CHAPTER ONE

THE PREDICTION OF ROAD TRAFFIC NOISE

1.1 INTRODUCTION

This thesis presents the culmination of almost six years work into the field of road traffic noise. The author undertook the work at both the University of Nottingham and the University of Leeds, during the period between Autumn 1995 and late Summer 2001. The bulk of the thesis is occupied with the development of a micro-simulation traffic model called TUNE (Traffic – Urban Noise Evaluator), which can predict noise levels in simple urban environments, using a wide variety of parameters.

The problems of noise annoyance have long been researched. State governments and local authorities across the European Union have recognised the need (CEC, 1996) to:

- assess the noise levels produced by transport systems.
- calculate the effect of legislative changes on noise levels.
- calculate the population numbers affected by any changes in noise level caused by the development of new, or upgrades of existing, transport and highway schemes.
- provide new assessment tools, management tools and methods of feedback to the general public. Such methods may require the use of noise mapping techniques.
- develop new noise parameters for assessment criteria, or enable near real-time noise prediction and assessment, for pro-active traffic management.

The spatial and temporal mapping of noise levels requires a large number of noise measurements be undertaken, at a variety of sites, on a regular basis. The cost of directly measuring such a number of noise levels is prohibitively
expensive. Therefore other solutions, such as appropriate prediction methods, must be found. These methods must be able to handle confounding affects on noise, such as buildings, barriers and vegetation. Most member states in the European Union have their own approved methods of predicting road traffic noise, and accounting for topographical effects (SoundPlan, 1996).

However, the accuracy of such prediction methods needs to be constantly reviewed in the light of shifting legislation to limit vehicle noise at its source. Some standard methods are based on empirical data, derived from observations of mainly free-flow traffic, collected a considerable time before the present. Such methods therefore, require revision for them to be appropriate for predicting noise in the urban environment, especially where congested or interrupted flows are more prevalent. The current UK standard, 'The Calculation of Road Traffic Noise' (DoT, 1988), is one such method where assumptions have to be made, when applied to urban traffic flows.

Another way of predicting urban traffic noise is through micro-simulation modelling. In a micro-simulation model, the passage of individual vehicles through a network is described in much detail, using a large range of vehicle parameters. This range of parameters allows detailed noise models to be constructed. However, such in depth modelling requires extensive input of vehicle, network, signal and flow data. The performance of a micro-simulation model will be governed by the algorithms used to control such features as vehicle arrival, car-following, gap-acceptance and interaction with traffic signals.

Modern UTC (Urban Traffic Control) systems, used by local authorities to manage traffic within city limits, collect and generate a vast amount of data on network flows, speeds and signal timings. Most of this data is simply discarded, but it is increasingly recognised that such data could provide a more integrated way of assessing the effects of traffic management decisions on urban pollution. Applications have already been successfully developed to use the output data from UTC systems, for the purposes of network simulation, or the assessment of air quality levels (Bell and Hodges, 1999). It would therefore be of benefit if a method of noise prediction could also be integrated with these systems.
The management of traffic to pro-actively ameliorate noise or pollution levels, requires integration of UTC data and the chosen prediction method. The near real-time prediction of noise levels for large areas may be required also.

It was against this background, that the work reported in this thesis, was undertaken.

1.2 SPECIFICATION OF WORK

The work in this thesis is intended to investigate the problems of predicting road traffic noise in urban areas, and to produce a model capable of overcoming those problems.

The modelling of noise in urban areas requires that the following fundamental problems be addressed:

1. The composition and volume of urban traffic flows;
2. The interrupted nature of urban traffic flows, due to congestion or selected traffic management measures;
3. The presence of topographical features found in the urban environment, such as buildings or barriers.

Also, it was considered desirable from the outset of the work that any model would:

1. Use data available as a by-product of the traffic control system SCOOT (Split, Cycle, Offset Optimisation Technique) commonly used within the UK as a source of input, in order to provide a degree of automation in the entry of real traffic parameters, and actual on-street flows;
2. Use data from SCOOT messages to allow actual signal timings input to the model;
3. In the absence of SCOOT data, allow the use of varying flow profiles, turning movements and signal data, in order to reproduce the daily variation in noise levels required for standard assessment criteria;
4. Provide the basis for the assessment of individual traffic schemes, traffic management measures or changes in vehicle source noise through legislation;

5. Output a number of noise parameters, in order to fulfil the individual requirements of EU member states, to allow comparisons to be made between parameters and to be sufficiently flexible to allow for the use of different parameters in future noise assessments;

6. Provide a method of creating noise contour maps for planning or dissemination purposes.

The solution of the above problems, has been achieved by:

