UNIVERSITY OF TASMANIA

THE COMPARISON OF ROAD TRAFFIC NOISE LEVELS FROM PREDICTION MODELS AND ACTUAL NOISE MEASUREMENT

BY

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DECLARATION

Except as stated herein, this thesis contains no material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

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ABSTRACT

This research focuses on the comparison of the traffic noise levels that are calculated from prediction models, and the noise levels from actual traffic noise measurement. The research was conducted on Regent Street, Sandy Bay Road and the Tasman Highway, Hobart. At each site, the traffic noise measurement was operated seven days continuously, with site topography and at least 10 hours of traffic volume studies. Repeat measurements were taken at each site. Three prediction models: T-Noise, STAMSON4.1 and ITFNS1.1 were used for predicting traffic noise levels at each study site.

The study showed that in day-time, all recorded noise levels under normal conditions exceeded both NSW road traffic noise criteria and Tasmanian road noise guideline ($L_{eq\ 15\ hr}$ = 60 dB(A)) and ($L_{10\ 18\ hr}$ = 63 dB(A), respectively), and most of the night-time noise levels exceeded both night-time criteria of NSW and Tasmania ($L_{eq\ 9hr}$ = 55 dB(A) and $L_{eq\ 1\ hr}$ = 55 dB(A), respectively).

Traffic volume studies showed that there were approximately 850 veh/hr with 11% trucks on Regent Street, 1600 veh/hr with 13% trucks on Sandy Bay Road and 3200 veh/hr with 6% trucks on the Tasman Highway.

The comparison studies showed that, within the absolute noise levels comparison, on Regent Street and Sandy Bay Road, T-Noise showed the greatest accuracy with the smallest variation, an average of 0.76 dB over prediction on Regent Street and 1.12 dB under prediction on Sandy Bay Road. STAMSON4.1 provided less accuracy than T-Noise, with an average under prediction of 1.86 dB on Regent Street and 2.51 dB under prediction on Sandy Bay Road. ITFNS1.1 exhibited unreliable predictions for all study sites. None of the models presented reliable results for the Tasman Highway study site.

The results from correlation tests on predicted and actual noise levels showed that T-Noise and STAMSON4.1 provided no significant difference in the correlation coefficient values. At the urban road sites T-Noise provided the greatest correlation of R^2 = 0.57, while STAMSON4.1 provided R^2 = 0.43, with only R^2 = 0.006 gained from ITFNS1.1. For highway conditions, T-Noise provided the greatest correlation of R^2 = 0.64, while R^2 = 0.43 was offered by STAMSON4.1. However, in correlation tests of urban and highway

conditions combined, both models showed poor results with $R^2 = 0.08$ and $R^2 = 0.27$ from T-Noise and STAMSON4.1 respectively. These results provide an indication of the accuracy of these models for this application. In the case of correlation between traffic volumes and the accuracy of noise level predictions; only T-Noise shows a correlation between these two factors indicating a propensity for improvement in its accuracy for this application.

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CHAPTER 1

INTRODUCTION

Traffic noise is an important source of environmental noise (Ouis, 2001). It generally causes considerable disturbance and annoyance, which leads to stress and other effects on human health. Research in Berlin on 801 women aged between 30-45 years old who were directly exposed to traffic noise showed that women who lived in streets with more than 20,000 vehicles per day felt highly disturbed by road traffic noise at home. This research also found that subjective disturbances due to traffic noise, particularly of sleep and communication at home, were significantly associated with increasing of noradrenaline levels in urine samples, known as a stress indicator (Babisch et al., 2001). Also, research by Babisch et al. (1993) supported the view that people who live adjacent to streets with high traffic noise levels suffer an increased risk of heart disease. The research found that exposure to traffic noise continuously for 6 to 22 hours at the level of 66 – 70 dB(A) led to an increase of cardiovascular risk factors which can cause heart disease. WHO (2001) added that, in particular, people who are living near noisy streets may develop permanent physiological effects namely hypertension and ischaemic heart disease. In addition, prolonged exposure to continuous road traffic noise levels of 65 - 75 dB(A) can induce cardiovascular effects. Furthermore, traffic noise can cause mental illness, sleeping interference, and affect performance of cognitive tasks such as reading, attention, problem solving and memory. In addition, social and behavioural effects can occur according to noise exposure. Continuous noise at levels above 80 dB(A) may reduce helpful behaviour and increase aggressive behaviour. Long-term high level noise exposure may lead to feeling of helplessness in school children (WHO, 2001).

A survey, conducted by Hede et al. (1986), found that 21 percent of Australians are affected by noise pollution. Seventeen percent of this group would most like to rid themselves of road traffic noise. The study also shows that traffic noise highly annoyed 6 percent of Australians, 21 percent were moderately annoyed, and sleeping was affected in 13 percent (Hede et al., 1986). Brown (1993), in his research on Australian population exposed to road traffic noise, states that over 9 percent of the Australian population were exposed to $L_{10,\ 18hr}$ of 68 dB(A) or above (the criteria of maximum acceptable level that was in use in Tasmania when the research was conducted); 19 percent of the population were exposed to $L_{10,\ 18hr}$ of 63 dB(A) or above (the criteria of maximum desirable level that was in use in Tasmania when the research was conducted) (Brown, 1993; Terts, 1996).

