

**Table 13. Examples of multi (vehicle) user class traffic models.**

| | | |
|---|---|---|
| Static | Macroscopic | ▪ **EMME/2**, University of Montreal, Canada, INRO Consultants Inc, Canada, www.inro.ca/en/products/emme2<br>▪ **LMS,** Transport Research Centre of the Ministry of Transport, the Netherlands, http://www.rws-avv.nl/vv2020/begin.htm<br>▪ **TRANSMOVE** (formerly SMART), TNO, the Netherlands |
| Dynamic | Macroscopic | ▪ **INDY**, TNO, the Netherlands, www.tno.nl/indy<br>▪ **VISUM**, PTV Germany & America, http://www.ptv.de/cgi-bin/traffic/traf_visum.pl, www.ptvamerica.com/visum.html |
| | Mesoscopic | ▪ **CONTRAM**, TRL, Mott MacDonald, UK, www.contram.com<br>▪ **DYNASMART**, University of Texas and Maryland, USA, www.dynasmart.com |
| | Microscopic | ▪ **AIMSUN**, TSS, Barcelona, Spain, www.aimsun.com<br>▪ **Paramics**, Quadstone, Edinburgh, UK, www.paramics-online.com<br>▪ **VISSIM**, PTV Germany & America, http://www.ptv.de/cgi-bin/traffic/traf_vissim.pl, www.ptvamerica.com/vissim.html<br>▪ **DYNAMIT**, Massachusetts Institute of Technology, USA, http://mit.edu/its/dynamit.html |

MUC models are particularly useful in action plans, because they ensure a traffic prediction in which there is integrity over vehicle distribution and routes over the network. In the case of measures influencing the routes used by truck traffic this is very important.

**Estimations of the share of each vehicle type**

In order to obtain differentiated traffic flows per network link, estimations of the share of each vehicle type are necessary. This can be done in different ways, e.g.:

1. use a fixed share of trucks for all links in the network;
2. use a fixed share of trucks, but vary over the different road types in the network;

3. use a fixed share of trucks, per area (e.g. use a higher truck share in and near industrial areas);
4. use a fixed share of trucks for the day/evening and Night

The last three options can be combined. In some cases, there is also a correlation between traffic intensity and percentage of heavy traffic. Knowledge on that relationship can also be used to improve estimates of the share of trucks.

Ad 1 and 2

Many manuals on how to estimate truck traffic shares (in many cases per road type) have been developed in the past. If they are recent and reflect the local/regional/national situation, they can give very useful information. In addition, travel surveys and other sources of information on the number of trips can be used. Examples in the Netherlands include the Handbook for truck traffic in municipalities [25][26], and two publications giving indicators for the amount of (truck and passenger) traffic generated by industrial areas have been developed [27][28]. Traffic counts, distinguishing multiple vehicle types, can be used to improve the estimates. If separate O/D-matrices are available for several vehicle types (e.g. for passenger cars and trucks), they can also help to derive general vehicle type shares. The Good Practice Guide also has a toolkit for Composition of road traffic [1].

Ad 3

In addition to obtaining vehicle type shares from multi user class O/D-matrices, these matrices can also be used to determine where shares deviating from the average can be expected. For instance, the streets near origins and destinations (zones) producing or attracting much truck traffic (e.g. industrial zones) are likely to have relatively high shares of truck traffic.

**Speeds per vehicle class**

For *speeds*, it is safe to use the same speed for passenger car, heavy vehicles and motorcycles, as long as the legal maximum speed for each vehicle type is not exceeded. See also the section on modelled speeds.

**Motorised two-wheelers**

For motorised two-wheelers, two different situations can be considered in relation to noise mapping and action planning:

- Every day two-wheeler traffic: if there is consistent data on the amount of two-wheelers traveling, this vehicle category is easy to model, because of its relatively low time loss in congestion situations. An all-or-nothing assignment is sufficient, added to e.g. an equilibrium approach for the other user classes.
- Two-wheelers in recreational touring conditions: this is very difficult to model (generally there is no data available), and the effect on $L_{den}$ will probably be very small. Neglecting this situation is probably not a problem, unless the effect on the overall noise measurements is expected to be high. Measurements of two-wheeler volumes on specific locations can help to establish whether two-wheelers might contribute significantly to the $L_{den}$ level.

## 3.3 Intersection modelling

### 3.3.1 Introduction

***Context***

The specific dynamics of traffic at junctions can influence local noise emissions. Temporal and spatial variations in speed and acceleration will cause different noise levels than free-flow traffic.

***Problem analysis***

The problem consists of the lack of accurate modelling of temporal and spatial evolutions of speeds and accelerations. Only micro-simulation models can incorporate these dynamic effects. The other types of models either don't incorporate intersections at all, or they only incorporate the influence of intersections on travel time (delays).

It should be mentioned that the accuracy of the modelled speeds in traffic models is a related problem that will be discussed in Section 3.5.

***Strategies***

When a traffic model doesn't simulate the dynamics of intersections, a correction factor can be applied to incorporate the effects on noise emissions. In Section 3.3.4 correction factors are proposed on the basis of a literature review (Section 3.3.2) and a case study (Section 3.3.3).

Correction factors are given for various types of intersections for different combinations of traffic demand on main road and minor road, for different percentages of through traffic and for different percentages of trucks.

### 3.3.2 Literature review

Several national standards exist for the prediction of road traffic noise [29]. Most of these engineering models assume that roads can be divided into sectors where the vehicle flow can be considered smooth and homogenous. Traffic flow calculations are mostly based on static traffic simulation models. Traditionally, the sound emission level caused by the traffic on each segment is modelled as a function mainly of the average vehicle speed and the traffic flow rate; most modern engineering models differentiate between the emissions produced by different types of vehicles [30].

The influence of intersections, and more in general of interrupted traffic flows, is evaluated in many different ways. The French prediction model, consisting of the Guide du Bruit [31] and the NMPB-96 propagation method [32], and the UK CRTN prediction method [33] do not include the impact of intersections at all – although recently efforts were undertaken to update the French model for different driving conditions [34]. In the Nordic model [35], the use of a correction on the vehicle noise emission for continuous acceleration (after a crossing) and continuous deceleration (before a crossing) is proposed; however no input data for these driving conditions is available, and the model thus recommends to use only the cruising vehicle emission values. The Dutch RMW2002 model [36] and the German RLS90 model [37] include a propagation correction term for intersections with traffic lights, for up to a distance of 150 m and 100 m from the intersection respectively. Also the non-European models of the US [38] and Japan [39][40] both introduce a correction on the noise emission for transient driving conditions near intersections.

In spite of the fact that intersection corrections are only marginally taken into account in most prediction models in use today, there has been a reasonably amount of research on the topic of noise (reduction) from traffic management in the last three decades; a review can be found in [41]. In the UK, the most early studies on interrupted traffic flows focused on $L_{10}$ measurements nearby conventional intersections [42] and roundabouts [43][44]. In general it was found that the noise from the accelerating traffic streams was within 1 dB(A) of the free flow level. In the early 1980s, basic computer models were introduced to predict traffic noise. In [45], [46] and [47], simulation models for $L_{10}$ for various types of interrupted flows were introduced. In a French study [48], a computer model for determining the noise radiated by a single vehicle approaching traffic lights was demonstrated. A Dutch model was also published [49], which was able to predict statistical noise levels of interrupted traffic flows in built-up environment. The propagation part for this model was based on transfer functions measured in a scale model. By the same author, a method for measuring the decrease and increase of vehicle noise levels at intersections was published [50].

After a less fruitful period, the study of noise at intersections gained renewed interest in the second half of the 1990s, possibly driven by new advances in the field of traffic modelling and the introduction of micro-simulation models in traffic flow prediction. The STRADABruit model [51], developed by the French National Institute for Transport and Safety Research (INRETS), is based on a fluid dynamics macroscopic traffic model, modified to be able to represent transitional flow states at intersections, and coupled with a vehicle emission model based on test track measurements. This model was validated with measurements at a signalized intersection [52], and has recently been extended with a micro-simulation model for special types of vehicles, and a more advanced propagation model [53]. Oshino et al. [54] made a coupling between a simple micro-simulation model and a noise emission model for individual vehicles; a validation with measurements near various types of signalized intersections was also published [55][56]. In the most recent models, a micro-simulation model is coupled with an individual vehicle noise emission model and an advanced propagation model. The model developed at the University of Oviedo [57][58], as well as the models developed at the University of Leeds [59][60] and at Ghent University [20][61], make it possible to assess traffic noise (statistical) levels at (signalized) intersections in complex urban built-up environments. These models were recently updated for the latest Harmonoise vehicle emission model.

Measurements of the influence of the replacement of traffic lights by roundabouts on noise levels are discussed in [62], and a regression model for assessing their impact is deduced. It is found that, in ideal conditions, a reduction in $L_{Aeq,24h}$ of 1 to 4 dB can be achieved. In [63], road traffic noise was measured before and after the installation of traffic lights. In general, higher levels were found in the vicinity of the intersection, while lower levels were found at some distance of the lights. The last decade, there was also a more theoretical movement in traffic intersection noise research. In [64], an analytical solution of the noise emitted from vehicles at a roundabout is derived. A comprehensive number of analytical studies were performed by Kokowski and Makarewicz [65][66][67][68], on the noise emitted from vehicles at signalized intersections and roundabouts.

### 3.3.3 Case study

***Overview***

A number of micro-simulations are run in Quadstone Paramics to study the influence of traffic dynamics at intersections on noise emissions.

Four[1] different types of intersections are distinguished, as illustrated on Figure 37: a priority-to-the-right junction (a), a priority junction (b), a junction with traffic signals (c) and a roundabout (d). Each of these junctions contains a major and a minor road. The flow on the major road is x veh/h, the flow on the minor road y veh/h. By varying x and y, different scenarios with calm, normal and busy traffic are created. The number of scenarios is increased by taking into account the fraction of traffic that turns left and right. This way the influence of detailed traffic operations on each intersection type can be studied. Furthermore three variations in traffic composition (car/ truck proportions) are considered (5, 10 and 20% trucks). For each scenario, 5 model runs are performed to enable statistically sound conclusions.

***Traffic operations modelling methodology***

The following assumptions were made for the development of the micro-simulation model:

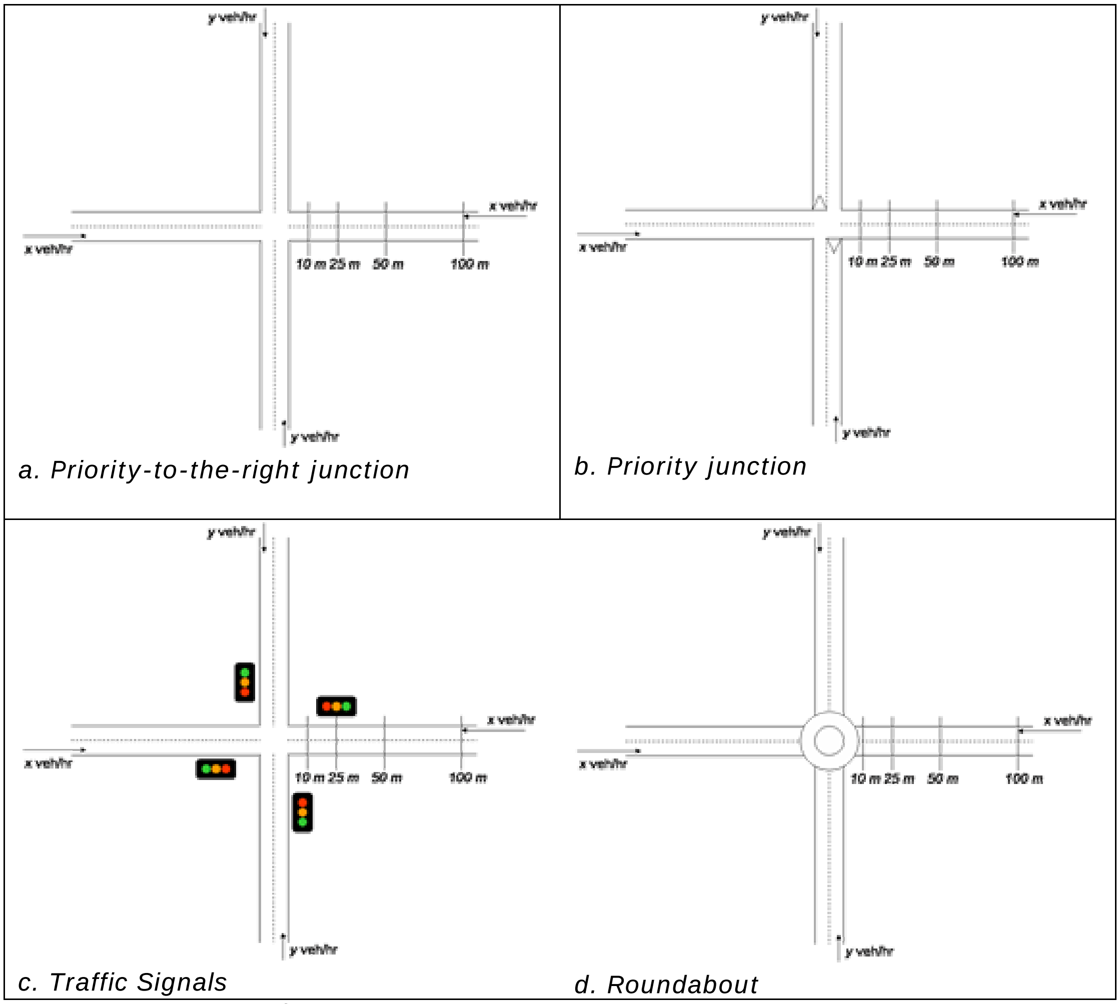
- Type of road: 2 x 1-lane; lane width = 3,5m
- Maximum speed: 70 km/h
- 1 hour simulation (the actual Paramics simulation was run over 1hour 40min, providing a 10min period before the actual simulation for initialization and 30min after the simulation for travel time calculations)
- traffic demand combinations : 36 combinations
    - 6 combinations of flows on the major road and minor road
    - 2 different turn rates: 80% through (10% left and 10% right) and 60% through (20% left and 20% right)
    - trucks: 5%, 10% and 20% of all traffic flows in all directions
- seed-values: 5 different runs

*Road capacity calibration of the model* was done on the basis of the Highway Capacity Manual 2000 [69].