1. Identifying a number of approaches to the prediction of road traffic noise;
2. Assessing the suitability of the data available from the SCOOT system as input to the identified noise models;
3. Investigating the format of models that have previously used SCOOT data;
4. Selecting an appropriate model format - that of traffic microsimulation;
5. Thoroughly investigating the components required to construct a comprehensive micro-simulation model able to predict noise in urban areas;
6. Exploring the behaviour of the traffic and vehicle generation models;
7. Carrying out sensitivity tests on the predicted noise levels to source noise algorithms, traffic parameters and network parameters;
8. Collecting and analysing on-street noise data from a number of sites, in several UK cities and towns. This was done in order to provide a data set for model comparison, calibration and validation;
9. Testing the simulation model by comparison with identified empirical noise models and measured noise data;
10. Calibrating both the SCOOT-based traffic and noise components of the simulation model against observed traffic and noise data, for a selected site.
1.3 THESIS STRUCTURE

This thesis has been structured into a number of chapters, broadly following the steps outlined above. The content of each chapter is outlined briefly below:

Chapter Two details the scale of the transport noise problem facing the European Union, and the implications for noise prediction requirements raised by the European Commission document, ‘Future Noise Policy’ (CEC, 1996) are discussed. A general look is taken at traffic noise legislation, expected and recommended noise levels and the general requirements for noise prediction.

Chapter Three introduces the concept of UTC (Urban Traffic Control) systems and examines the wealth of data available from such systems that, currently, may go unused. The TRANSYT (TRAffic Network Study Tool) (Robertson, 1969) and SCOOT (Hunt, Robertson, Bretherton and Winton, 1981) systems of achieving UTC are described briefly. The reasons for the choice of SCOOT for the work in this thesis are outlined. The remainder of the chapter concentrates on the data messages available from SCOOT, and identifies models that have previously used SCOOT data. The formats of those models are discussed, before conclusions are drawn as to why a micro-simulation model using SCOOT occupancy data is most appropriate.

Chapter Four deals with the specification of the micro-simulation model to enable SCOOT data to be used. Four program modules for data processing, traffic modelling, noise assignment and data output are described. The data processing module that allows the use of SCOOT messages is examined in depth. Also, this chapter examines the use of appropriate SCOOT messages to generate signal timings needed by the proposed model.

Chapter Five deals with all aspects of vehicle kinematics and driver behaviour in the proposed model. These include the specification of appropriate algorithms for car-following, acceleration rates, brake reaction times, amber reaction times, gap acceptance parameters and vehicle turning speeds. Vehicle interactions with
traffic signals are examined. The traffic model is examined in a number of simple scenarios to assess its performance in the light of previous research.

Chapter Six looks at the generation of vehicle parameters for the micro-simulation model. This chapter concentrates particularly on those parameters that may be generated either through the use of a random number sequence or through the use of SCOOT data.

Chapter Seven looks at the noise sources of a vehicle, and reviews previous research on vehicle source levels. Appropriate source noise algorithms are identified for the micro-simulation model. A critique of the information presented tries to draw conclusions in respect to trends in vehicle source noise levels.

Chapter Eight examines the factors affecting the propagation of sound from a vehicle location to a receiver point. The implications of assuming that a vehicle is a point source and the method of summing individual noise levels, taking into account propagation of sound over differing ground types are discussed. Three methods of sound propagation are described, these being direct propagation, propagation via reflection and propagation via diffraction. Some advice is drawn from previous research on the correct positioning and allocation of background noise levels to receptor locations. Finally the excluded propagation factors are described.

Chapter Nine examines the manual input required to set up the TUNE Model. An example is given of the construction of a simple scenario. Various approaches to modelling the scenario are discussed, to highlight their potential impact on predicted noise levels. Issues relating to the turning movements of vehicles are addressed also.

Chapter Ten looks at the sensitivity of the noise parameters, generated by the selected source noise algorithms implemented in the TUNE model to: the number of simulation runs, distributions applied to source noise levels, traffic
flow parameters, various receiver locations and signal timings at a sample junction.

Chapter Eleven assesses the performance of predictions from the initial TUNE model against noise data collected on-site. A number of changes to the basic source noise algorithms are applied, in an attempt to address shortcomings in the model performance. Conclusions are drawn regarding the relative performance of each of the source noise algorithms. The TUNE model predictions and on-site measurements are compared to the predictions from the current UK CRTN (DoT, 1988) methodology.