This consequence has led to the great interest in reducing noise from road traffic, and increased traffic noise planning. As traffic noise is a complex phenomenon, it is physically difficult to measure and time consuming. For this reason, traffic noise prediction models were introduced as a tool for facilitating noise planning. The traffic noise prediction models basically forecast noise levels that could occur if any actions, which relate to the possible increase or decrease of traffic noise levels, are introduced into roadside areas. Prediction models are widely used for three main objectives: to predict noise levels from new road construction; to predict noise levels from the enlargement or any kind of improvement of existing roads; and to predict for the mitigation of traffic noise such as the use of noise barriers (OECD, 1995).

However, an OECD (1995) report states that despite prediction models being very useful in traffic noise planning, all existing prediction models are limited by the small number of different scenarios available and only certain types of road structures are considered in prediction models. These lead to possibilities of inaccuracy of noise levels calculated by the prediction models. The report also points out that due to changes in vehicle noise emissions and road surface, levels have been changing slightly through time, therefore, the prediction models must be regularly tested (OECD, 1995).

1.1 THESIS OBJECTIVES

The hypothesis for this thesis is that the noise models investigated will accurately predict the measured noise levels at sites in urban Hobart. In order to test this hypothesis the following three main objectives were set:

- the study of traffic noise levels and noise patterns on arterial roads and highways in Hobart;
- the study of traffic volume that occurred at each study site; and
- the investigation of the accuracies of traffic noise prediction models.

The first objective is intended to demonstrate the noise levels and the common noise patterns on the study site, as well as the situation of traffic noise in those areas compared with current traffic noise criteria. These studies provided a rough idea of the traffic noise situation in Hobart.

The study of traffic volume is intended to provide information on the number of vehicles that pass by the study sites. The traffic volumes were also needed as inputs to traffic noise prediction models.

The last objective involves a comparison of the predicted noise levels calculated from the prediction models with the noise levels gained from the actual measurement. This allows investigation of the accuracy of prediction models, and a comparison of the accuracies of each prediction model.

1.2 THE STRUCTURE OF THESIS

This chapter (section 1.3) explains the noise descriptors that are found in the study of noise and the nature of traffic noise (section 1.4). Chapter 2 elucidates traffic noise prediction models. This includes: the basic characteristics of prediction models and traffic prediction models; traffic prediction models that are currently used in Australia; and the traffic noise prediction models used in this thesis. Chapter 3 describes the field study. The details of noise measurement equipment and data collection, and study sites and data analysis methods, are also included in this chapter. All the results of this research are presented in Chapter 4. Chapter 5 provides the discussion and conclusion.

1.3 NOISE DESCRIPTORS

There are several noise descriptors that are used in this thesis. The meaning of each noise descriptor is explained so that the meaning adopted in this thesis is clear. All the noise descriptors below are universally accepted.

Sound absorption

Sound absorption is the reduction of sound energy as it passes through an acoustic medium (Barber, 1992). The process of sound absorption is a conversion of acoustic energy to thermal energy, which takes place both on the material's surface and within the material (Anderson and Bratos, 1993; Cunniff, 1977). Porous surfaces such as acoustic tiles, rugs, and draperies are more absorptive than hard surface materials such as glass, metal or plaster. On the other hand the hard surfaces perform significantly better in their reflection properties (Cunniff, 1977).

Reflection

Reflection is the phenomenon by which a sound wave is returned from a surface separating two media, at an angle to the normal equal to the angle of incidence (Harris, 1979).

Ambient noise

Ambient noise is all encompassing noise associated with a given environment. There is no particular dominant sound, it is usually a composite of sounds from many sources near and far (Harris, 1979).

Background Noise

Background noise is the noise from all sources other than a particular sound that is of interest (Harris, 1979).

Decibel (dB)

Decibel (dB) is a logarithmic scale applied in acoustics to scaling the ratio of sound intensities or the ratio of sound pressures. A logarithmic scale is used in acoustics to simply cover a wide rage of sound pressure amplitudes detected by the human ear. The lowest sound pressure that the healthy human ear can detect is 2×10^{-5} Pa and the threshold of pain is approximately 100 Pa. This is a range from 0 to 120 in decibel units. As a decibel is a ratio value, a level of 0 dB does not represent absence of sound, but rather that the concerned sound pressure is equal to the reference level (Barber, 1992).

Free field

Free field is an environment in which there is no reflective surface. Within the boundary of a free field, the measured sound would not be disturbed by any reflection (Anderson and Bratos, 1993; Barber, 1992).

Far field

Far field is the part of the sound field where the sound wave spreads spherically from the sound source, and the sound pressure decreases by 6 dB for each doubling of the distance from the source (Barber, 1992; Harris, 1979).

Noise and sound

Noise is generally considered as unwanted sound, although noise and sound are often used interchangeably. The term sound is preferred when studying physical properties, because it does not carry any sense of subjectivity (Barber, 1992).

Receiver

A receiver is a person, persons or equipment affected by noise (Harris, 1979).