*Calculation of travel time, averaged over the simulation period (1 hour) and averaged over traffic on the entire intersection*, was made on the basis of individual trip data. The average is calculated of travel time data for trips departing within the 1 hour simulation period. This means that a

[1] To determine free-flow travel times in the model, a fifth type was added as a reference. This way, the free-flow travel times are directly comparable to the travel times of the other intersections types. After all, free-flow travel times in the model are not completely the same as those calculated on the basis of the distance and the maximum speed.
To accomplish free-flow conditions in this fifth type of network, no priority rules were considered. Simulations were divided into four parts: a separate run for each origin zone. In this way, there is no interaction between vehicles of the different origin zones.
It should be noted that this reference case should not be used to compare noise emissions, because vehicles still decelerate and accelerate near the intersection. This has very little influence on travel times, but it is significant for the noise emissions.

number of trips arrive after the actual simulation period. This way the travel times can be compared to travel times in static assignment models[2].




a. Priority-to-the-right junction
b. Priority junction
c. Traffic Signals
d. Roundabout

**Figure 37. Four types of intersections used in this study**

*Travel times for separate network links* were also calculated, but here a simplified methodology was used. Travel times were calculated on the basis of travel times reported by Paramics in 5 min intervals.

*Queue lengths* were calculated similarly. On the basis of queue lengths reported by Paramics[3] in 5 min intervals, the average queue length was calculated. It should be noted that Paramics sometimes reports several queues on the same link. In such a case, the sum of the different queues was made.

---

[2] In static assignment models it is assumed that ALL traffic completes its journey through the network within the simulation period. In micro-simulation models this is not necessarily true (especially in the case of congestion). To compare travel times for total traffic demand, all trips in the micro-simulation model departing within the simulation period should be considered until they arrive.

[3] Queue lengths reported by Paramics when the following configuration was used:

- queue speed 20.000 kph
- queue distance 20.000 m

***Traffic noise modelling methodology***

Based on software developed by UGent [20] noise emission of each vehicle in the simulation is calculated for each simulation step. The Harmonoise emission model is used with the following parameters :

- Vehicle 1: default passenger car
- Vehicle 2: class 3 truck, 5 axles
- Road surface: default (DAC, chipsize 11mm; age = 3 years; temp-coeff. = 20 degrees Celsius)

Noise emission values were aggregated on a grid with a horizontal resolution of 1m, and the 1 hour noise immission level $L_{Aeq,1h}$ was calculated using a beamtrace-based propagation model in a square area of 200m x 200m, without any buildings. The ISO 9613 attenuation model was used, extended with diffraction along vertical edges according to Nord 2000.

***Influence of intersection type***

This section discusses the influence of intersection type on noise levels. The intersection type has a large influence on speed and acceleration of vehicles around the intersection, resulting in different noise levels.

Figure 38 illustrates the noise levels for the different types of intersections considered in this study. Traffic volume is 250 vehicles per hour on the main (horizontal) road, 100 vehicles per hour on the minor (vertical) road. 80% of traffic demand is through traffic (10% turns left, 10% turns right) and 20% of the total traffic demand are trucks.

The comparison between the different intersections is done by calculating the difference between the noise levels. In Figure 39 the difference is made between the noise levels for the signalised junction and the noise levels for the other intersections (the same scenario is considered as in Figure 38).

The largest differences are reported for the roundabout. These differences can be attributed to the different physical road layout and to the higher average speeds of approaching traffic on signalised intersections. The differences between the signalised intersection and the priority-to-the-right junction are smaller, which holds for all traffic intensities. The influence of the larger speeds but lower accelerations on signalised junctions (when the light is green) is visible for traffic that leaves the intersection and on the intersection itself. Traffic approaching the intersection produces less noise when priority rules are present, due to repeated deceleration. The influence of the intersection type on noise levels is very local. However, close to the road the differences in noise levels between the different types of intersections can be quite high.

***Influence of traffic volume***

The traffic volume on the links influences traffic operations on the intersection and influences the noise emitted.

The influence on travel time is illustrated in Table 14. Travel times for the different scenarios are represented as a percentage. This value indicates the increase in travel time compared to a reference case study. The reference scenario is a fictitious situation where traffic operations are perfect and where the intersection does not influence travel time (free-flow conditions). For all intersections, travel times increase with traffic volume. However, large differences between the different intersection layouts can be observed. The yellow boxes represent the type of intersection with the smallest travel time for the given traffic volumes. The red combinations represent the intersections with the lowest capacity.

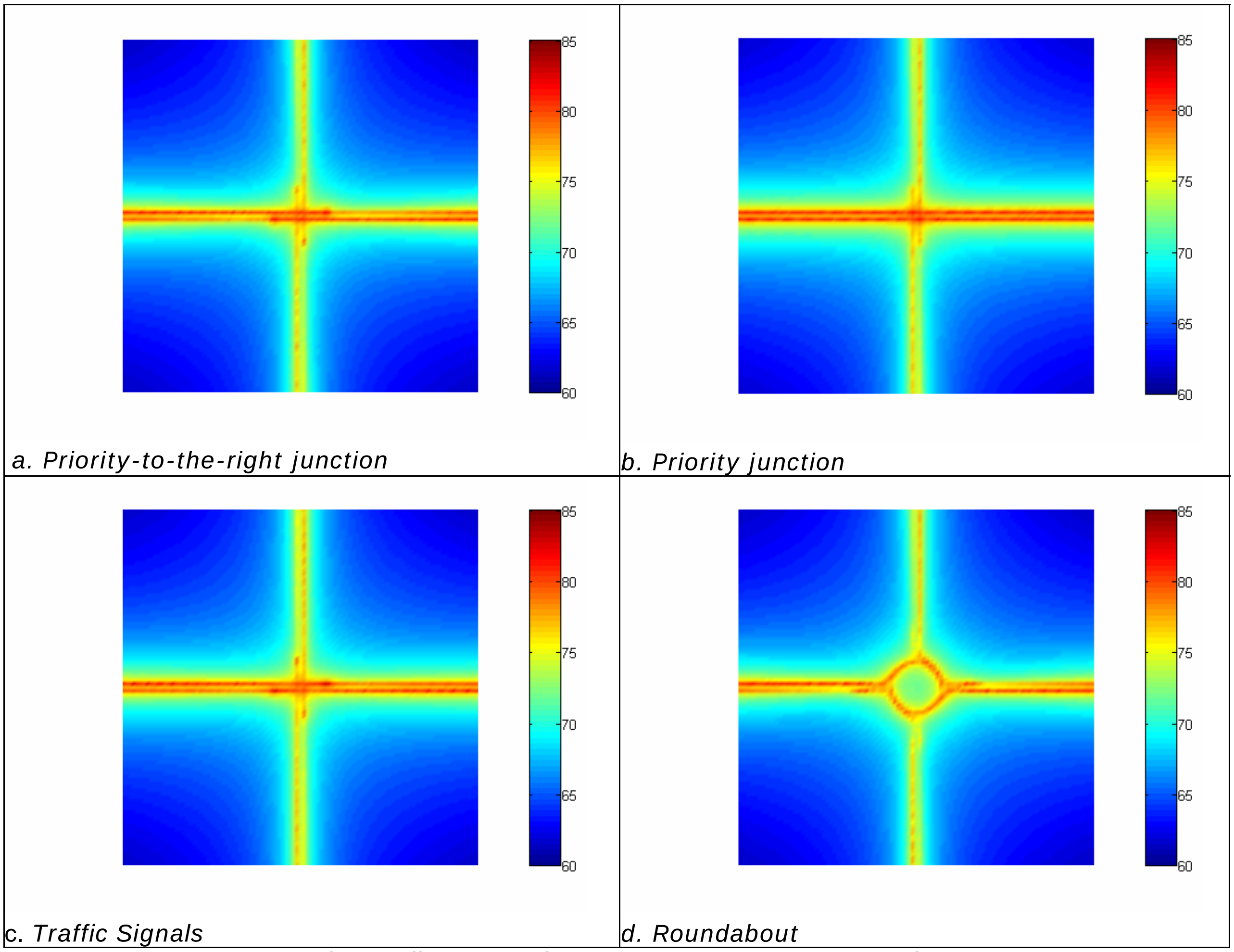
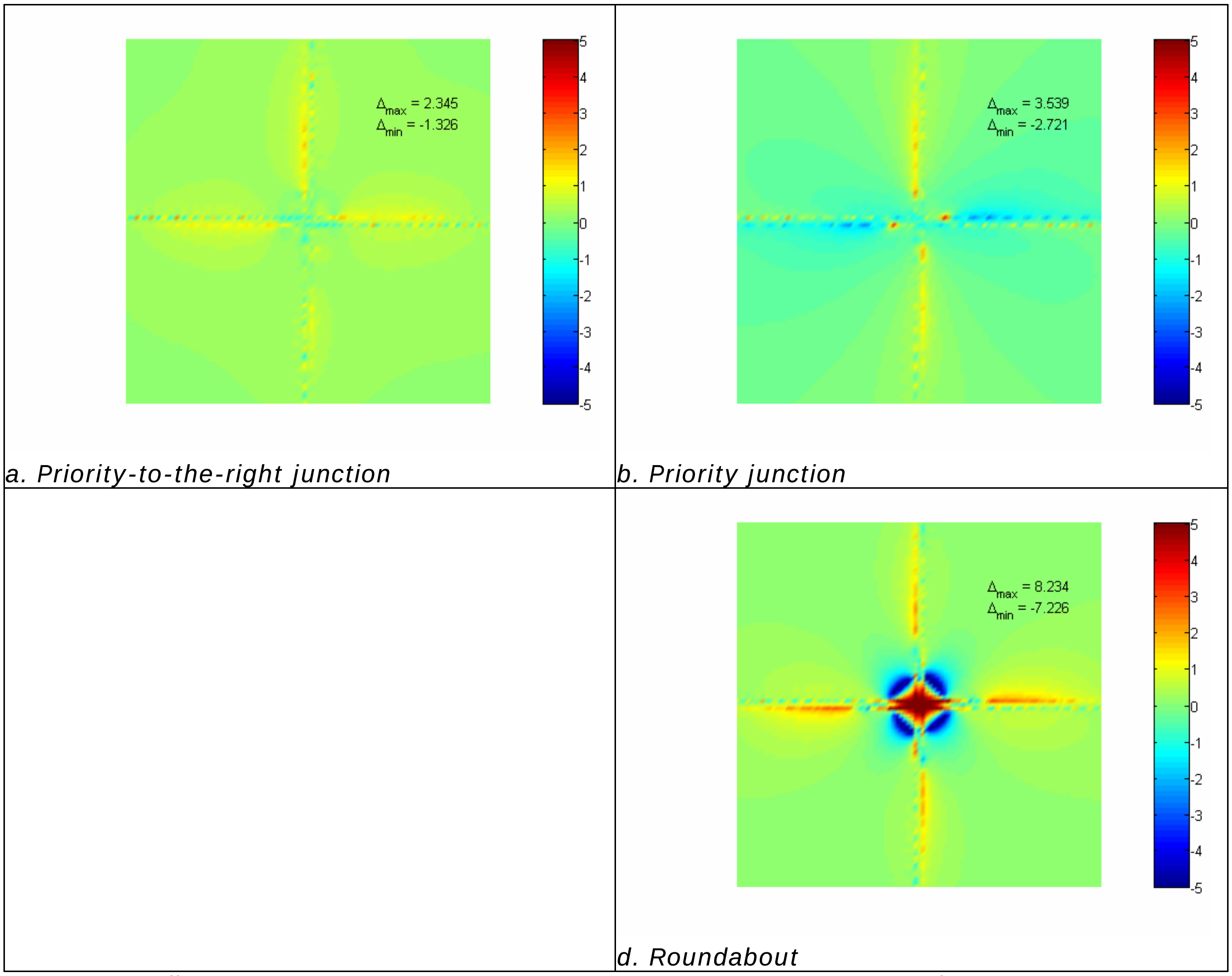



**Figure 38. Noise levels for the different types of intersections considered in this study, for 250 veh/h on the major road, 100 veh/h on the minor road, 80% through traffic and 20% heavy traffic.**




*a. Priority-to-the-right junction*

*b. Priority junction*

*d. Roundabout*

**Figure 39. Difference in noise levels between the signalised intersection and the other types of intersections considered**

The impact on noise levels is illustrated in Table 15. For each scenario, the noise levels in the neighbourhood of the intersection where calculated. The percentage of the area (200m*200m) near the intersection where the noise level is higher than 70dBA is calculated. In free flow the area where a given level is exceeded theoretically scales proportional to the traffic intensity for each road separately. Roundabouts increase $L_{Aeq}$ above 70 dBA in the smallest area in the studied range of traffic volumes. In most cases, signalised intersections produce the highest noise levels. The priority junction creates large areas of high $L_{Aeq}$ for the highest traffic volumes on the major road. It should be noted that the better performance of traffic signals with regard to travel time is not reflected in the noise levels.