Chapter Twelve looks at the simultaneous collection of SCOOT data, alongside video recording and noise measurement, to provide a data set for the calibration of the TUNE model. The recorded data is analysed to assess model performance in flow generation, classifying vehicle types, predicting link speeds, modelling downstream queue lengths and predicting noise levels. The performance of a number of test scenarios is examined. Also included in this chapter is an examination of the suitability of using the model to provide noise maps.

Finally, Chapter Thirteen summarises the achievements, conclusions and major findings of this thesis and makes recommendations for model improvements. The final section of the thesis suggests a number of avenues for future research.

The appendices to the main thesis include:

- A user-guide to the current version of the TUNE model (Version 1.80 – compiled on 5th September 2001). Several sample TUNE input and output files are included in the user guide (Appendix A).
- The derivation of the CARSIM car-following algorithms, safe vehicle speed and free acceleration/deceleration models (Appendix B).
- Sample survey data sheets (Appendix C).
- Listings for a number of macro programs used during the course of the thesis (Appendix D).
- Descriptions of the Sound Level Meters used (Appendix E).
CHAPTER TWO

ROAD TRAFFIC NOISE – AN OVERVIEW

2.1 INTRODUCTION


The forms of legislation that may be introduced to remedy excessive road traffic noise levels are discussed briefly. Monitoring the noise problem, examining the effects of legislation for noise abatement and assessing the impacts of new road schemes all have the general requirement that noise levels need to be accurately measured or predicted. Given the scale and expense of undertaking the former, the latter is of more benefit.

An introduction is made to the units and parameters used to assess noise levels. The traffic, topographical and meteorological factors that affect noise levels in the urban environment are then introduced. Three traditional methods of modelling traffic noise levels are discussed, and the strengths and weaknesses of each are highlighted.

2.2 TRANSPORT NOISE – A European overview

The noise generated by transport has long been recognised as having a major impact on the environment, as outlined by The Wilson Committee report on noise problems in UK cities in the 1960s (HMSO, 1963). Noise affects both transport users and non-users alike, causing annoyance, stress, and disturbance to
sleep. Indirectly the effects of noise exposure may cause long-term hearing loss or cardiovascular and psychophysiological problems (CEC, 1996).

A certain degree of noise has always been accepted as part of modern life. However, the rapid growth of transport over the past decades, especially on highways, has exposed more people to noise than ever before (OECD, 1991). It has been estimated that between 17% and 22% of the European Union’s (EU) population, or approximately 80 million people, are exposed to unacceptable transport noise daily, with $L_{Aeq}$ (see Section 2.2.2) noise levels greater than 65dB(A). A further 170 million are exposed to $L_{Aeq}$ levels that could cause annoyance, of between 55 and 65 dB(A) (CEC, 1996). Estimates of the cost of noise, in terms of abatement or prevention, through work lost and medical costs, and in devaluation of property, range from between 0.2% and 2% of GDP. Even the lower estimate yields a total cost of 12 billion Euro across the European Union (CEC, 1996). Early surveys in London showed “that at 80% of the sites measured, traffic produced a higher level of noise than any other source” (GLC, 1996). More recent surveys show that traffic noise accounts for approximately 90% of population exposure to noise in the EU (CEC, 1996).

The growing exposure of people to road traffic noise, plus the greater concentration in the media on environmental issues, has increased public awareness of the problem, and raised public expectations for better, more pleasant living and working conditions (Shearn, Wood and Bowen, 1997). It has been recognised that the situation must change. How such changes can be made is discussed in the next section.

### 2.2.1 Changing the noise climate – ‘Future Noise Policy’

The way to change the noise climate lies through legislation. The European Commission has recently published its ‘Future Noise Policy’ document (CEC, 1996). This document provides the guidelines for future noise legislation within the European Union.

Currently legislation on noise throughout the Union is adopted in each member state, in a rather piecemeal fashion, after the European Commission has issued a
directive. There is a requirement for member states to adopt the content of the directive in the relevant context of their legislation. Generally, there are three possible areas in which legislation can improve the noise climate. These may be summarised as follows:

1. The control of noise emissions at the source, through the type approval scheme for new vehicles, annual roadworthiness tests for current vehicles or regulation of vehicle flows on the road. Examples of the latter include speed limits, the banning of certain vehicles from particular areas, strict loading and unloading periods for heavy goods vehicles etc.

2. Regulations in the planning of new road schemes, the alteration of current road schemes and in land use planning. There is a general requirement for abatement measures to be provided, if road schemes are expected to adversely effect the noise climate, by causing levels to exceed threshold values. Such abatement measures may include the placement of acoustic screens between the scheme and the public, the insulation of affected buildings from noise or the use of different road surfaces.