Root mean square (rms) averaging

Root mean square (rms) is the method used to calculate an average sound pressure. Since a sound performs as a harmonic wave or a sinusoidal form, the use of arithmatic averaging gives zero as a result (Figure 1.1). The rms average is found from:

$$p_{rms} = \frac{1}{T}\left\{\int_0^T p^2(t)dt\right\}^{0.5}$$

If $p(t) = p_{max} \sin \omega t$ and $T = \frac{2\pi}{\varpi}$

Then $p_{rms} = \frac{1}{\sqrt{2}} p_{max} = 0.707\ p_{max}$

When p is sound pressure,

p_{max} is peak pressure;

ω is the frequency in cycles per second;

T is time per cycle; and

t is time interval.

Hence, for a simple sine wave and any linear summation of sine waves, the rms average of the sound pressure is 0.707 x the peak pressure. Most sound level meters give rms values, except for special instruments intended for impulse noise or single events (Barber, 1992).

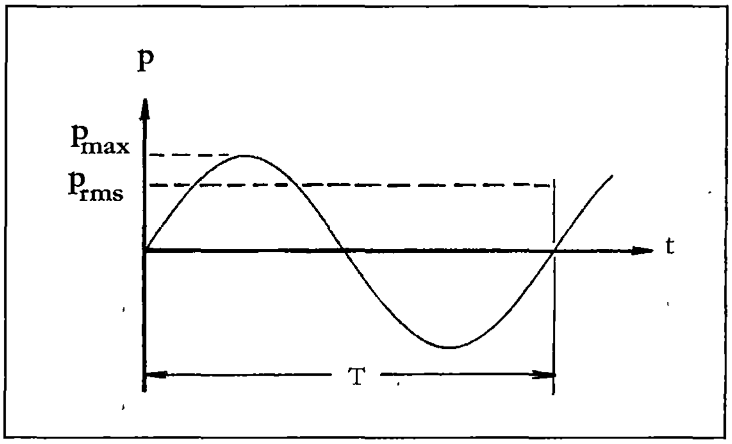


Figure 1.1 Root mean square of a harmonic function

Adapted from Anderson and Bratos, 1993

Sound pressure level

Sound pressure level (unit in decibel) is the root mean square of instantaneous sound pressure over a given time interval (Harris, 1979). The sound pressure level is defined by:

$$L_p = 10 \log \left(\frac{p^2}{p_{ref}^2} \right) dB = 20 \log \left(\frac{p}{p_{ref}} \right) dB$$

Where p is the rms value of the sound pressure at a particular point and $p_{ref} = 2 \times 10^{-5}$ Pa. The reference level is chosen by convention to be the rms pressure that is equal to the limit of audibility in a healthy young adult at 1000 Hz (Barber, 1992). Sound pressure can be measured by a sound level meter that satisfies a standard requirement, such as the American National Standard Specification for Sound Level Meters S1.4-1971 (Harris, 1979).

Weighting network

Weighting network is a prescribed frequency response provided in a sound level meter which attempts to alter the measured signal in a similar fashion to the human hearing mechanism (Cunniff, 1977; Harris, 1979). The weighing networks shown in Figures 1.2 and 1.3 were developed for different uses. The A-weighting network is generally used to analyse a sound pressure level similar to a human ear response for low sound levels. Figure 1.2, compares the response of a sound level meter using an A level Network filter to that of the human ear at various frequencies. The broken line indicates the sound levels after integration with the A-weighting network filter and the solid lines specify the human ear response to sound of different frequencies. The B-weighting network is used for human response for moderate sound level. The C-weighting network is for human response for high sound levels. Occasionally, the D-weighting network was introduced as a correlation with human response from noise around airports and aircraft (Figure 1.3) (Barber 1992; Cunniff, 1977). Readings using a weighting network must indicate the particular weighting network applied. For example, if a sound level is shown as 65 dB on the meter when using the A-weighting network, the sound level is recorded as 65 dB(A) (Cunniff, 1977).