**Table 14. Increase in total travel time in comparison to free-flow conditions (80% through traffic, 20% trucks)**

| | | Minor road volume (veh/hour) | | |
|---|---|---|---|---|
| Intersection_type | Major road volume (veh/hour) | 100 | 250 | 500 |
| a_priority-to-the-right_junction | 100 | 2.62% | | |
| | 250 | 4.07% | 20.33% | |
| | 500 | | 236.54% | 469.54% |
| | 750 | | 379.34% | |
| b_priority_junction | 100 | 1.29% | | |
| | 250 | 1.06% | 2.48% | |
| | 500 | | 5.02% | 142.48% |
| | 750 | | 32.49% | |
| c_traffic_signals | 100 | 3.43% | | |
| | 250 | 3.84% | 4.35% | |
| | 500 | | 5.65% | 12.75% |
| | 750 | | 10.33% | |
| d_roundabout | 100 | 1.60% | | |
| | 250 | 1.83% | 2.22% | |
| | 500 | | 2.87% | 4.06% |
| | 750 | | 4.22% | |

| | |
|---|---|
| (yellow) | *= lowest value (of the 4 types of intersections)* |
| (red) | *= highest value (of the 4 types of intersections)* |

Similar conclusions can be drawn on the basis of the total traffic sound power level generated in an area within 200m of the centre of the intersection as shown in Table 16. In free flow, this sound power level should increase as 10log(Q) with Q the total number of vehicles passing through the study area per hour. So when the noise sources within 200m around the centre of the intersection are replaced by a point noise source with this power level, the $L_{Aeq}$ will be the same, when seen from a large distance.

**Table 15. Percentage of the 200m*200m area around the intersection with noise levels larger than 70dBA (80% through traffic, 20% trucks)**

| | | Minor road volume (veh/hour) | | |
|---|---|---|---|---|
| Intersection_type | Major road volume (veh/hour) | 100 | 250 | 500 |
| a_priority-to-the-right_junction | 100 | 0.00% | | |
| | 250 | 1.80% | 7.42% | |
| | 500 | | 11.56% | 14.12% |
| | 750 | | 11.54% | |
| b_priority_junction | 100 | 0.00% | | |
| | 250 | 3.96% | 6.84% | |
| | 500 | | 10.56% | 13.70% |
| | 750 | | 16.14% | |
| c_traffic_signals | 100 | 0.10% | | |

| | | | | |
|---|---|---|---|---|
| | 250 | 4.62% | 7.98% | |
| | 500 | | 10.94% | 15.20% |
| | 750 | | 14.14% | |
| d_roundabout | 100 | 0.12% | | |
| | 250 | 1.82% | 5.50% | |
| | 500 | | 8.68% | 11.60% |
| | 750 | | 11.98% | |
| (yellow) | = lowest value (of the 4 types of intersections) | | | |
| (red) | = highest value (of the 4 types of intersections) | | | |

**Table 16. Sound power level generated in the study area (dBA) for the different scenarios (80% through traffic, 20% trucks)**

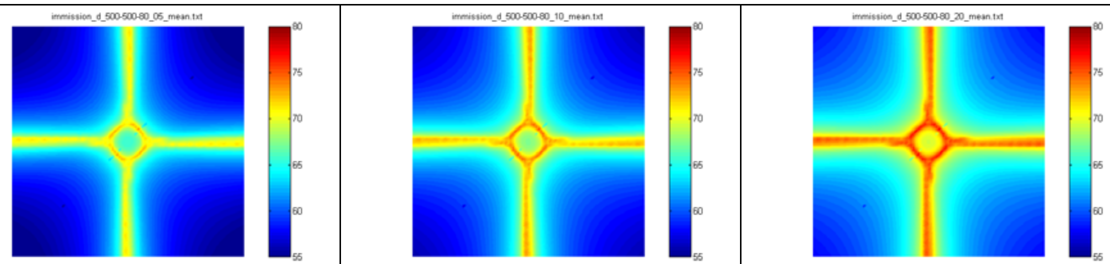
| | | Minor road volume (veh/hour) | | |
|---|---|---|---|---|
| Intersection_type | Major road volume (veh/hour) | 100 | 250 | 500 |
| a_priority-to-the-right_junction | 100 | 108.94 | | |
| | 250 | 111.4 | 113.26 | |
| | 500 | | 115.55 | 116.42 |
| | 750 | | 115.71 | |
| b_priority_junction | 100 | 109.23 | | |
| | 250 | 111.81 | 113.26 | |
| | 500 | | 115.17 | 116.67 |
| | 750 | | 116.73 | |
| c_traffic_signals | 100 | 109.58 | | |
| | 250 | 112.03 | 113.66 | |
| | 500 | | 115.38 | 116.55 |
| | 750 | | 116.55 | |
| d_roundabout | 100 | 108.98 | | |
| | 250 | 111.45 | 113.05 | |
| | 500 | | 114.73 | 115.84 |
| | 750 | | 115.78 | |
| (yellow) | = lowest value (of the 4 types of intersections) | | | |
| (red) | = highest value (of the 4 types of intersections) | | | |

***Influence of traffic composition***

Even with the same number of vehicles on the links, traffic operations can be influenced by the type of the vehicles. First of all, trucks influence traffic operations, especially on intersections. This results in different speed characteristics and other noise emissions. Furthermore, trucks differ from cars in their noise emission properties. The effect on traffic operations is illustrated in Table 17. It shows the overall travel time for a roundabout with 500 vehicles approaching on each link (80% through traffic). A higher share of trucks results in slightly higher travel times. The combined effect on noise levels can be seen in Figure 40. In this example, the difference between 5% and 20% trucks results in a difference in noise levels near the road of about 3 to 4dBA.

**Table 17. The influence of truck share on travel time on a roundabout (500 veh/hour on major link, 500 veh/hour on minor link, 80% through traffic)**

| Share of trucks in total traffic demand | Increase in travel time compared to 5% trucks |
|---|---|
| 10 % trucks | 0.43 % |
| 20 % trucks | 1.05 % |

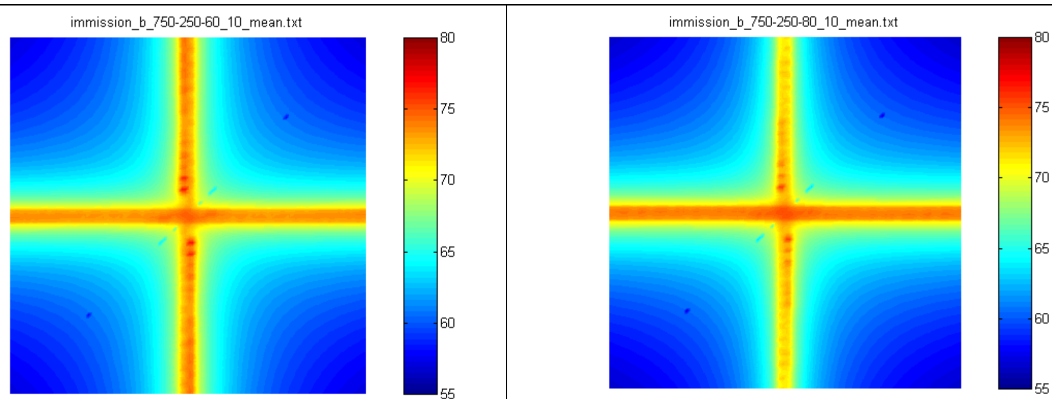


*a. 5% trucks* *b. 10% trucks* *c. 20% trucks*

**Figure 40. Roundabout with constant overall traffic demand, but with changing truck rates**

### *Influence of turning rates*

Tuning rates determine the amount of through traffic and turning traffic on the intersection. Turning traffic influences the performance of traffic operations on the intersection, especially in the priority and priority-to-the-right cases. Especially the amount of left-turning traffic can have a large impact, due to a large number of conflicting traffic streams. Figure 41 represents the priority junction. Traffic on the major (horizontal) road has priority. Traffic demand is the same in both figures, but the amount of through traffic is higher in the figure on the right. This has an impact on the noise levels. We see larger emission values on the minor road in the left figure due to lower capacity performance. However, the influence of the turning rates on signalised intersections and roundabouts is small.



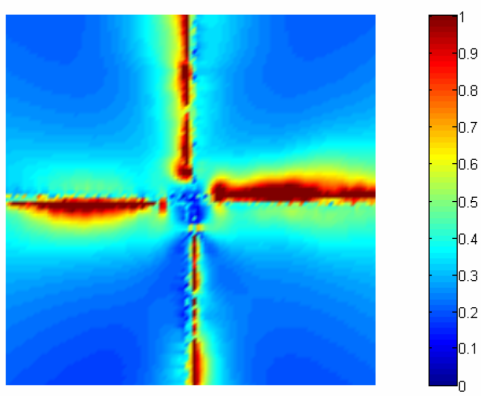

*a. priority junction with 60% through traffic* *b. priority junction with 80% through traffic*

**Figure 41. Influence of turning rates on a priority junction**

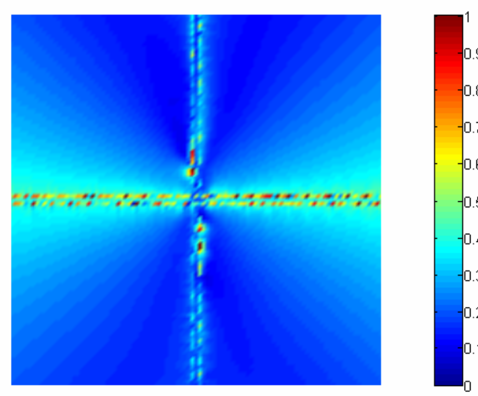
### *Influence of modelling uncertainty*

The simulation of traffic operations is done with a micro-simulation model. Individual behavioural rules are used to calculate the position of vehicles in each time step. To take uncertainty into account, the model uses some randomisation. In Paramics, most of this randomisation is done

when vehicles are released into the network: the exact time a vehicle is released, the vehicle type and the driver characteristics are randomly determined upon release into the network. The randomization is done using a seed parameter.
This means that at one specific moment in time, the position of vehicles in the network will be different for different seed values. Furthermore, the types of vehicles and the vehicle characteristics will be different.
So different seed parameters result in different simulation outcomes. This incorporates the chaotic characteristics of traffic.
We simulated each case study five times with different seed values. The presented results so far, all represent the average (linear in dBA) of the five simulations. Figure 42 represents the standard deviation of the five simulations that led to the results shown in Figure 39 around this average.
For roundabouts and signalised intersections the standard deviation on calculated noise levels is low. The small dots appearing on the road are related to exact stopping positions that may depend on input parameters of the model. Once away from these, the standard deviation is in general no more than 0.3 dBA thus leading to standard error well below 1 dBA[4] on proposed intersection-corrections that are extracted from these simulations
For the priority-to-the-right and the priority junction standard deviations are much larger on the roads where individual drivers must give way. There may be two explanations for this. Firstly, since most cars are stopping on these streets, the dependence on acceleration behaviour and corresponding increase in sound levels is larger. Secondly, and probably more importantly, the length of the queue waiting to enter the intersection is very chaotic and unpredictable also on real junctions with approximately this traffic load. Thus, provided that the number of simulations leading to the average effect is large enough, corrections for these types of intersections could still be extracted from the simulation, but they will certainly not be valid for comparison to short term observations.

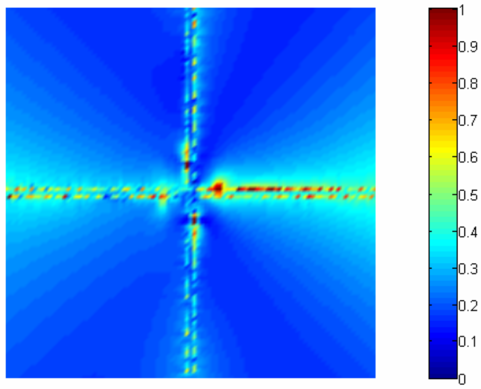



*a. Priority-to-the-right junction*

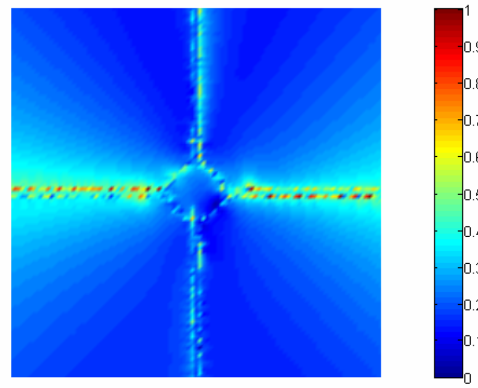



*b. Priority junction*

[4] This does not exclude the possibility that other, systematic errors exist, but it is at least a good indication.




*c. Traffic Signals*




*d. Roundabout*

**Figure 42. Influence of modelling uncertainty: standard deviation of the simulations for 5 different seed-values (250 veh/h on the major as well as on the minor road, 80% through traffic and 20% heavy vehicles).**

### 3.3.4 Corrections

In this section, an onset is given in formulating correction factors, which can be applied to the noise emissions resulting from macroscopic traffic models that do not take into account the influence of intersections. A spatial approach will be used, in which inbound and outbound lanes are divided into deceleration, queuing, stopline and acceleration zones. Meaningful relationships between traffic flow parameters and noise corrections will be derived by the use of regression analysis.