3. Regulation in the design, construction and operation of buildings, to ensure adequate insulation from noise.

‘Future Noise Policy’ (CEC, 1996) suggests that there is a need for more harmonisation between EU member states, on the assessment of noise. Any assessment of the effect of legislation on vehicle emissions and land use regulations, or on the impact assessment of proposed schemes, requires that accurate, standardised methods of measuring and predicting road traffic noise exist.

Currently, almost every EU member state possesses its own recommended system for assessing noise. For example the United Kingdom uses ‘The Calculation of Road Traffic Noise’ (DoT, 1988), Germany uses the RLS 90 Guidelines (Bundesminister für Verkehr, 1990), the Scandinavian Countries use the Nordic Method (TemaNord, 1996). Countries may also base their assessment criteria on different noise parameters, with the use of the $L_{A10}$ parameter being favoured in the UK, over the mainland European standard of the $L_{Aeq}$ level.
2.2.2 Noise units, weightings and parameters

This section is intended as a reference for those not familiar with the parameters used in the measurement of sound. For a more detailed introduction to acoustic principles the reader is referred to Hassall and Zaveri, 1979.

The main quantity used to describe sound is the *decibel* (dB), and is defined as ‘the logarithm to the base ten of the ratio of two acoustical powers or intensities’ (Hassall and Zaveri, 1979). Acoustic intensity is defined as the power passing through a unit area, which is proportional to the square of the sound pressure. Therefore, a sound pressure level may be defined in decibels as:

\[
\text{Sound Pressure Level} = 10 \log_{10} \left( \frac{p}{p_o} \right)^2 \tag{2.1}
\]

where:
\[ p \] is the sound pressure being measured, and,
\[ p_o \] is the reference pressure level, usually defined as 20µPa.

Alternatively, the dB scale may be used when measuring acoustic power as:

\[
\text{Sound Power Level} = 10 \log_{10} \left( \frac{W}{W_o} \right) \tag{2.2}
\]

where:
\[ W \] is the power emitted, and,
\[ W_o \] is the reference power, usually defined as 10^{-12} Watt.

(Equations 2.1 & 2.2 from Hassall and Zaveri, 1979)

The reference pressure/power is defined such, that a human has a hearing range from 0 dB, called *the threshold of perception*, to approximately 120 dB, called *the threshold of pain*. Generally a change of 1 dB in sound pressure level is the smallest value of significance to a human, a change in 3 dB is barely perceivable, a 5 dB change would be clearly perceivable to the majority and a 10 dB change would appear twice as loud (Hassall and Zaveri, 1979).
Sound, audible to a human covers a range of frequencies from approximately 20Hz to 20,000 Hz. Unfortunately human perception of sound is not linear over the entire frequency range. Those frequencies around 1 kHz to 4 kHz, associated with speech, are perceived as being slightly louder, whilst frequencies at either end of the spectrum are perceived as being far quieter. Various experiments have developed equal loudness contours, which relate the perceived sound pressure level at a certain frequency to the sound pressure level of reference tone at 1 kHz (Brüel and Kjær, 1984).

Sound pressure levels are measured using a Sound Level Meter (SLM) (see Appendix E). In order to assess subjective response to noise, it is therefore necessary to weight the electrical signal from the microphone on the SLM. This is done by internationally standardised decibel-weighting curves, which apply approximate inverted equal loudness contours to the measured signal (Brüel and Kjær, 1984). The ‘A’ weighting is the most commonly used curve, having been consistently shown to correlate very well with subjective human response (Hassall and Zaveri, 1979). Decibels weighted using the ‘A’ curve are termed A-weighted decibels or dB(A).

It is the ‘A’ weighting system that is used for all measurements of traffic noise, though there is evidence that subjective annoyance to motorcycle noise does not correlate as well to the ‘A’ weighting system.

There are a number of parameters that may be used to describe traffic noise, examples include the maximum level received, or the $L_{A1}$, $L_{A10}$, $L_{A50}$, $L_{A90}$ and $L_{Aeq}$ parameters (Hassall and Zaveri, 1979).
The $L_{A1}$, $L_{A10}$, $L_{A50}$ and $L_{A90}$ parameters are defined as being the noise levels exceeded for 1%, 10%, 50% and 90% respectively, of the overall measurement period. Figure 2.1 shows a sample cumulative distribution of sound pressure levels, with the $L_{A10}$, $L_{A50}$ and $L_{A90}$ levels marked. For free-flow traffic the overall distribution of sound levels is generally considered to be normal, therefore the $L_{A10}$ and $L_{A90}$ parameters should be $+1.28\sigma$ and $-1.28\sigma$ from the mean noise level, $\mu$, which should correspond to the $L_{A50}$ value.