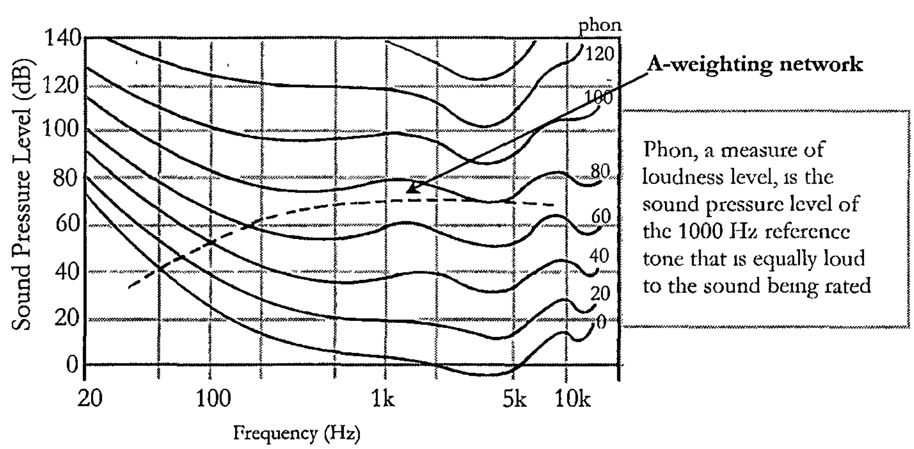


Figure 1.2 A-weighting network compared with the ear's response

Adapted from Barber, 1992

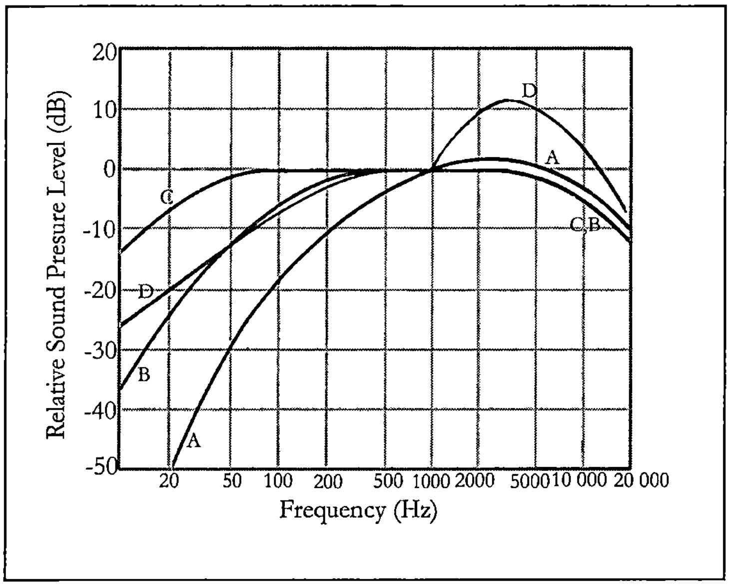


Figure 1.3 Relative frequency responses of A-, B-, C- and D-weighting networks for sound level meters

Adapted from Barber, 1992

Symbols and abbreviations

L_A: A weighted sound level, the sound level obtained by use of A-weighting. The unit is decibel (A) or dB(A) to indicate that A-weighting network is used (Harris, 1979).

L_{Amax}: maximum A-weighted sound level within the determination time intervals. This descriptor is generally used in associated with the study of the effects from a peak loud noise on human (Harris, 1979).

L_{Amin}: minimum A-weighted sound level within the determination time intervals. This descriptor is often used and associated with the study of background noise and noise from the sources of interest (Harris, 1979).

L_{eq}: Equivalent continuous sound level, originally developed for assessing environmental noise. L_{eq} is an A-weighted energy of the sound level averaged over the specified measurement period. It can be defined as the continuous noise which would have the same acoustic power as the real measured noise over the same period. It has found much favour both as a means of assessing community noise as well as estimating hearing damage. L_{eq} can be defined mathematically as:

$$\text{Leq} = 10 \log \left\{ \frac{1}{T} \int_0^T \left(\frac{p_A(t)}{p_0} \right)^2 dt \right\}$$

Where: t is the total time, $p_A(t)$ is the instantaneous value of the sound pressure and p_0 is the reference pressure. If the overall sound during the time T can be adequately represented by a limited number of discrete levels, then

$$\text{Leq} = 10 \log \frac{t_1 \log^{-1} \frac{L_1}{10} + t_2 \log^{-1} \frac{L_2}{10} + ... + t_n \log^{-1} \frac{L_n}{10}}{T}$$

Where L_1, $L_2 \ldots L_n$ are the measured A-weighted sound pressure levels and t_1, $t_2 \ldots t_n$ are the measured durations (Barber, 1992)

L_{eq} is normally presented as $L_{eq,\ T}$ for example $L_{eq\ 1\ hr}$ represent the 1 hour average sound level, the equivalent continuous sound level, i.e. the time average A-weighted sound level, in decibels, over a 1 hour time period (Harris, 1979).

L_n stands for percentile levels, where n represents the percentage of a measurement time during which the level is exceeded. An example is given in Figure 1.4, which shows L_{10}, L_{40} and L_{90} figures and their cumulative probability distribution function of sound levels. If the L_{10} level is 70 dB(A) it means that the sound level exceeds 70 dB(A) for 10% of the time. More exactly, the A-weighted percentile levels are designed $L_{An,T}$ where A denotes A weighting, n means a percentile number and T stands for a measurement duration (Harris, 1979).

The A-weighted L_{10} level is extensively used for measurement and prediction of road traffic noise. Typically, traffic noise generates high noise levels for about 10% of the time, so the L_{10} level is a good discriminator for traffic noise. Whereas L_{90} is usually found using associated with the study of background noise (Anderson and Bratos, 1993).