***General considerations***

Some junction configurations were a priori excluded from the correction factor analysis, because no stable traffic situation was achieved on the inbound lanes during simulation (queue lengths grow during the full simulation due to jams). The outbound lanes of these configurations were nevertheless taken into account, since no jams are formed there. More precisely, it concerns the priority-to-the-right junction with a traffic volume of 500 veh/h or more on the major road, and the priority junction with a traffic volume of 500 veh/h on the minor road, or 750 veh/h on the major road. These types of intersections will in practice probably never be used for these traffic volumes. The roundabout is not (yet) taken into account for the correction factors, as the layout of this type of junction differs highly from the other 3 types.

It has to be noted that the simulated networks all have a limit speed of 70 km/h on both major and minor arms. It can be expected that this limit speed has a large impact on the size of the corrections near the junctions, as the noise emission at a distance from the junction (on which the corrections are based) will largely depend on this limit speed. Also, in Appendix A.1 it is shown that although acceleration has a larger impact on noise emission for lower speeds, the noise emission at low speeds with maximum acceleration is still lower than the level at 70 km/h cruising, which indicates that the intersections considered here could overall be more quiet than their free flow equivalents. This limits somewhat the usefulness of the proposed correction factors; further research on this topic should include this limit speed as a parameter.

***Methodology***

Hourly average emission values were calculated along each lane in 5m segments, using Paramics and a Harmonoise vehicle noise emission plugin. Figure 43 shows an example of an emission profile. To get the noise emission per lane in dB(A)/m, one should subtract $10\log_{10}(5) \approx 7$ dB(A); this has however no implications for the derivation of the correction factors, as only differences are considered.

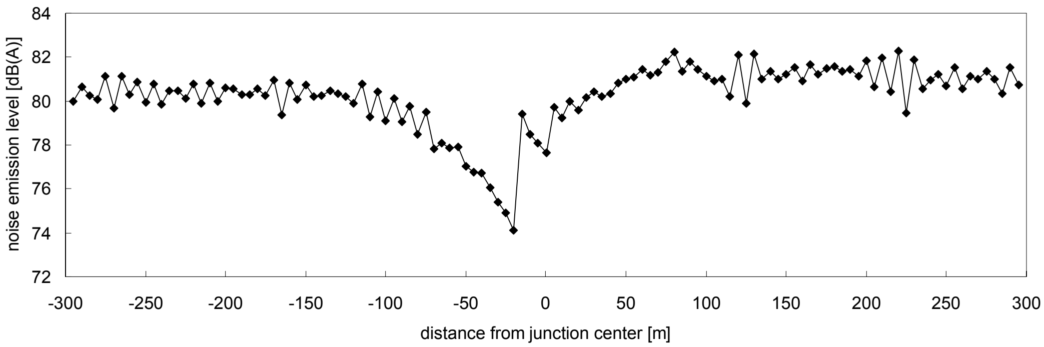
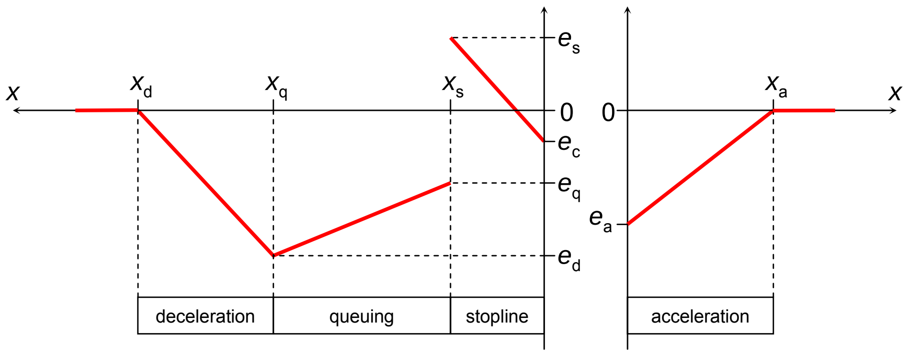



**Figure 43. Noise emission profile for the major arm (inbound and outbound lane), for the priority-to-the-right network with a traffic volume of 100 veh/h on both major and minor arms, a through traffic rate of 60% and 5% heavy vehicles (averaged over 5 micro-simulation runs).**

At larger distances from the junction the noise emission is independent of the location, as can be expected for cruising vehicles. Noise corrections will be based on this limit emission, as it is assumed that this is the usual emission output of macroscopic model based traffic noise prediction.

Based on a close inspection of the emission profiles of all networks and configurations taken into account, the model as shown in Figure 44 is proposed, which fits well to most of the emission profiles. Correction factors are derived for the inbound and outbound lanes separately, as a function of the distance $x$ to the centre of the junction (the origin on the figure). Vehicles approaching the intersection will on average start decelerating at a distance $x_d$ from the centre of the junction. This will be modelled with a decrease in noise emission proportionally to the distance $x$, up to a distance $x_q$ where a possible queue starts. The noise emission is again linearly modelled in this queuing zone. At the distance $x_s$ on the inbound road, the vehicles start accelerating, which results in a peak in the noise emission; this is near the stopline of the inbound lane. On the outbound lane, the acceleration noise emission is again modelled by a linear relationship with the distance $x$, up to a distance $x_a$ from the intersection, where the outbound lane limit speed is reached. The emission values $e_i$ represent the rises (or drops if negative) in emission compared to the limit emission value (inbound or outbound).




$$\text{inbound}\begin{cases}\text{deceleration} & e_d + \dfrac{0-e_d}{x_d - x_q}\left(x - x_q\right) & x_q < x \le x_d \\[2ex] \text{queuing} & e_q + \dfrac{e_d - e_q}{x_q - x_s}\left(x - x_s\right) & x_s < x \le x_q \\[2ex] \text{stopline} & e_c + \dfrac{e_s - e_c}{x_s - 0}\left(x - 0\right) & 0 < x \le x_s \end{cases}$$

$$\text{outbound} \quad \text{acceleration} \quad e_a + \frac{0-e_a}{x_a - 0}\left(x - 0\right) \qquad 0 < x \le x_a$$

**Figure 44. Proposed correction model, applicable to the priority-to-the-right junction, the priority junction and the signalised junction.**

This curve was fitted to the emission profiles of all network configurations (traffic volume on major and minor road, amount of through traffic, amount of heavy traffic), using a least squares method in Matlab. Furthermore, exact traffic counts and percentages of heavy vehicles were gathered from the micro-simulation, to make a more correct model possible. Finally, the relation between the $x_i$, and $e_i$ parameters and the model parameters was estimated using standard linear regression. Model parameters taken into account are: the percentage of heavy vehicles *f*, the traffic flow on the lane *logQ* (with *Q* in vehicles/hour), the percentage of left or right turning vehicles *Turn* on the junction, and the average extra traveltime *logTT* (with TT in seconds) it takes for a vehicle to pass the inbound lane, compared to the reference situation where there are no delays for all vehicles. For each linear regression model, parameters that did not pass a t-test ($\alpha = 0.05$) were restrained.

It has to be noted that the given formulas are only valid within the simulated limits, which are from 5% to 20% for *f*, from 100 to 750 vehicles/hour for *logQ*, from 20% to 40% for *Turn*, and roughly between -1 and 2 for *logTT*. Extrapolations outside these intervals should be handled with caution.

### *Acceleration area*

The results are summarized in Table 18. For all types of intersections, the amount of heavy traffic has the largest influence on the length of the acceleration area, because the maximum acceleration for heavy traffic is lower. For the priority-to-the-right junction, it is found that also the traffic volume makes the acceleration after a junction more slowly; vehicles are more interrupted at the crossing when the traffic volume increases. Note that the traffic volume on the outbound lane is influenced by both the traffic volume on the minor and the major inbound arms. For the major outbound arm of the priority junction, no correction factors are found, because the larger part of the vehicles does not accelerate or decelerate on this arm; traffic on this arm has priority. On the minor arm, the length of the acceleration area is to a small extent also influenced by the amount of vehicles that enters this lane from the major arm (turning rate). For the signalized intersection, the influence of the heavy traffic percentage becomes smaller, because during the greentime on the major arm (which is most of the time), vehicles do not have to decelerate at the crossing. As the acceleration after a junction becomes more smoothed out, the emission correction becomes smaller for all types of junctions; a good correlation between $e_a$ and the inverse of $x_a$ is found. In all cases, a negative $e_a$ was found; positive values (corresponing to higher levels due to acceleration) may be possible if the speed limit on the lane is lower (as already mentioned).

**Table 18. Correction coefficients for the acceleration area.**

| | **Major (priority) arm** | **Minor (priority) arm** |
|---|---|---|
| **Priority-to-the-right junction** | $x_a = -35.033 + 1.968f + 33.523\log Q$ <br> $e_a = -1.194 - \frac{39.272}{x_a}$ | |
| **Priority junction** | $x_a = 0$ <br> $e_a = 0$ | $x_a = 47.096 + 1.751f - 0.542Turn$ <br> $e_a = -0.570 - \frac{79.202}{x_a}$ |
| **Signalized junction** | $x_a = 33.694 + 1.046f$ <br> $e_a = -0.802 - \frac{72.143}{x_a}$ | |

***Stopline area***

The parameter $x_s$ should be located just before the stopline (at the centre of the first vehicle waiting at the stopline), which was 12.5 m for all non-roundabout intersections modelled in this study. Noise emission corrections on the stopline are mainly influenced by the amount of heavy traffic and the extra traveltime associated with the inbound arm, as is summarized in Table 19. The correction starts negative for a crossing with no congestion, and rises when the congestion becomes larger; higher values are the result of the high acceleration of the stopped traffic at this location. As can be expected, the correction is smaller for the signalized intersection, because large part of the traffic here can cross the intersection without stopping. Again, no correction is found for the major priority arms of priority junctions.

**Table 19. Correction coefficients at the stopline.**

| | **Major (priority) arm** | **Minor (priority) arm** |
|---|---|---|
| **Priority-to-the-right junction** | $e_s = -3.061 + 0.057f + 4.255\log TT$ | |
| **Priority junction** | $e_s = 0$ | $e_s = -3.935 + 0.049f + 5.293\log TT$ |
| **Signalized junction** | $e_s = -1.794 + 0.055f + 3.180\log TT$ | |

Corrections at the centre of the intersection are given in Table 20. It was found that for the priority-to-the-right junction, the correction coefficients could best be formulated using an alternate classification of the inbound arms. A pivoting point for the correction was found when the extra traveltime exceeded 10s (*logTT* = 1). For values lower than 10s, no large queues are formed, and the correction largely depends on the extra travel time and the traffic flow. For values higher than 10s, the correction becomes smaller and less dependent on the extra travel time and traffic flow. For the other types of intersections, the best categorization was still based on the priority of the arm.

**Table 20. Correction coefficients at the centre of the intersection.**

| | logTT < 1 | logTT ≥ 1 |
|---|---|---|
| **Priority-to-the-right junction** | $e_c = 11.922 - 8.798 \log Q + 6.276 \log TT$ | $e_c = -3.421 - 0.030 Turn + 1.016 \log TT$ |
| | **Major (priority) arm** | **Minor (priority) arm** |
| **Priority junction** | $e_c = 1.755 - 0.727 \log Q - 0.063 Turn$ | $e_c = 10.048 - 5.084 \log Q - 0.044 Turn + 1.636 \log TT$ |
| **Signalized junction** | $e_c = -4.828 + 2.068 \log TT$ | $e_c = 0.253 - 2.031 \log Q - 0.016 Turn + 2.590 \log TT$ |

***Queuing area***

For the queuing area, the classification based on the travel time was also used; correction coefficients are shown in Table 21. For values lower than 10s, there is no queuing zone at all, and $x_q$ can be chosen near the stopline. For values larger than 10s, a good correlation between the queue correction coefficients and the amount of heavy traffic (longer vehicles) and the extra travel time is found.

**Table 21. Correction coefficients for the queuing area.**

| | logTT < 1 | logTT ≥ 1 |
|---|---|---|
| **All junctions** | $x_q = x_s$<br>$e_q = 0$ | $x_q = -82.607 + 1.317 f + 107.739 \log TT$<br>$e_q = -8.236 + 0.039 f + 5.542 \log TT$ |

***Deceleration area***

Table 22 finally summarizes the coefficients for the deceleration area. In most cases, a correlation is found with the traffic flow *logQ* and the extra travel time of the inbound lane, *logTT*. It must be noted that the corrections are only valid for $x_d$ < 300m, because of the limited size of the area taken into account for the calculation of these coefficients.

**Table 22. Correction coefficients for the deceleration area.**

| | Major (priority) arm | Minor (priority) arm |
|---|---|---|
| **Priority-to-the-right junction** | $x_d = 10.134 + 157.024 \log TT$<br>$e_d = -16.249 + 3.638 \log Q + 3.682 \log TT$ | |
| **Priority junction** | $x_d = 0$<br>$e_d = 0$ | $x_d = 148.103 - 68.133 \log Q + 169.833 \log TT$<br>$e_d = -10.644 + 5.640 \log TT$ |
| **Signalized junction** | $x_d = -254.705 + 96.909 \log Q + 200.458 \log TT$<br>$e_d = -8.639 + 2.147 \log Q + 0.535 \log TT$ | |

***Accuracy of the model***

Some remarks have to be made about the validity of the proposed coefficients. Several micro-simulation parameters can have an influence on the numerical values, such as the mean headway between vehicles, the signposting distance and the awareness distribution of the vehicle drivers. The influence of these parameters on the results was not studied, because this would make the number of simulations become too large. Also, as already mentioned, the limit speed may have a large influence on the correction coefficients.