The $L_{Aeq}$ level is defined as being the equivalent, continuous, sound energy level over the measurement period:

$$L_{Aeq} = 10 \log_{10} \frac{1}{T} \int_{0}^{T} \left( \frac{p_A(t)}{p_{Ao}} \right)^2 dt$$

where:

$T$ is the total measurement period,

$p_A(t)$ is the instantaneous sound pressure level in dB(A), and,

$p_{Ao}$ is the reference pressure in dB(A).
For an overall normal distribution of sound pressure levels the $L_{Aeq}$ is usually 3 dB(A) lower than the $L_{A10}$ level.

Generally, at the time of writing, road traffic noise assessment in the UK is carried out on the $L_{A10}$ noise level, whereas continental Europe prefers to use the $L_{Aeq}$ level. The reason for the difference in the UK is given as the susceptibility of the $L_{Aeq}$ level to short duration, peak noise levels that may be unrelated to road traffic (e.g. passing aircraft or trains, sirens, dogs barking etc.) (DoT, 1993). The recommended measurement period for the UK traffic noise assessment criteria is defined as an 18-hour period from 06:00 to 24:00. However, the most recent draft proposals for a European wide Directive on Environmental Noise call for the harmonisation of parameters on $L_{Aeq}$ based measures (CEC, 2000). These measures include the $L_{\text{day}}$, $L_{\text{evening}}$, $L_{\text{night}}$ and the $L_{\text{den}}$ measures.

CEC (2000) defines $L_{\text{day}}$ as the long-term average $L_{Aeq}$ level during a 12-hour period from 07:00 to 19:00, $L_{\text{evening}}$ is defined as the long term average $L_{Aeq}$ level during the 4-hour period 19:00 to 23:00 and $L_{\text{night}}$ is defined as the long-term average $L_{Aeq}$ level for the remaining 8-hour period from 23:00 to 07:00. The exact definition of a long-term average $L_{Aeq}$ level is given in ISO 1996-2: 1987(E). The $L_{\text{den}}$ level is defined by a weighted sum of the $L_{Aeq}$ levels from the three periods, as shown in Equation 2.4:

$$L_{\text{den}} = 10 \log_{10} \left( \frac{1}{24} \left( 12 \times 10^{-10} + 4 \times 10^{-10} + 8 \times 10^{-10} \right) \right)$$  \hspace{1cm} [2.4]

It has also been suggested that the maximum noise level may correlate with sleep disturbance, and could also be adopted as an assessment criteria (CEC, 1996). Other researchers have suggested that the overall noise climate is important in assessing human subjective response, and a number of additional parameters have been previously proposed. These include the Noise Pollution Level, $L_{\text{NP}}$, based on variation above the $L_{Aeq}$ level (Robinson, 1969), or the Traffic Noise Index (TNI), based on the noise climate above the background ($L_{A90}$) level (Langdon and Scholes, 1968).
The $L_{NP}$ Level is defined as:

$$ L_{NP} = L_{Aeq} + K\sigma $$

[2.5]

where:
- $L_{Aeq}$ is the continuous equivalent energy level in dB(A) for the measurement period,
- $K$ is a constant set by Robinson to be 2.56, and,
- $\sigma$ is the standard deviation of the instantaneous pressure levels recorded in the measurement period.

The TNI is defined as:

$$ TNI = L_{490} + 4(L_{A10} - L_{490}) - 30 $$

[2.6]

Given these diverse criteria, any noise model developed should be able to produce a number of parameters, to allow comparisons of their effectiveness in certain situations to be undertaken.

2.2.3 Road traffic noise, traffic flows and site geometry

Traffic noise is recognised as a complex phenomenon, being a function of a number of variables. Each individual vehicle emits a spectrum of frequencies, depending for example, on such factors as its engine type and speed, bodywork style and condition, loading, transmission and tyre type. Therefore, the spectral frequency content will vary with different gear, on a gradient, in wet or dry conditions or as the vehicle brakes or accelerates. The noise at a given point consists of contributions received from all individual vehicles in the vicinity, attenuated over the distance from vehicle to receiver. Vehicle noise contributions may reach a receptor point either directly or be reflected off, diffracted round or scattered by, nearby objects. Atmospheric conditions and ground vegetation also play a part in sound propagation.
Therefore, the traffic noise at a point varies temporally, both macroscopically, with the daily variations in traffic volumes, speeds and compositions, and microscopically, as individual vehicles or platoons pass the receptor point (Samuels and Shepherd, 1989). Figure 2.2 illustrates this by showing a recording of noise levels taken over a five-minute period (a sound level history). The presence of individual vehicles and platoons are clearly illustrated.