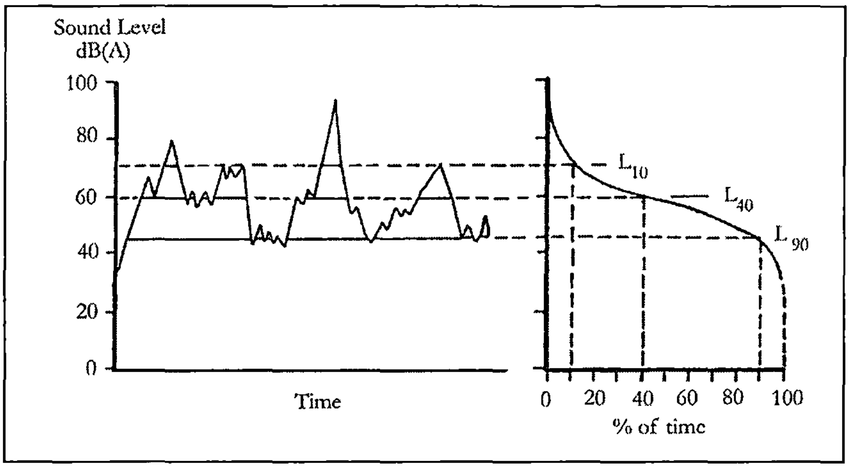


Figure 1.4 An illustration of L_{10}, L_{40} and L_{90} and the cumulative probability distribution function of sound levels

Adapted from Barber, 1992

1.4 THE NATURE OF TRAFFIC NOISE

Road traffic noise is dependent on the number and type of vehicles present and both driving conditions and driver behaviour. In fact, traffic noise is caused by three main factors, aerodynamic profile (wind noise), power-train noise (fan, gear box, engine, exhaust system, cylinder block and air intake), and tyre-road noise (Lester, 2000; OECD, 1995). At low vehicular speed, the majority of road traffic noise is caused by power-train noise derived from engines, transmissions, exhausts and brakes. Lester (2000) shows that noise generated from moving vehicles at speeds lower than 70 kilometres per hour consists of 34 percent from the engine, 30 percent from the tyres, 27 percent from the exhaust system and 9 percent from the air intake. With speed increase, noise generated from the interaction between tyres and the road surface increases. At speeds over approximately 70 kilometres per hour, tyre-road noise and air disturbance from vehicle movement (aerodynamic profile) become the dominant components. Tyre-road noise is a result of a combination of road surface texture, tread pattern and tyre profile. The tyre-road noise is approximately 2-4 dB(A) greater than the other noise produced by light vehicle traffic running at speeds over 50 kilometres per hour and by heavy vehicles at speeds starting at 80 kilometres per hour (OECD, 1995). In addition, road texture can influence the overall noise level by 9 to 14 dB(A) while tyre type has been reported to influence noise level by up to 5 dB(A) for cars and up to 10 dB(A) for trucks (Lester, 2000).

There are a variety of methods that have been introduced to deal with traffic noise problems. Generally, the methods include road resurfacing; installation of noise barriers; encouraging smooth traffic flows; regulating traffic speeds; implementing vehicle condition standards such as conditions of exhaust pipes, tyres; and zoning vehicles in particular areas. The application of prediction models involved decision-making and action plans in order to promote a reduction of traffic noise.

CHAPTER 2

TRAFFIC NOISE PREDICTION MODELS

This chapter describes the main characteristics of numerical noise models, the models currently being used in Australia and the specific models used for this research.

2.1 PREDICTION MODEL DESCRIPTION

Models are tools to help test hypotheses and integration of scientific knowledge. Although models are vastly different depending on the field of study, they are categorised into two main groups: those that are simplified representations of some aspect of the real world, physical models, a model of a house for instance; and mathematical models which present simplifications in the form of a series of numerical equations. This set of mathematical equations is formulated to express the behaviour of a studied system. The calculated result is intended to represent some aspect of the inherent behaviour. In general, mathematical models combine relevant environmental characteristics with proposed future outcomes to project future circumstances (Aris, 1978; Lertsawat, 2001). Physical and mathematical models can be used together or separately, depending on job requirements.

These models have been widely used in acoustic studies predicting noise characteristics in various situations. Noise prediction models are usually numerically based, however physical models are occasionally applied. The models are fundamentally based on acoustic theories of sound emission and propagation used to calculate noise levels in hypothetical situations. Prediction models can be applied in situations where new factors associated with noise pollution are introduced into study areas as well as in designing plans and strategies to solve noise problems. It has been proved that prediction models are very useful in terms of planning and decision-making. Prediction models can estimate future noise levels in both a cost and time effective manner. The accuracy of results depends on the quality of data and the appropriateness of the equations used (Lertsawat, 2001; OECD, 1995).

One of the practical applications of these models is their use in predicting noise from road traffic where it is considered one of the important contributing noise sources. The methods used for traffic noise prediction can be classified into three basic groups:

- manual calculations or simple analytical equations, these methods are used for preliminary assessment, and are mostly applied to simple situations;

- physical scale models, simulations using physical scale models are appropriate for highly detailed reproduction of very complex spatial situations. However, this approach is extremely expensive in terms of construction cost and the sophisticated experimentation required; and

- numerical simulations by automatic calculation, this method employs the use of computer software programmed to evaluate noise levels incorporating variables such as different topography, reflection/absorption phenomena and sound paths. Its details and accuracy depend on the complexity of models and quality of input data.

Mostly, mathematical calculations are used for predicting traffic noise. These calculations result from theoretical considerations of sound propagation and empirical considerations involving emission power and attenuation values. Noise prediction calculation typically incorporates: sound source (including traffic parameters); topographical conditions; location of reception points; attenuation by air and ground; and the presence of obstacles between source and receivers. In most prediction models, meteorological influences are not considered important factors (OECD, 1995).