## 3.4 Low flow roads

***Context***

If all roads in an agglomeration must be mapped, then the low flow roads will present a problem, as accurate predictions for these roads are very difficult to make. Traffic assignment models are originally constructed to predict reliable travel times between origins and destinations on the one hand, and to predict the traffic flows on network links on the other hand. The purpose of the latter is to find the links that are congested (bottlenecks in the network). Low flow roads are not particularly interesting for these purposes. In most classical traffic models (especially static and dynamic assignment), the traffic flow predictions on the links of the lowest scale level are unreliable. This is inherent to the way the models work. There will always be a form of aggregation on the spatial level: spatial areas are arranged in zones because there is no data at the level of individual buildings nor is it computationally feasible to include that amount of detail. Not only the traffic intensity but also traffic speeds on these low level roads are unreliable or simply not available.

Note that although the accuracy does not necessarily have to be very high for low flow roads (see Section 2.4), inaccuracy of traffic model estimates for low flow roads can be substantial, so that some attention for possible improvements is required.

***Problem analysis***

Noise maps need to be made for all roads in an area, including the ones with low traffic volumes. For all these roads, adequate traffic flow and speed predictions should therefore be available.

In most models, not all roads are included in the network modelled. Minor roads (mostly residential streets) are usually left out, in order to reduce the complexity of the model (less data, shorter calculation times). On a positive note, this will become less of the problem in the future (with more powerful computers and (GIS-)databases of the road networks, connected to traffic models).

Another problem is that in all traffic models, the roads of the lowest scale level available are unreliable in their flow prediction. The main reason for this is the structure of link network and spatial zone arrangement. Traffic travels in all model types from origin to destination. These origins and destinations are always aggregated in a spatial area of a certain size, in which all characteristics are equal. The size of the zones determines the spatial detail of the model. For instance, one could model the complete city of Lille (France) in two zones: one zone for the Western part of Lille, the other for the Eastern part of the city. Traffic only leaves a zone if it has a destination in another zone (intra-zonal traffic is not assigned to the network). If traffic leaves a zone, it uses a so-called connector (or feeder link), which connects a zone with the road network. Traffic from Lille-East to Lille-West is the only traffic on the network in this example, and all this traffic will enter the network at a node to which a connector is connected. It is easy to understand that this zonal size level is not suitable for an urban transport model (used to make the noise map of an agglomeration). Far too few vehicles will be present on the network, and the chosen routes will be influenced by the connector location in a far too important way. However, when modelling on a national scale in France (e.g. for a noise map of the major roads), it is probably a good choice to divide Lille in only two or three zones. The traffic to other parts of the region of country can be predicted fairly well with this zonal size level.

So the size of the zones determines to a great extent the quality of traffic flow predictions on the network. However, the only way to predict the flows on the lowest scale level roads in urban areas, is to use very small zones: perhaps as small as individual buildings. This demands a lot of data collection, and it is very difficult to predict the behaviour of individual inhabitants of a city. This is therefore an unfeasible option. For urban models, the best size of the zones is probably the neighbourhoods, but this could still mean that the low flow roads prediction reliability is not good enough for noise mapping purposes.

Recapitulated: Very large zones cause too much internal traffic (which never appears on the network), and when very small zones are used it is necessary to describe the behaviour of small groups of people, which requires a large amount of data (e.g. age, income, educational level, driver license possession) and calculation capacity.

Additional problems are:

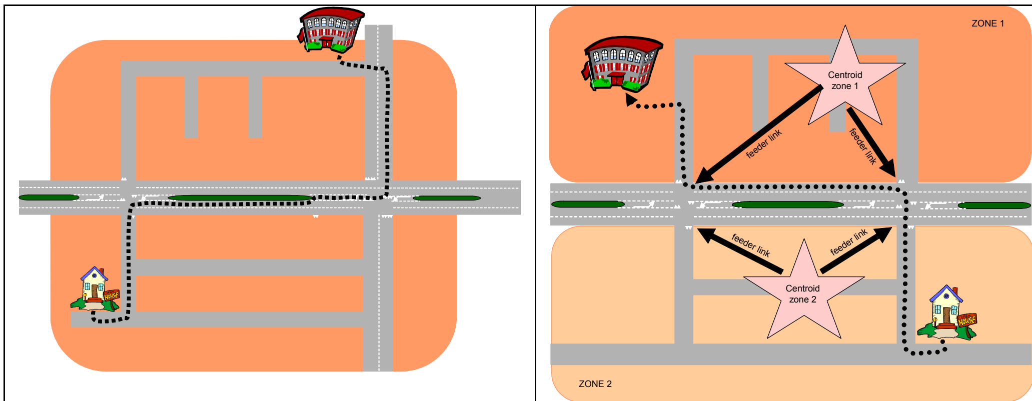
- The relative errors in volumes on low flow roads can easily become large, because of the fact that small numbers cause large errors easily (a relative error of 15 vehicles in 1000 is not very large, but a relative error of 15 in 30 vehicles is).
- In most cases, there are no traffic counts available for low flow roads. The calibration and validation of the flow predictions is therefore difficult.
- Many people live near low flow roads so the error in the noise exposure statistics of the population can be significant. However, in general, the dwellings near low flow roads are not the highest exposed and thus not the noise problem areas.

***Strategies***

**Check (and adjust) size of zones in traffic model**

The main strategy involves some steps to carry out:

1. Check if the zonal scale is suitable for the calculation of the low flow roads that are included in the network modelled. A good size of zones at urban level is the neighbourhoods of a town.
2. Check whether the zones do not overlap any main roads. In that case, too much internal traffic will be the result. This traffic will not be assigned to the network, which results in underestimates for the flows on these roads. See Figure 45 for an illustration of this problem. In Figure Figure 45a, a trip from a home to a school will not be assigned to the network because it is considered to be internal traffic. Still, this internal traffic will use the main road, for which accurate estimates of traffic volumes may be very important. Note, however, that choosing the zones in such a way that they are not bisected by main roads solves this problem for part of the traffic, but the use of feeder links means that some of the traffic will travel solely by these feeder links, as is demonstrated in figure Figure 45b.




a. Main road bisects zone; trip will not be assigned to network

b. Trip will not be assigned to network either (feeder links will be ‘used’ instead)

**Figure 45. Problems resulting from the zones and feeder links system of traffic models.**

3. That means that it is also important to check how the zones are connected to the network (i.e. how the centroid of the zone is connected, by feeder link, to a point in the network, usually an intersection). It is important that traffic from a zone enters the network at logical locations, so that traffic leaves the zone in the direction that it would in reality. If this is not the case, some intersections/routes may be overloaded, which would influence the route choice and ultimately the accuracy of the traffic volumes and traffic speeds.
4. Make sure that the length or cost function on the connector represents the building density distribution within the zone. For instance, a centre of gravity for the zone can be used, in which all buildings are incorporated.

The traffic model does not have to be refined further by adding more zones (taking into account the rules of good conduct explained above) if it can be assumed that the traffic intensity on roads not included in the model carry les than the traffic intensity that on average has no effect at the $L_{Aeq}$ level that is expected to be correctly modelled (see Section 2.4)  If the traffic model cannot be improved to that point, the approximate estimation methods described below can be used, taking into account that the quality of the noise map is reduced.

**Estimate flows on roads not (properly) included in traffic model**

If the model has zones that are too large and there is not sufficient data to adjust the zonal level and/or the level of detail of the road network, the best way to predict the flows on the minor roads of the network is to make an estimate. There are many ways to do that; many authorities have published guidelines on how to do that. The Good Practice Guide [1] also gives toolkits to estimate flows – see toolkit 4 and 5). These toolkits allow estimating traffic on roads where traffic intensity is unknown but do not fully explore the knowledge that is available within the traffic model that is used to calculate traffic on main roads.

Several examples were found (e.g. Urbis by TNO, an instrument for Local Environmental Surveys [70], and the noise mapping performed for the evaluation of the Mobility plan Flanders by UGent), where noise mapping found a creative way around these shortcomings. Based on these experiences we propose the following procedure.

1. Obtain the number of trips inside each zone. This number consists of the number of trips leaving the zone, the number of trips entering and the number of trips with origin and destination within the same zone (intra-zonal traffic).
2. If the intra-zonal traffic is not produced by the demand model, assign additional traffic based on e.g. fuel consumption (nation wide or regional) using a realistic estimate of the trip length within the zone.

Now assign the trips to road segments within the zone. This can be done based on measured traffic intensities or on trip origins depending on the data that is available.

- Based on knowledge on traffic intensities.
    1. Generate the number of kilometres driven inside the zone, $T_z$, by multiplying the number of trips with the radius of the zone. $T_z=R_z*(O_z+D_z+OD_z)$ where $O_z$ is the number of trips generated in the zone, $D_z$ the number of trips arriving and $OD_z$ the intra-zonal traffic.
    2. If[5] relative intensities, $I_{rc}$, on different categories of roads, c, are available e.g. from counting at randomly selected locations in the region under study, the traffic can be assigned to the roads taking into account the total length of each category of road in the zone, $L_{cz}$. All roads of category c thus get a traffic intensity $I_{cz}=I_{rc}*C_z$ where $C_z = T_z \Big/ \sum_c I_{rc} L_{cz}$
    3. **Optional:** Further refinements can be made by assuming a certain distribution of traffic intensity for the different types of roads (e.g. by fitting gamma-distributions), taking into account the average traffic densities that were calculated.
- Based on trips.
    1. Traffic is generated uniformly on all residential streets within an OD zone. The total number of trips, ($O_z+D_z+OD_z$), is divided by the total length, $L_z$, of the residential streets in the OD zone, which gives the number of trips generated per meter $T_{dz}$. The residential streets are divided into segments of max. 25 m. The traffic generated on these segments can be calculated.
    2. This traffic is assigned to the network of residential streets on the basis of the assumption that traffic takes the shortest route to the nearest road on a higher level (i.e. a road with a traffic volume in the model).

Which one of the two approaches described above is more accurate depends on the size and structure of the zones in the traffic model. It can be expected that for smaller zones with no thru

[5] If no data per road category is available, a single type of road can be used, but accuracy is strongly reduced.

traffic, the second approach is more appropriate, while for larger zones that could be parts of a city, the first approach yields more accurate results.

Additional measurements (on low flow roads!) can help improve the accuracy of the estimates. *Additional data collection is the subject of task 2.4 of this work package and will be discussed in a separate document.*

**Speeds on low flow roads**
With regard to the calculation or estimation of speeds on low flow roads, we expect fewer problems if traffic flow on these roads is mostly uninterrupted (if traffic has to slow down for speed humps, pedestrians crossing, etc. very often, the average speed may drop). On most low flow roads, we would therefore expect the speed to approximate the legal maximum speed. Additional speed measurements can be carried out to verify that that is the case in a specific area. *Additional data collection is the subject of task 2.4 of this work package and will be discussed in a separate document.*

## 3.5 Modelled speed

***Context***
There are indications that modelled speeds do not meet the accuracy requirements [1]. It is important to obtain accurate vehicle speeds on the busiest roads, because large errors (> 10 km/h) have significant effects (> 1 dBA) on calculated noise levels.

***Problem analysis***
The uncertainty about modelled speeds is particularly relevant for macroscopic models. Many macroscopic models do not include intersection modelling. The travel times on links include (ideally) delays at intersections, which means that speeds on links leading to or away from an intersection may be underestimated. Another problem is that it is impossible to model congestion accurately with these models (especially ‘blocking back’ effects, where a queue extends beyond the next intersection).
Even if intersections are modelled, this was not done with the aim to improve the accuracy of modelled speeds, so care should be taken to check the modelled speeds against measured speeds. Unfortunately, there seems to be very little information on the expected magnitude of errors in modelled speeds. The recent RAND Europe study giving an overview of the literature available on uncertainty of traffic forecasts does not mention errors in modelled speeds (only some references to travel times) [6].
A very similar problem arises with road gradients. The harmonised vehicle noise power model proposes a correction for uphill and downhill driving (WP5 [71]). This correction is particularly important for trucks. The correction does not consider the fact that trucks will drive slower when going uphill. Thus, to find the correct sound power, this speed reduction should be generated by the traffic model.
Macroscopic traffic models do not produce vehicle speed distributions. As noise emission by cars is not a linear function of speed, neglecting this distribution may result in 0.5 dBA error on $L_{Aeq}$.
Micro-simulation yields the speed and acceleration of all vehicles in the simulation at any time and thus is much more accurate in that respect. Nevertheless, average speed and speed distribution depend on parameters of the simulation and on the driver model that is used. Fortunately the sensitivity on speed of the contribution of a vehicle to the neighbourhood Lden is

lowest at a speed of around 40 km/h and it is precisely in this speed area that traffic speed modelling errors may be largest.

Another problem here is that although in many places speed measurements are carried out, these seldom give an accurate picture for all the roads and time periods that are part of a noise map. Most speed measurements are carried out on the busiest roads, and often only for part of the day (usually excluding the evening and night periods). Also, it has to be kept in mind that speeds may vary over a link (which is important for noise calculations) and that measurements only reflect the speeds at a certain location.

***Strategies***

To improve the accuracy of speed modelled in macroscopic models, road segments will often have to be chosen much smaller than required for traffic modelling applications. Further improvement

If the micro-simulation traffic model chosen does not fulfil the speed accuracy requirements, the driver model can be improved to better reflect the actual behaviour of the drivers and its variability. This requires a serious effort that is not always possible within the context of noise mapping. Two ways to work around this problem can be considered. Short segments of roads can be assigned a lower speed limit to represent e.g. displacement of the road axis or speed bumps. Another approach consists of splitting up vehicle categories in subcategories that are each assigned different maximum driving speed (this is generally done already in models which assign traffic for several user classes separately). On local trips, a vehicle speed lower than the urban speed limit can be assigned to a fraction of the vehicles (mostly passenger cars).