![Figure 2.2: Example Sound Level History, from Beacon Road Nottingham, 24th June 1996, 13:00 - 13:05](image)

Traffic noise also varies spatially, depending on the receiver’s proximity to the roads, the geometry of the site, ground cover, the road surface and presence of adjacent obstacles or nearby flow restrictions.

In order to be successful, an urban noise model ideally has to take into account the majority of these factors. Methods that may be used to achieve this are discussed in later this thesis. Also, the manual collection of traffic and site parameters for a large area is a non-trivial task, requiring substantial amounts of time and resources. The model developed in this thesis attempts to address the problem of traffic data collection, by using data already available from a current UTC system employed in a number of UK cities, SCOOT (see Chapter 3).
2.2.4 Methods of modelling noise

Historically, three different modelling methods have been applied to make predictions of road traffic noise. These being Empirical, Computer Simulation and Scale modelling techniques.

Empirical modelling involves the collection of a large number of noise measurements and accompanying traffic parameters. A statistical technique, such as multiple regression is then used to relate the noise data to the chosen traffic parameters. A single regression analysis will relate one of the $L_{Aeq}$, $L_{A10}$, $L_{A50}$ or $L_{A90}$ parameters to traffic variables such as flow volume, mean speed, traffic composition (i.e. % heavy vehicles) and site parameters such as gradient and receiver distance from the road.

Care must be taken when identifying appropriate formats of parameters for the regression given that certain traffic parameters may be related to one another. Attention must also be paid to the transferability of empirical models, regression based on data from a limited number of sites may not be valid for sites with different conditions. The effect of any excluded parameters on the model must be assessed also.

Much data has been collected to construct empirical noise models (e.g. Johnson and Saunders, 1968; Delany, 1972; Crompton and Gilbert, 1974), though the data is generally confined to roads with high speed, free-flow traffic, as such roads were perceived to be the greatest problem in the 1960s and 1970s. The use of such models in the urban environment may require additional correction terms to account for parameters outside the original regression analysis. The lower speeds encountered in urban traffic flows may also force predictions to be made outside the valid ranges of variables for which the initial regression was undertaken. Without the collection and analysis of further data, the application of empirical models to urban, interrupted flows must be viewed with some scepticism.

However, as deriving a baseline noise prediction from an empirical model consists only of solving the regression equation, for a given set of input
parameters, computation by hand or by computer is usually rapid. Given correctly formatted input data, a modern computer could provide thousands of such predictions in a single second.

**Computer simulation modelling** of road traffic noise requires two separate components. A traffic component able to describe vehicle flows and a noise component able to assign noise levels to those vehicles and transfer individual vehicle noise to a receptor location.

The traffic component generally uses ‘Monte Carlo’ simulation techniques (the random generation of parameters that are considered to conform to certain theoretical probability distributions), to generate individual vehicle attributes, such as vehicle classification, speed, and headway.

The noise component initially assigns noise levels to individual vehicles. Such levels may be discrete values for vehicle classes (e.g. Bowen, 1978) or based on a more complex function relating vehicle parameters to output sound level (e.g. Favre, 1978; Diggory and Oakes, 1980). After the assignment of sound levels, an appropriate algorithm must be used to transfer contributions from each individual vehicle in the system to a receiver location, and then to sum those contributions to produce an overall level. Generally, such transfer functions are derived from acoustic theory or empirical observation.

Each calculated overall level represents a single noise sample for a given point in time. A large number of samples are produced to give an overall distribution of noise levels for the receptor. Appropriate statistical techniques may then be used to generate individual noise parameters from the distribution. Historically, two methods have been used to generate individual noise samples in simulation models:

1. The ‘snapshot’ method. In this method each noise sample comes from a random instant in time. A number of vehicles are randomly generated along the simulated road at various positions. These positions depend on the exact speed and headway distributions used. A noise sample is calculated from the
resulting vehicle configuration. After the noise sample has been taken, the process begins again with an entirely new vehicle configuration.

2. The ‘time interval’ method. In this method each sample represents an instant drawn from a linear progression of time. Vehicles enter the simulated road at times dependent on the headway model, with a certain initial speed. The traffic model updates the vehicle positions between every time instant using appropriate kinematics equations. A noise sample is taken after the vehicle locations have been updated.

Obviously the first method carries with it a degree of abstraction. The assignment of vehicle locations generally requires that the vehicles are freely flowing. The second method is more logical and offers the opportunity for sound levels to be examined as individual vehicles pass-by a receptor location. The second method also facilitates the use of car-following or other algorithms to better model vehicle behaviour.