The basic structure of the mathematical models consists of:

- topographical description data, including the locations of receiver points; sound absorption characteristics of the ground; the presence of natural and artificial barriers; other relevant data;

- acoustic characteristics of sources e.g. traffic flow, average speed, types of vehicles;

- analysis of sound diffusion in propagation; the attenuation due to distance;

ground absorption; reflection and diffraction by obstacles; sound absorption by the air;

- the accuracy of the equations used, the equations base on the acoustic theories and the variety of relevant factors, the more variety of factors that are taken into account, the more accurate prediction; and

- the readout and analysis of results (OECD, 1995).

Mathematical models of traffic noise generally comprise three basic parts: input data; the calculation system; and output data as described in Figure 2.1.

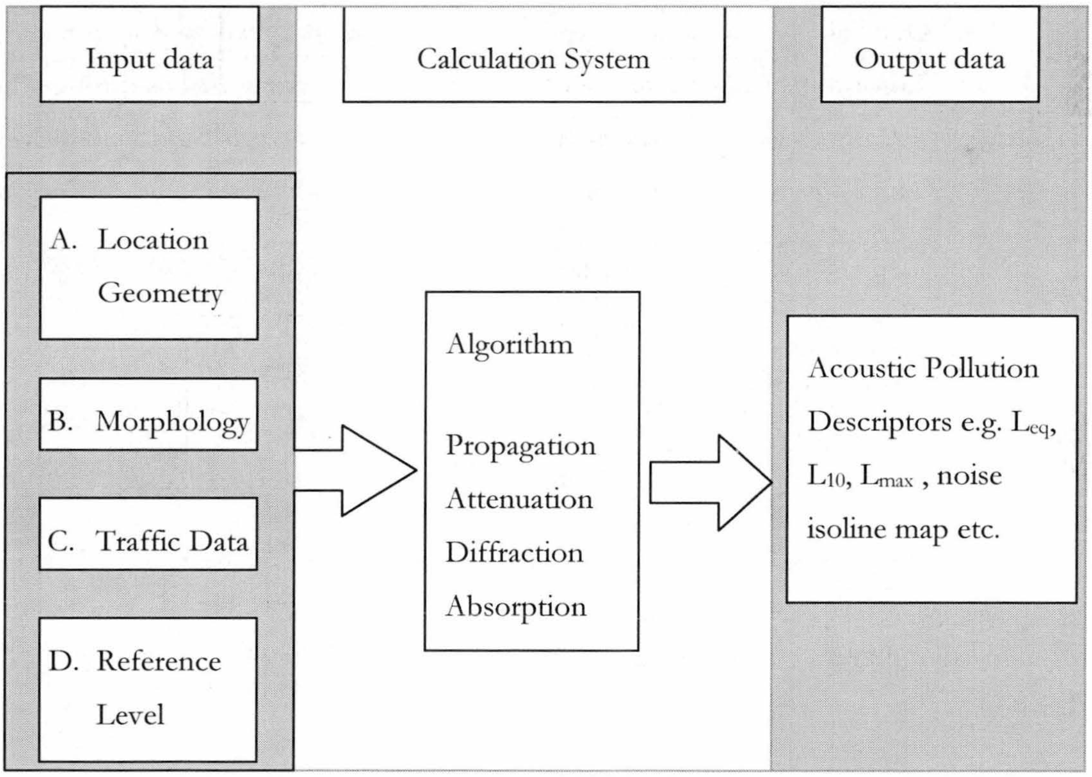


Figure 2.1 Flow chart of traffic noise prediction models

Adapted from OECD, 1995.

2.2 TRAFFIC NOISE MODELS IN AUSTRALIA

There are a variety of numerical models that are presently used in Australia. The information gained from a survey of mathematic models used in every state and territory in Australia shows that the six following models are used to undertake traffic noise prediction (Table 2.1).

1. CoRTN (Calculation of Road Traffic Noise) is a road traffic noise model that is solely designed to enable prediction of $L_{10\ (1\ hour)}$ and $L_{10\ (18\ hour)}$. This model has been developed by the Department of Transport Welsh Office. It describes the procedure of noise calculation from road traffic and the guidance appropriate to the calculation of traffic noise for general applications. However, this model introduces traffic noise calculation without any distinction between various properties of noise barriers. This model does not accurately consider traffic flow of less than 40 vehicles per hour. Furthermore, it delivers only an L_{10} figure. As a result of these characteristics it is necessary to make regular corrections for other descriptors to predict noise levels. (EPA, 1999; Lester, 2000).

2. T-NOISE, is modified from CoRTN by Main Roads Western Australia. This model provides $L_{10(18\ hour)}$ and $L_{10(hourly)}$ figures. The L_{eq} figure can be obtained via conversion of calculated L_{10} values (Lester, 2000; Main Roads Western Australia, 1993).

3. STAMINA has been developed by the US Federal Highway Administration (FHWA). This model calculates noise in terms of L_{eq} values over a time averaging period. This model is considered more mathematically rigorous than CoRTN (EPA, 1999; Lester, 2000).

4. TNM (Transport Noise Model) is an upgrade version of STAMINA 2.0. This model computes highway traffic noise at nearby receivers. The calculation of traffic noise levels incorporates different categories of vehicle types, traffic flow conditions, rows of buildings and dense vegetation beside roads, effects of parallel noise barriers and road conditions (FHWA, 2001).