If possible, the traffic model should be calibrated on speeds (as well as on flows, where it should be noted that errors in the traffic volumes have a smaller impact on the accuracy of the noise calculations, so it is more important to get the speeds right than the flows). A general recommendation to authorities would be to carry out more speed (and flow) measurements on roads other than the main roads (where traffic counts and speed measurements may be carried out routinely to monitor congestion), which would be justified from the point of view of noise mapping (and air quality modelling). This would also enable more research into the relationship between speeds and traffic volumes (or traffic density), which could lead to better speed flow curves for the models.

*Additional data collection is the subject of task 2.4 of this work package and will be discussed in a separate document.*

In the absence of measured speed data, it is also possible to do a sensitivity analysis, in which speeds on road sections are varied to see how this impacts the calculated noise levels.

Finally, if the traffic and/or noise modellers have no faith in the modelled speeds, it may be better to use the prevailing speed limit as a proxy for the speed on a road section. An estimation of this error can be found in Section 2.2.2. See also the Good Practice Guide toolkit on Speeds on low flow roads in agglomerations [1].

# 4 Traffic modelling in action planning

## 4.1 Modelling of Measures

This section assesses the suitability of traffic models to simulate the effect of general traffic measures that might reduce noise emissions. For each measure, it is important to look at possible side-effects as well. This is often very complex, as will be illustrated by some examples in the remainder of this section. In all cases, the ensemble of all effects and side-effects must be looked at, to see if benefits in terms of noise reduction can be expected and it is precisely here that traffic models may come in useful.

Measures can be categorized by their goal. There are typically 4 types namely reduction of traffic intensity, changing fleet composition, reducing traffic speed and making traffic less dynamic. This section does not aim to give a complete overview of possible measures. Some examples are given in each category.

### 4.1.1 Reduction of traffic intensity

Traditionally, many measures aim at reducing traffic intensities, e.g. improved public transport, promotion of teleworking, etc. Locally, measures aiming at banning traffic from certain streets can be applied. Side effects can, however, always be expected. Below, a few examples are given.

Improving the quality of public transport might reduce the number of passenger cars. This improvement could be achieved e.g. by increasing the frequency on busy routes, by increasing the number of stops/stations or by making the use of public transport cheaper. A multimodal traffic macroscopic model should be used. When separate bus lanes are introduced, spatial re-organisation of traffic will take place (over the lanes of a road section). To assess the latter, a micro-simulation model is best suited. If this measure should eventually result in a decrease in traffic volumes, passenger cars may be able to drive at higher speeds (road capacity increases) and this could counteract the gain in noise emission by intensity reduction. This example clearly illustrates the complexity and importance of side-effects.

A number of measures can be modelled by adapting OD-matrices or the network characteristics in a macroscopic model. A first one is looking at the effect of making individual cars more expensive (by e.g. implementing pay-as-you-drive measures, or by increasing car taxes). Decreasing the amount of commuter traffic by increasing teleworking can be assessed in the same way. Another measure that can be modelled is the creation of pedestrian areas or of roads where heavy traffic is not allowed. An important side-effect possible here is an increase in the number of kilometres travelled on other roads in order to avoid these zones and a consequent spatial shift of noise emissions.

It can be concluded that macroscopic traffic models are best suited to simulate measures aiming at the reduction of traffic intensity. Micro-simulation models are usually less suitable for analysing measures aiming at a reduction of intensities.

### 4.1.2 Changing traffic composition

The effectiveness of measures to change traffic composition seems unclear from the viewpoint of reducing noise emission. Take, for instance, the prohibition of heavy traffic during peak hours on major roads. This changes traffic composition drastically during these periods. Side-effects are however important. The share of heavy traffic during off-peak hours (this means also during the evening and at night) will increase. Yearly averaged $L_{den}$ values might increase, taking into account the 5 dB and 10 dB penalties for the evening and night period. A multi-user-class macroscopic model is suited to model the effect of this type of measure. Another commonly applied measure is an overtaking-prohibition during peak hours (or at all times).. A side-effect may be the increase of traffic speed of light vehicles. The effects of such a measure can best be investigated with a micro-simulation model. Preventing heavy vehicles to enter city centres is similar to introducing pedestrian areas (see Section 4.1.1).
Strict regulations with regard to the noise emission of new cars or public transport are positive from the viewpoint of noise reduction. They do not have any repercussions on traffic modelling.

Depending on the situation, both macroscopic and micro-simulation models can be used to assess measures aiming at changing traffic composition, provided that the model assigns traffic from different vehicle types separately (multi-user-class assignment).

### 4.1.3 Changing flow speed

Decreasing traffic speed, with the aim to reduce noise emissions, can be achieved in a number of ways. Speed reduction is possible by reducing speed limits, by stricter enforcement of the speed limit, by introducing ISA (intelligent speed adaptation) systems or by placing slow-down measures and speed ramps. Since the change in speed distributions will be important when applying one of these measures, a micro-simulation model is best suited for this analysis. One has to keep in mind however that accurate modelling of speed is still a problem (see Section 3.5). In case of using traffic calming measures by means of obstacles, acceleration and deceleration data is needed as well, which can only by given by micro-simulation models. Side-effects of speed reduction (e.g. due to lower speed limits) are related to rerouting of traffic. A macroscopic traffic model is best suited to study whether this side-effect is of importance for overall noise exposure.

### 4.1.4 Making traffic less dynamic

As was the case for measures aiming at speed reduction, micro-simulation models are needed to assess measures aiming at making traffic less dynamic. A roundabout is known (in most situations) to make traffic less dynamic than e.g. a crossing with traffic lights. Phased traffic light systems (green waves) limit the number of cars accelerating and decelerating. Strict enforcement of speed limits is known to be positive in this respect as well (and make speed distributions narrower). Benefits can further be obtained from adapting intersections and by changing the geometry of roads (e.g. narrower lanes), although effects of these types of measures are difficult to model.

# 5 Conclusions and recommendations

## 5.1 Conclusions

The needed accuracy of individual traffic parameters can serve as a first estimate to obtain the desired accuracy in noise mapping. In practice, one is however faced with a combination of these parameters. These can counteract or strengthen each other. Therefore, Monte Carlo Simulations (MCS) were performed to combine uncertainties from individual macroscopic traffic parameters (vehicle speed, vehicles flows and traffic composition) to the overall uncertainty in noise emission. From the MCS analysis it was found that the relative error on mean speed, which is allowed to achieve a predefined accuracy in noise maps, decreases significantly with vehicle speed. The absolute error stays more or less the same, and is near 10 km/h to achieve 1-dBA accuracy; this conclusion could be drawn from both the individual and combined error analysis. The needed accuracy for traffic intensity is rather insensitive to changes in the mean speed, and to the present traffic intensity itself. The allowed error on speed and traffic intensity also depends on the prevailing % heavy good vehicles. It can be concluded that the accuracy demands depend on the magnitude of the parameters, and simple criteria on individual traffic parameters are therefore often not suited. In this report, an overview is given of the allowed inaccuracies of some traffic parameters to achieve an overall accuracy goal of 0.5 dBA and 1 dBA.

The importance of micro-simulation traffic parameters such as acceleration/deceleration and vehicle speed distribution was assessed as well, in a realistic situation (immission, including complex propagation of sound). Similarly to the MCS, speed distribution on the major roads (with higher mean speeds) was found to be important. Neglecting acceleration and deceleration data results (mostly) in an underestimation of the equivalent sound pressure levels, not only near intersections but also at a distance from them, certainly when saturation starts to occur. Confidence on the combination of the (tuned) micro-simulation model of the study area and the emission model is obtained by performing emission measurements in the study area. Reasonable agreement was found between these measurements and simulations with the HARMONOISE emission model, fed with traffic parameters provided by the micro-simulation traffic model. The accuracy of the emitted acoustical energy increases with increasing vehicle velocity. Higher emission levels are better predicted than lower levels.

On a temporal scale, the need for detailed traffic intensity data is not very stringent, certainly when looking at $L_{den}$ values over longer periods. This holds both on the emission side and the immission side, combined with (temporal) propagation conditions. The variation in speed distribution data over time on the other hand seemed more important.

It is known from literature and experiences that accurate speed data is hard to get from traffic models, certainly when using macroscopic models. Accurate speed data and speed distribution data were shown to be important. Calibration and sensitivity analysis will therefore often be important in practice. *This issue will be discussed in detail in task 2.4 of the IMAGINE project on additional data collection.*

The problem of intersection modelling was treated in detail. In literature, corrections were found between 1 and 4 dBA for equivalent sound pressure levels, relative to ignoring intersections. The local errors by neglecting acceleration and deceleration data in the study area lie within this interval. A methodology has been applied to a case study in order to derive correction factors for different types of intersections when using macroscopic traffic models that neglect intersections. Based on the above findings, a spatial approach seemed most appropriate. Meaningful relationships between traffic flow parameters and noise corrections are obtained by means of regression analysis.

Heavy motor vehicles make more noise than light motor vehicles, and will dominate the noise climate when their share is large. They also influence the accuracy needed for other traffic parameters, as was shown by the MCS. A decent estimate of the share of heavy traffic is therefore important. In Section 3.2, some guidelines are provided in this respect.

Low flow roads should be taken into account, depending on the prevailing sound pressure levels. It is e.g. not necessary to model a low intensity road in the neighbourhood of a large road that dominates the noise climate. Estimating traffic parameters on low flow roads suffers from the fact that origin and destination matrices are always aggregated in a spatial area of a certain size in traffic models. A general methodology to extract traffic parameters on these roads is hard to assess. Some examples of current practice are given in Section 3.4.

It was shown by some examples that traffic measures to decrease noise emissions (action plans) are often very complex. Side-effects are important, and the traffic model that is used must also account for these. In general, (multi-modal) macroscopic traffic models are suited to investigate measures aiming at the reduction of traffic intensity. To investigate speed reducing measures and measures to make traffic less dynamic, micro-simulation models are needed.

As a general conclusion, it can be stated that traffic intensity, traffic speed and traffic composition on the major roads seemed to be of primary importance for strategic noise mapping purposes for major roads. For noise mapping of urban roads, the use of acceleration and deceleration data, in addition of the firstly mentioned traffic parameters, leads to further improvements in the accuracy of the noise map. Correction factors can be used in case the traffic model is not capable to provide this data. The importance of low flow roads in urban context depends on the required accuracy at lower exposure levels. Further improvements in the accuracy of noise mapping of both major and urban roads may come from including speed distribution, and from accounting for long term (or diurnal) variations in flow patterns.

## 5.2 Recommendations

Recommendations are structured around three types of applications of noise mapping: strategic noise mapping for main roads, urban noise mapping, and analyses of action plans. In accordance with the report of task 2.2 four categories of traffic models are distinguished [8]. The four categories are:

- Static assignment models
- Dynamic assignment models
- Continuum models
- Micro-simulation models

We also distinguish between using output of existing traffic models usually constructed to assess a traffic problem and traffic models optimised with noise mapping in mind.

***Strategic noise mapping for main roads***

All types of traffic models can be used to produce useful input for strategic noise mapping for main roads. Additional efforts should be spent to check accuracy and improve if necessary on the following aspects (in order of importance):

1. **Traffic speed:** For static or dynamic models, the model speed should be checked against measurements. A model aimed at traffic studies may not be accurate enough for noise modelling in this respect. If the model can be refined, at least a different road segment should be introduced for every section where different speed limits apply. The speed-flow curve may have to be improved. If no effort can be made for improving the model, measured speed distributions at a number of typical locations (characterised by traffic flow and road capacity) are a very suitable solution. In mountainous areas the speed reduction (in particular of trucks) due to long slopes should be included. Continuum models and micro-simulation models will usually produce speed distributions that are accurate enough and are readily applicable.
2. **Traffic composition:** Fleet composition has an influence on noise emission and may differ between countries. This is studied in WP5. The traffic model should however produce the traffic intensity of different vehicle categories (cars, light and heavy trucks, two-wheelers). For existing traffic models, it is acceptable to estimate the percentage of heavy vehicles in accordance with guidelines such as the Good Practice Guide.
   Traffic models specially constructed for noise mapping should use multi user class (MUC) assignment including at least two categories of vehicles (cars and trucks). Even if MUC demand matrices are rough estimates this can still have the additional benefit to improve vehicle speed estimates.
3. **Diurnal and long-time pattern:** Existing traffic models of every type quite often will be limited to calculating peak hour, 16h or 24h traffic intensities for week days. For calculating high exposure levels in a strategic noise mapping effort, it will in general be sufficient to assume a fixed diurnal distribution for all roads, all seasons, and all days of the week. If such statistics are not available from counting stations or local guidelines, the GPG values may be used.
   Traffic models specially constructed for noise mapping should from the start aim at including day and night traffic separately. If additional effort is possible, it should first be spent on distinguishing between week day and weekend, then on getting hourly traffic data. If there is a particular interest in exposure at longer distances (>200m) from the road, it would make sense to consider hourly data only if meteorological influence on propagation is considered in detail as well.

***Strategic noise mapping for urban area***

The guidelines given in this section apply to non-main roads (END definition) in urban area. If such roads cross the study area, the guidelines above should be applied for them.