As simulation modelling describes the various processes in considerable detail, many more parameters need to be defined than for empirical models. Appropriate algorithms and coefficients need to be identified, developed or measured, so that vehicle interactions, source noise levels and mechanisms of sound propagation, are accurately treated.

A correctly designed simulation model should:

“...be a tool to analyse and obtain a better understanding of traffic behaviour” and“... must be built in such a way so as to allow a flexible design of simulation experiments for testing different modelling hypotheses...”

(Barceló, 1991)

In this case, such hypotheses would involve the testing of different values and distributions of input parameters, for both the traffic and noise components. Therefore the method of changing those parameters should be effective and simple to use.
After the coding of a computer simulation model, there are three further stages required before that model may be considered complete, these being:

1. *Verification*. This is the process of checking that a simulation model performs as the original specification intended. Program errors and bugs are removed at this stage.

2. *Calibration*. The performance of the model, using a certain set of input parameters, is assessed against measurements, using those same input parameters. If a discrepancy is found then components of the simulation model are modified in such a way that model output better reflects the measurements.

3. *Validation*. The performance of the calibrated model is assessed against a separate set of measurements and input parameters from those used in the calibration process. Further lessons learnt from the validation exercise may be reapplied to the simulation model. Hence, the process of calibration and validation may be an iterative one, with the model performance improving with each cycle of the two-stage process.

Recently, more interest has been shown in the use of computer simulation, rather than in new empirical models, for predicting urban noise levels (e.g. Favre, 1978; Diggory and Oakes, 1980; Jones, Hothersall and Salter, 1981; Wayson and MacDonald, 1995). Each simulation is different in the exact approach used, e.g. in the performance of vehicles in the model and the assumptions made about source noise levels. A detailed study of these models has been carried out to understand the current state-of-art in simulation/noise modelling and to set out guidelines on best practice.

*Scale modelling* has generally been used to provide information on sound propagation. Care must be taken in any scale modelling to ensure that the dimensions of the model and properties of the materials used accurately reflect those of the real world.
Data from the scale models presented by Maekawa (1969) has long been incorporated in empirical models to account for the effects of barriers (Delany, Harland, Hood and Scholes, 1976). Delany et al. noted that there was a discrepancy between the frequency spectra of traffic noise and the pure tone sound used by Maekawa. This discrepancy limited the effectiveness of applying the scale model data to real world sites. Other experimenters have used moving pneumatic air jets, producing a range of frequencies, to simulate the noise of moving vehicles (Jacobs, Nijs and van Willigenburg, 1980), though again, discrepancies in spectra limited the overall application of the model results. However, Jacobs et al. noted that the modelled trends in noise level, for a receiver point in a variety of site configurations, closely matched theoretical trends. Therefore, the scale model data may be used to provide an idea of the trends in sound levels around barriers and buildings, with exact attenuation rates being calibrated from on-site measurements.

The three modelling techniques, outlined above, have been traditionally applied to predicting road traffic noise. Developments in computing, such as the use of neural networks or genetic algorithms (Nader, 1998), could potentially be applied to the prediction of traffic noise levels. However, such techniques have been considered outside the scope of this thesis.

2.2.5 The UK standard – ‘Calculation of Road Traffic Noise’

The current UK standard method for noise prediction, ‘Calculation of Road Traffic Noise’ (DTP, 1988), combines experience in using all three traditional methods. CRTN produces a prediction of the $L_{A10}$ level for any given site, based on an empirical model for free flow traffic, with some interrupted flow data included (Delany et al., 1976). The empirical data used in the model is now over 20 years old. Corrections may be made to the baseline noise prediction to account for buildings, screening, grassland areas, roads in cuts and other complex site configurations. Again, much of the data for these corrections has been derived from all three traditional modelling methods. In order to use the CRTN method to predict noise levels around junctions, an assumption needs to be made about the mean speeds of vehicles passing through the junction. This assumption is that the effects of the reduced noise levels from vehicles decelerating to the
junction and the increased noise levels of vehicles accelerating away from the junction are of the same order of magnitude, and hence cancel each other out. Therefore, the estimate of $L_{A_{10}}$ levels in the vicinity of the junction is derived by assuming that the mean vehicle speeds through the junction is no different from the cruising speeds of the approach roads. This assumption may lead to an over-prediction of $L_{A_{10}}$ levels near the approaches to a junction (decelerating vehicles are quieter than cruising vehicles), and an under-prediction of noise at the centre and adjacent to the exits of the junction (no treatment of accelerating vehicles). As the standard is used as the basis for compensation claims for adjacent properties in new road construction, it may be failing people who live very close to an intersection.