5. ENM (Environmental Noise Model) has been developed by RTA Technology Pty Ltd in order to predict environmental noise in various atmospheric conditions.

Compared to CORTN and FHWA, it incorporates more sophisticated ground effect corrections. Furthermore, the Environmental criterion for road traffic noise indicates that this may be the most appropriate model for calculating noise levels at large distances (EPA, 1999; Lester, 2000).

6. SoundPLAN is the product of Braunstein and Berndt GmbH of Germany. This model provides a sophisticated and complex approach to various areas of acoustic calculation. It can evaluate environmental noise incorporating road, rail, aircraft, and industry noise characteristics both indoors and outdoors. It also provides cost effective analysis and engineering designs for applications such as walls and noise barriers (Braunstein and Berndt GmbH, 2000; Lester, 2000).

CoRTN has been the most popular model used in Australia as a basic guide for road traffic noise calculation. However, the requirement of determining noise levels by using descriptor L_{eq}, which is not covered by CoRTN, has led to an increase in the use of TNM. In Victoria, South Australia, Western Australia and Queensland, L_{eq} is being explored but it has not yet been classified as the official model. In the future, it can be anticipated that software that calculate L_{eq} will dominate in noise prediction in Australia.

Table 2.1 Noise Model Used in Australia

(Based on telephone and e-mail contact with noise control authorities in each state and territory)

Agency		Noise Models Used						
		CoRTN	CoRTN/T-NOISE	STAMINA	TNM	SoundPLAN	ENM	Comment
ACT	Planning and Land Management Authority		✓					With a 2 dB(A) 'PLAM' adjustment to allow for standard over-prediction
NSW	Road & Traffic Authority & EPA	✓		✓	✓		✓	Varies due to use of consultants for acoustic analysis of projects TNM seldom used due to long run-time.
NT	Department of Transport &Work							Non specific model - use other States practice
QLD	Department of Main Roads	✓						TNM is under evaluation but is still demonstrating some inaccuracies
	Environment Protection Authority	✓		✓	✓			-
SA	Transport South Australia	✓			✓	✓		-
TAS	Department of Infrastructure, Energy and Resources		✓					-
VIC	VicRoads	✓						An investigation of the TNM model was completed in October 99
WA	Main Roads Western Australia		✓					-
NZ	Transit New Zealand	✓						CoRTN, with L_{10} value converted to L_{eq} by manual adjustment Of other models investigated, the Nordic Model has been found to be accurate and is being considered for wide use

2.3 PREDICTION MODELS USED IN THIS STUDY

There were three numerical models used in this research: T-noise, ITFNS 1.1 and STAMSON4.1. The details of each software are explained as the following sub topics.

2.3.1 T-Noise

T-Noise is a computer program for calculating traffic noise. The program requires a computer that runs Windows 3.0 or higher. The calculations of T-Noise are based on the procedures described in the memorandum "Calculation of Road Traffic Noise" (CoRTN), issued by the Department of Transport Welsh Office, 1988 (Main Roads Western Australia, 1993).

This model consists of three main sections: input, calculation and output. The input section requires basic site information that includes:

- the site environment consisting of receiver position, road gradient, road surface type, road surface depth, road width, noise reflection/absorption conditions in the noise path and noise barriers if utilised in the study areas;

- traffic conditions incorporating total traffic flow, percentage of heavy vehicles and traffic speed.

However, the road surface corrections input is automatically provided by T-Noise in cases where the user does not input this data.

The calculation section provides noise values in the following three main types:

- $L_{10\ (18\ hour)}$, the L_{10} value from 6 am until midnight, which is the most common way of calculating traffic noise in Australia. Traffic data requirements include traffic flow, percentage of heavy vehicles and speed for the total 18 hour period between 6 am and midnight;

- $L_{10\ (hourly)}$, the L_{10} value for each hour over the 24 hour testing period; and

- X section is a facility to indicate the noise level relationship with distance from the source. The user can nominate a noise level and T-noise calculates how far from the road these levels occur, alternatively the user can nominate various distances from the road and T-noise calculates noise levels at these distances.

T-Noise can also give the L_{eq} value. The L_{eq} obtained from T-noise is not directly calculated, but is derived from each L_{10} value. $L_{eq(24\ hour)} = L_{10(18\ hour)}$ - 3.5 dB(A) and $L_{eq(hourly)} = L_{10(hourly)}$ - 3 dB(A). Therefore, the L_{eq} value from T-noise is only an approximation.

The output section displays the results of a calculation. The results are shown as a summary of calculated noise level values. A detailed list of correction values used in the process of calculation is also provided. The result can be displayed on screen or printed.

2.3.2 ITFNS1.1

The Prediction of Traffic Noise at Simple, Signalised Intersections (ITFNS1.1) was developed by The Australian Road Research Board. The ITFNS1.1 released in 1990 is the improved version of ITFNS 1 (released in 1989). The model considers the generation of traffic noise specific to intersections. The model was developed initially as a prediction tool for traffic noise from interrupted flow conditions that occur at intersections, where acceleration and braking manoeuvres are common (Samuels and Shepherd, 1990). However, in this study the model was used for both intersection conditions and straight road conditions because in the author's opinion a straight road could be considered as an intersection where none of vehicles run across the main road, but interrupted flow sometimes occurs.