1. **Traffic speed (mean and distribution):** For static or dynamic models, the model speed should be checked against measurements. A model aimed at traffic studies may not be accurate enough for noise modelling in this respect. If the model can be refined, at least a different road segment should be introduced for every section where different speed limits apply. If no effort can be made for improving the model, measured speed distributions at a large number of typical locations (characterised by road type and direct

road environment) may be helpful. Continuum models and micro-simulation models will usually produce speed distributions. The distribution should be checked against measurements of vehicle speed or noise measurements.

2. **Acceleration/deceleration and intersections:** Only micro-simulation models allow modelling the specific dynamics of vehicles near intersections. If these models exist, the results obtained near intersections should still be handled with care since they depend on a number of model parameters. For other types of traffic models, corrections near intersections such as the ones presented in this report may be used. They required knowledge of the additional delay introduced by the intersection. Traffic models specially introduced for noise mapping should treat this intersection delay explicitly for every intersection.
3. **Low flow roads:** Low flow roads are only important if there is an interest in producing accurate exposure results for low exposure levels (e.g. if accuracy is required down to 60 dB(A) in urban context, roads with as low as 100 vehicles/hour should be included). Existing traffic models will hardly ever produce traffic data for the very low flow roads. Assign surface traffic within demand nodes to estimate the traffic intensity on these roads.

   Even if traffic models are specially constructed for noise mapping, it will hardly ever be possible to include low flow roads because demand data are scarce for these urban roads. If (micro) traffic models do produce data on low flow roads, traffic speed should carefully be checked because factors that are in general not modelled in traffic models may influence traffic speed on these low flow roads.
4. **Traffic composition:** Fleet composition may differ in cities for different reasons. Due to air pollution restrictions, city government may stimulate the use of (near) zero emission passenger vehicles. The truck fleet may also differ significantly from the countrywide average. It is unlikely that demand matrices for trucks are available in urban areas. It can however be expected that the percentage of (heavy) trucks is very low, except near industrial estates and shopping areas. Public transport (busses) may be significant. If not included in the traffic model, detailed data on the fixed routes and the intensity can be obtained and added. .

   If a continuum traffic model or a micro-simulation model is specially constructed to produce the noise map, it is suggested to add public transport to the model in order to improve simulated speed distribution.
5. **Diurnal and long-term patterns:** Existing traffic models will rarely produce hourly traffic intensities. It is likely to be sufficient to supplement the traffic model output with typical diurnal patterns for a typical day in the city under study, to obtain noise maps with the required accuracy.

   If a traffic model is constructed specifically for noise mapping, using hourly demand matrices is advisable to cover unexpected local flow patterns. Micro-simulation models and continuum models that include calculations of speed distribution may benefit additionally from hourly input parameters through their influence on traffic speed..

### *Action planning*

The use of traffic models in noise action planning differs considerable between the actions that one has in mind. The focus is on the accuracy in predicting the foreseen change rather than on the accuracy on itself.

1. **Make sure the traffic model produces the parameters and all side effects that you expect to change as a result of your action.**

2. **Make sure the relation between input and output of the model that is critical for the planned action is validated and not only the traffic model outcome.**.

A few examples illustrate these guidelines:

- For predicting the effect of flow reduction actions, include low flow roads that could become alternative routes.
- For predicting the effect of flow reduction or reduction of the amount of heavy traffic on nearly saturated roads, use a traffic model with accurate traffic speed modelling.
- For predicting the effect of reducing the allowed driving speed, use a model that produces speed distributions in order to allow estimating the effect of side measures to enforce speed limits.

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## A.1 Vehicle sound power vs Road segment sound power

In this appendix we want to caution the reader concerning the fundamental difference between the sound power emitted by a single vehicle $L_{Wi}$ and the average sound power produced by all vehicles within a given road segment $L_{Ws}$ and how they relate to $L_{den}$ in the neighbourhood of the road.
The source model for road vehicles that Harmonoise WP2 derived and IMAGINE WP5 refines, gives $L_{Wi}$ for different categories of road vehicles as a function of vehicle speed, acceleration and slope of the road. The contribution of a vehicle passing by to the $L_{den}$ at a location near the road depends on the sound power level $L_{Wi}$ and the distance $d_i$ to the vehicle. The latter changes as a function of time due to the velocity $v_i$ of the vehicle. This is shown in Figure 46.
If some simplifications are made with regard to the vehicle path, an analytical formula can be derived. Assuming that the vehicle moves on a straight road at distance d from the observer and the total pass by of the vehicle falls within the time period of concern T for calculating the $L_{Aeq}$ (and eventually the $L_{den}$) and that ground reflection, air absorption and other propagation effects can be neglected, than

$$L_{Aeq,i} = L_{Wi} + 10\log\left(\frac{1}{4\pi T}\int_{-\infty}^{+\infty}\frac{1}{d^2 + (v_i t)^2}dt\right) = L_{Wi} - 10\log\left(\frac{Tv_i d}{4}\right).$$

This approximate formula reflects a dependence on the distance to the road corresponding to that of a line source, as expected. On top of this an additional dependence on vehicle speed is introduced. It partly compensates the increase of $L_{Wi}$ with $v_i$ (see Figure 46). Note that this formula does not give realistic results as $v_i$ approaches zero because the hypotheses that the vehicle passes by within the time frame T no longer holds. Also note that the average of contributions $L_{Aeq,I}$ of vehicles passing by at different speeds does not correspond to the contribution of the same number of vehicles passing at the average speed. Hence the need to take into account speed distribution for accurate simulations of $L_{den}$.

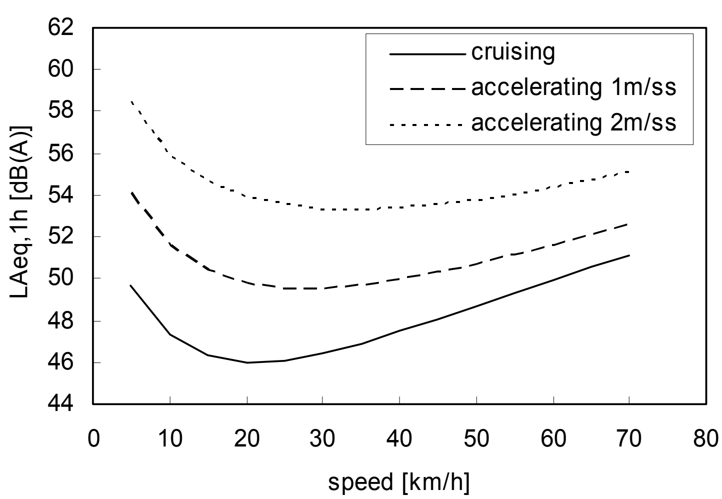


**Figure 46. Equivalent sound pressure level in relation to the speed, for the pass-by of a single vehicle, at 1 m from the road**

For practical noise mapping one very seldom traces individual vehicles. Instead, the sound power emitted by all vehicles in a given road segment during the observation time is added to obtain the total sound power level emitted by the road segment s

$$L_{Ws} = 10\log\left(\sum_i \frac{\ell_s}{v_i T} 10^{L_{Wi}/10}\right),$$

where $\ell_s$ is the length of the segment and thus $\ell_s/v_i$ is the time spend by the vehicle in the road segment. The contribution of each road segment to the overall $L_{Aeq}$ can now be calculated using a propagation model for the fixed source. This calculation no longer depends on vehicle speed. This line of reasoning thus leads to exactly the same conclusions on dependence on vehicle speed, but it is not limited anymore by the hypothesis that the vehicle follows a straight path.

## A.2 Example results from MCS in Section 2.2.1

In this appendix, some samples of the MCS results, based on the urban motorway scenario (mean flow of 1000veh/h/lane, mean speed of 105 km/h) are shown. Axes have been labelled with the abbreviations '%U(F)' for 'Percentage uncertainty in flow' and '%U(S)' for 'Percentage uncertainty in speed'. The red surface in the figures represents the results obtained when assuming that the flow is 100% Category 1 vehicles, whilst the blue surface represents the results obtained when assuming 80% Category 1 and 20% Category 3 vehicles.

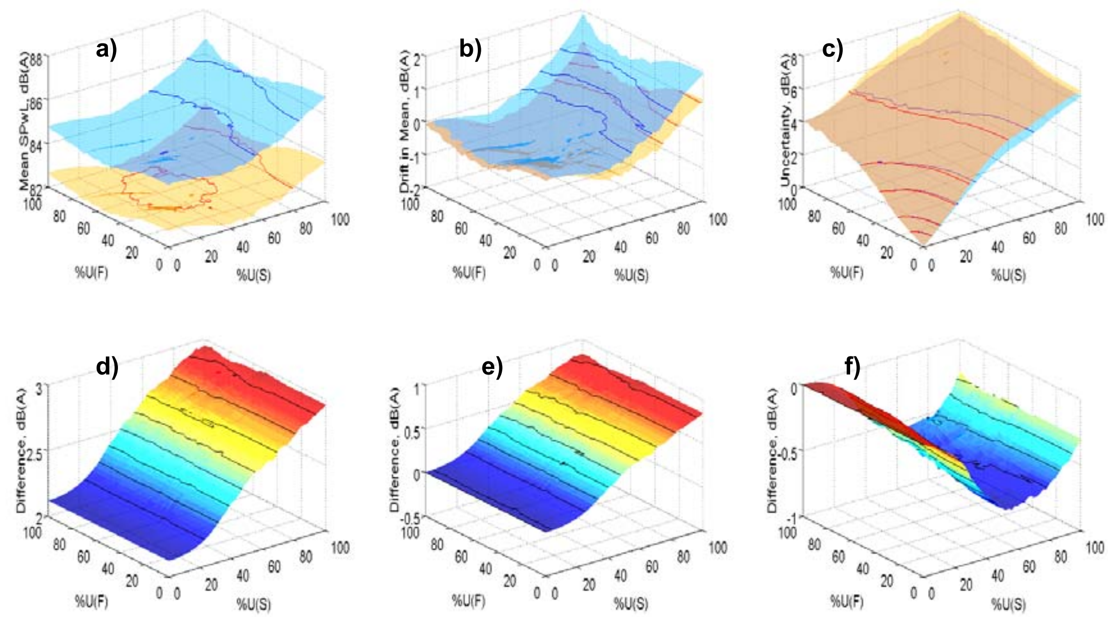


**Figure 47. MCS results for mean sound power level (a), drift in mean sound power level (b) and standard uncertainty (c), for Harmonoise Source X, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h, Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles calculated as fixed percentages of overall flow. Figures d-f : plot the differences between the surfaces in figures a-c.**

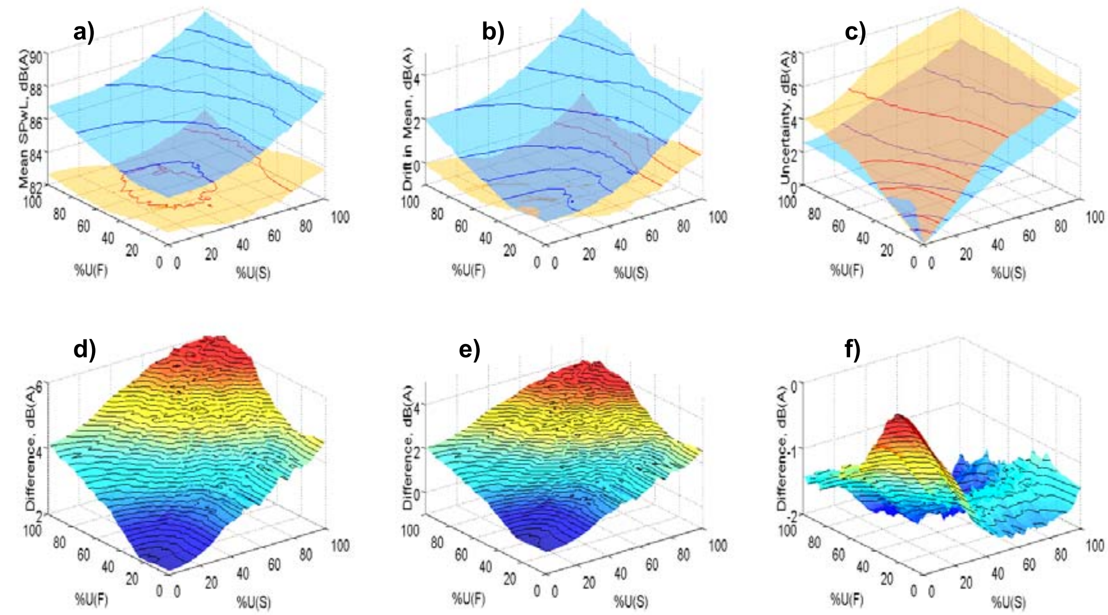


**Figure 48. MCS results for mean sound power level (a), drift in mean sound power level (b) and standard uncertainty (c), for Harmonoise Source 1, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h, Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles sampled from truncated normal distribution. Figures d-f: Plot the differences between the surfaces in figures a-c above.**