2.2.6 Noise mapping

The assessment of the population affected by noise requires that accurate mapping of the spatial distributions of sound levels be undertaken. For example, the UK method of assessment for road schemes (DTp, 1993), requires that changes in noise be assessed out to a distance of 300 metres from the road centre-line for rural and inter urban roads, and a distance of 100 metres for urban roads. Both the European Commission (CEC, 1996) and the present UK Government, in its recent ‘Transport White Paper’ (DETR, 1998) have recognised that there is an increasing need for noise mapping. Indeed, the latest draft proposals for an EC Directive on Noise (CEC, 2000) call for noise mapping exercises, based on long-term average $L_{den}$, $L_{day}$ and $L_{night}$ values to be carried out on a 5-yearly basis for all conurbations over 250,000 inhabitants. It has been recognised that beyond the traditional aspect of scheme impact assessment, noise mapping has the potential to locate noise ‘black-spots’. In the future there is a need to consider noise as a component in pro-active traffic management, and to provide informative and useful information on noise in the environment to the general public.

2.2.7 Trends in road traffic noise – legislation versus reality

Given the legislation options outlined in Section 1.2.1, the most effective way of reducing public exposure to road traffic noise is the reduction of noise at the source. Therefore there has been an ongoing policy in the European Union, to
introduce ever-stricter regulations on vehicle noise emissions, starting with EC directive 70/157/EEC through to the current directive 92/97/EC. Figure 2.3 illustrates this point, showing selected changes in EC emission limits with time.

![Graph showing vehicle noise emission limits from 1970 to 2000.](image)

**Figure 2.3: Evolution of European Union vehicle noise emission limits with time (composite data from CEC, 1996)**

Table 2.1 shows the UK vehicle emissions standards for type approval, taken from the UK ‘The Road Vehicle (Construction and Use) (Amendment) (No. 5) Regulations 1996 (HMSO, 1996). The first column shows the values in force prior to 1 October 1996, the second those values in force after 1 October 1996. The test to assess vehicle compliance to these values (ISO/R 362, 1966 – current European directive 96/20/EC) is discussed later in this thesis.

It is generally acknowledged that while legislation may be brought into force for new vehicle types, such changes may take a considerable time to impact the overall vehicle fleet, and hence reduce the noise levels measured on street. CEC (1996) suggests that whilst reductions in source noise of the order of 10 dB(A), through type approval schemes have been possible, on-street noise levels have declined by only 1 – 2 dB(A).
The lack of a large decrease in on-street levels, is attributable to inertia in the vehicle fleet to changes, the maintenance condition of vehicles and roads, increased urban traffic flows and the lack of ‘real’ driving cycles in the ISO test procedure (CEC, 1996). The latter point reflects the use of only a 48kph constant speed pass-by test and a 3\textsuperscript{rd} gear increasing engine rpm test in the type approval of new vehicle models, rather than a range of tests covering various driving modes.

\textit{Table 2.1: UK vehicle noise emission limits, in dB(A), from The Road Vehicles (Construction and Use) Act, 1996}

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Limits prior to 1\textsuperscript{st} October 1996</th>
<th>Limits post 1\textsuperscript{st} October 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>77</td>
<td>74</td>
</tr>
<tr>
<td>Large buses or coaches &gt;3.5 tonnes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- engine power &lt;150 kW</td>
<td>80</td>
<td>78</td>
</tr>
<tr>
<td>- engine power &gt;150 kW</td>
<td>83</td>
<td>77</td>
</tr>
<tr>
<td>Small buses or light goods vehicles of ≤ 3.5 tonnes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- gross weight ≤ 2 tonnes</td>
<td>78</td>
<td>76</td>
</tr>
<tr>
<td>- gross weight &gt; 2 tonnes</td>
<td>79</td>
<td>77</td>
</tr>
<tr>
<td>Heavy vehicles &gt; 3.5 tonnes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- engine power &lt; 75 kW</td>
<td>81</td>
<td>77</td>
</tr>
<tr>
<td>75 kW ≤ engine power ≤ 150 kW</td>
<td>83</td>
<td>78</td>
</tr>
<tr>
<td>- engine power &gt; 150 kW</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>

\textbf{2.3 SUMMARY}

This fairly short chapter has provided a basic introduction to the parameters used for measuring and modelling noise, typical noise modelling techniques and the current European Union situation regarding environmental noise. The next chapter introduces the concepts of UTC in general and examines the use of the SCOOT system in particular as a source of input to an environmental model.