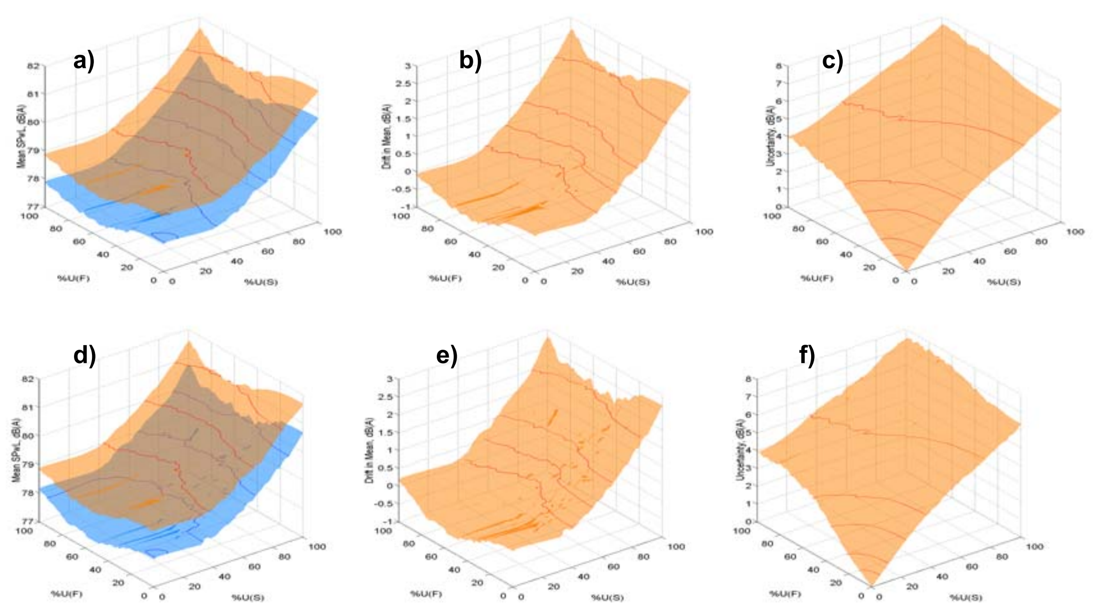


**Figure 49. MCS results for mean sound power level (a and d), drift in mean sound power level (b and e) and standard uncertainty (c and f), for Harmonoise Source 2, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h.**
**Figs (a-c) Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles calculated as fixed percentages of overall flow.**
**Figs (d-f) Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles sampled from truncated normal distribution.**

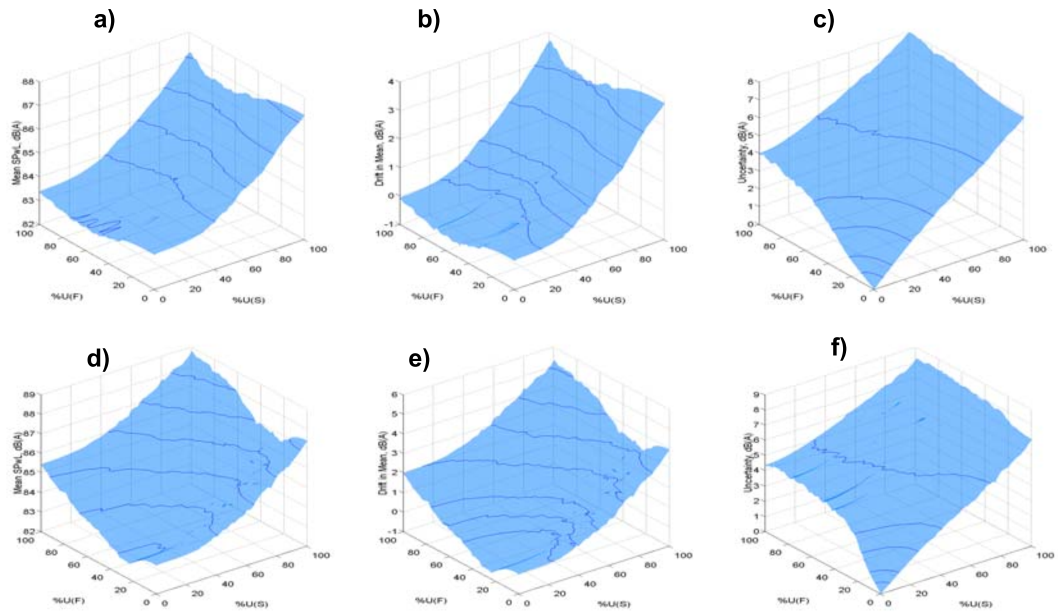


**Figure 50. MCS results for mean sound power level (a and d), drift in mean sound power level (b and e) and standard uncertainty (c and f), for Harmonoise Source 3, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h.**
**Figs (a-c) Blue surface 80% Class 1, 20% Class 3 vehicles calculated as fixed percentages of overall flow.**
**Figs (d-f) Blue surface 80% Class 1, 20% Class 3 vehicles sampled from truncated normal distribution.**

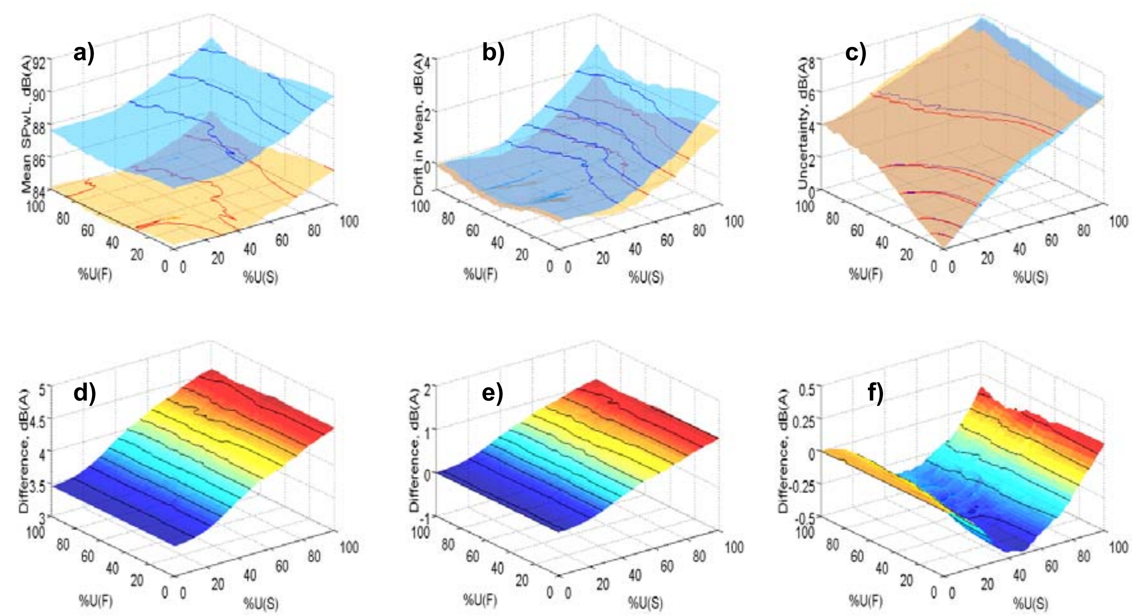


**Figure 51. MCS results for mean sound power level (a), drift in mean sound power level (b) and standard uncertainty (c), for all Harmonoise Sources combined, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h, Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles calculated as a fixed percentage of overall flow. Figures d-f: Plot the differences between the surfaces in figures a-c above.**

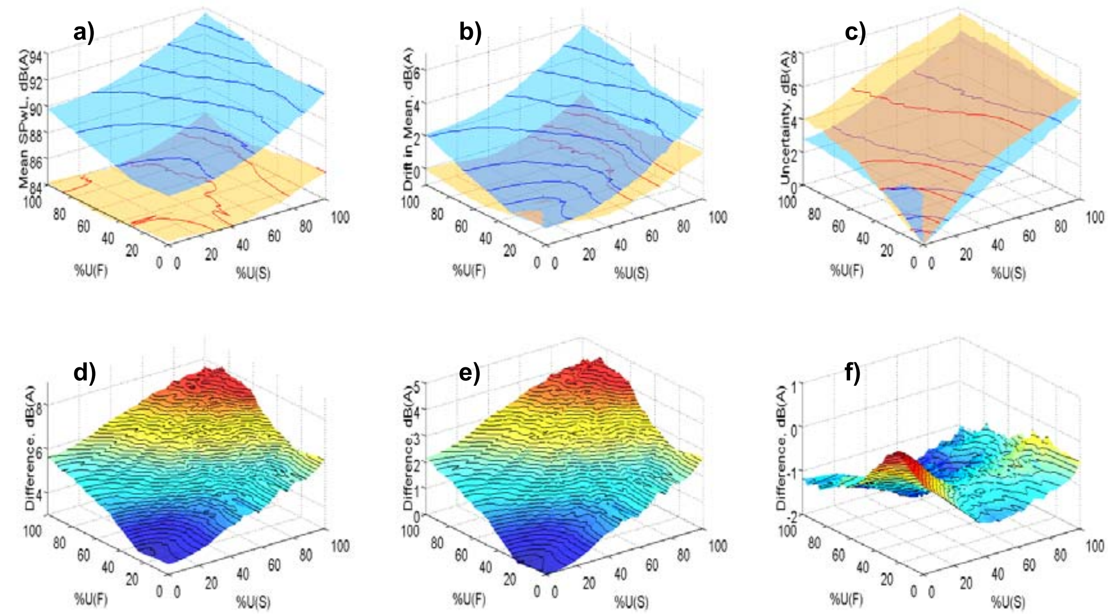


**Figure 52. MCS results for mean sound power level (a), drift in mean sound power level (b) and standard uncertainty (c), for all Harmonoise Sources combined, based on a mean flow of 1000veh/h/lane at a mean speed of 105km/h, Red surface: 100% Class 1 vehicles, Blue surface 80% Class 1, 20% Class 3 vehicles sampled from truncated normal distribution. Figures d-f: Plot the differences between the surfaces in figures a-c above.**

## A.3 Report of WP 2.3 Workshop in Budapest

***Presentations***

| | | | |
|---|---|---|---|
| 1 | The Environmental Noise Directive, WG-AEN, and IMAGINE | J. Hinton | Birmingham City Council, UK |
| 2 | What do noise mappers want from traffic models? | D. Botteldooren | INTEC, Ghent University, Belgium |
| 3 | Everything you ever wanted to know about traffic modelling | I. Wilmink | TNO, The Netherlands |
| 4 | How can we tune static and dynamic assignment models to meet noise mappers needs? | I. Wilmink | TNO, The Netherlands |
| 5 | How can (micro-) simulation be used in a noise mapping and action planning? | F. Van Hove | Transport & Mobility Leuven, Belgium |
| 6a | Examples, Case studies, Opinions : open forum | J. Hinton | Birmingham City Council, UK |
| 6b | | C. Popp | Lärmkontor GmbH, Germany |
| 6c | | H. Van Leeuwen | DGMR Consultants, The Netherlands |

***Overview of comments/discussions per subject***

- Low intensity roads
    - When traffic counts indicate less than 1000 vehicles/day or in case of no data: use 1000 vehicles/day because of the precaution principle. Assigning zero-values creates non-existing quiet areas.
    - Good Practice Guide : values lower than 1000 veh./day are mentioned, minimum is 100 veh./day. All small roads must be mapped (e.g. $L_{den}$=55 dB is possible on small roads)
    - It was questioned on the other hand whether 1000 veh./day must be modelled, since no annoyance is expected from these roads.
- Standard measurement height in noise mapping
    - equals 4 m
    - sound pressure levels at other heights should be considered, certainly in case of the sound maps in the build-up environment (high-rise buildings). Façades at low heights are often screened. The levels at 4 m are therefore often not representative for higher receivers.
    - calculations at all floors should be demanded in new European noise directives
- Availability of input for traffic data
    - usually very poor
        - examples are given from cities like Budapest, Bucharest, Gdansk, Krakau where the most detailed data consists in tables or estimates of traffic data in classes.
    - It will be quite a challenge to have traffic densities and traffic compositions by 2012 in all member states.
- Two-wheelers

    - sound emission is usually just below the EC limits (noisy vehicles seem to be attractive for persons buying two-wheelers).
    - contribute largely to the noise annoyance, certainly in southern European countries
    - should be included in noise maps where possible
- $L_{den}$ vs noise annoyance
    - noise maps vs laymen
        - noise maps often conflict with people's expectations
        - people are usually annoyed by individual events
        - people's expectations must be "managed" (strategic noise mapping)
    - $L_{den}$ is chosen on European level for
        - reporting reasons
        - to make easy comparison between different countries
        - there exist dose/response information as regards annoyance
        - locate problem areas
    - Other noise indicators often more appropriate for modelling noise annoyance like $L_{95}$
    - Noise annoyance should be treated on a local scale (surveys are often needed); $L_{den}$ is usually not sufficient to reduce annoyance.
- Needed accuracy
    - concept "strategic noise mapping" is important.
    - The needed accuracy in terms of "level difference" should be audible.
    - less accurate noise maps are (e.g. with errors > 3 dB) no problem as long as the problem areas are identified.
- Influence of navigation tools
    - can be important for noise mapping (e.g. choosing alternative routes to avoid traffic jams)
    - not/nearly present in current traffic models

***List of participants***

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| 9 | Ingrid Luneet | Health Protection Service of Tallinn | Estonia |
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| 17 | Dietrich Kuehner | deBAKOM | Germany |
| 18 | Christian Popp | Laermkontor | Germany |

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| 22 | Mihaly Berndt | Enviroplus Kft | Hungary |
| 23 | Haidu Sandor | KTI (Institute for transport sciences) | Hungary |
| 24 | Maria Cseffalvary | KTI (Institute for transport sciences) | Hungary |
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| 41 | Itzar Aspuru | Labein | Spain |
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| 43 | Jens Forssen | Applied Acoustics, Chalmers | Sweden |
| 44 | Henk Schuurman | AVV | The Netherlands |
| 45 | Hans van Leeuwen | DGMR Consultants | The Netherlands |
| 46 | Paul De vos | DHV Environment and transportation | The Netherlands |
| 47 | Chiel Roovers | M+P | The Netherlands |
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| 51 | Roy Lawrence | cmms? | United Kingdom |
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