ITFNS1.1 software requires any IBM-compatible personal computer with 1 Megabite of hard disk memory. The model consists of three main components, input data, calculation and output. The data required in the input section consists of source-receiver geometry information, vehicle information and noise-source relationship of vehicle types and vehicle attributes. All these components are combined mathematically to calculate the output as L_{10} and L_{eq} which can be printed or shown on screen (Samuels and Shepherd, 1990).

The input data required for ITFNS1.1 follows:

- Type of vehicle is categorised into three groups: cars, medium vehicles and trucks, that habitually run in each carriageway;

- Vehicle flow information (East to West, West to East, South to North and North to South) over each hour of the simulation. This information is also categorised with the delineations car, medium vehicle or truck.

- Total vehicle flow rates for each direction.

- Carriageway widths and receiver position descriptions.

- Linear vehicle noise source for each vehicle type.

- Traffic characteristics incorporating speed, volume and type of vehicle (Samuels and Shepherd, 1990).

2.3.3 STAMSON4.1

STAMSON4.1 is the improved version of STAMSON 3.X. It was introduced in 1990 by the Noise Assessment and Systems Support Approvals Branch of the Ministry of the Environment, Canada. This computer program has been developed to simplify the prediction of road and rail traffic noise. The technical content of the program is based on the road traffic prediction scheme, ORNAMENT, that was published in 1989, and the rail traffic prediction scheme, STEAM, that was published in 1990. It is designed for IBM PCs or compatible computers with PC-DOS or MS-DOS and a minimum of 512 kilobite of RAM and CGA, EGA, VGA, MDA Hercules graphics cards.

Inputs required for running STAMSON4.1 are similar to the prediction models explained above. However, there is some dissimilarity, which includes the categorisation of vehicle types, day/night time period calculation options, and built-in correction of intermediate surfaces (surface of the ground between the road segment and the receiver). For STAMSON4.1, vehicles are separated into three categories namely:

- automobiles that are passenger cars with two axles, four wheels and weigh less than 4,500 kg;

- medium trucks which are vehicles with two axles and six wheels and weigh less than 12,000 kg; and

- heavy trucks which are vehicles with three or more axles and weigh more than 12,000 kg.

The output acquired from STAMSON4.1 is the noise level in L_{eq}. The value can be expressed as $L_{eq(24\ hr)}$ or L_{eq} day/night value (Noise Assessment and Systems Support Approvals Branch, 1990).

CHAPTER 3

FIELD STUDY

This chapter describes the method of actual traffic noise measurement at the three locations where the models were compared. This includes information on guidelines and equipment used in this research as well as details of the measurement locations.

The measurement component of this study has been completed to achieve two main objectives, traffic noise measurement and traffic study for input to prediction models. Three study sites in the Hobart area were selected. The sites are located on Regent Street, Sandy Bay Road and the Tasman Highway. The traffic noise was measured continuously over a seven-day period. While a data logger was recording noise measurements, a traffic study was conducted consisting of traffic counting and a site condition study carried out over a minimum period of 10 hours for each site. The process was repeated for each site.

3.1 NOISE MEASUREMENT EQUIPMENT AND DATA COLLECTION

The basic equipment used for noise data collection consisted of two noise data loggers, the EL-215 Host Program and an acoustic calibrator. Average traffic count data and site information were obtained from the Department of Infrastructure Energy and Resources and Hobart City Council. A manual traffic count was also conducted at each site.

The Enviro-Log-215 noise data logger (Figure 3.1) and EL-215 Host Program, supported by Environmental Division, Department of Primary Industries, Water and Environment (DPIWE), Tasmania, were used to record noise data. These loggers are produced by Acoustic Research Laboratory Ltd. They are designed for medium to long-term noise monitoring applications with output of L_{eq} and statistical figures namely L_n, L_{max} and L_{min}. Normal control and configuration is accomplished via the EL-215 Host Program, which runs on DOS 3.3 (Acoustic Research Laboratory Ltd, 1997). The logger specifications are described in Appendix A.

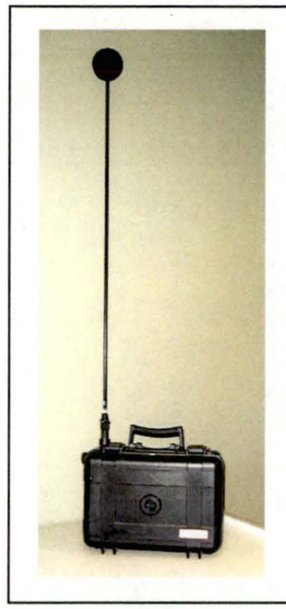


Figure 3.1 Enviro-Log-215 noise data logger

The main components of the instrument consist of a case (containing a circuit box, battery and control panel for the data logger), a microphone (Type 2 accuracy, according to Australian Standard AS 1259.1-1990 and AS 1259.2 – 1990), the EL-215 Host Program, a communications cable, calibrator adapter and a windshield. A Bruel and Kjaer acoustic calibrator was used for pre-measurement and post-measurement reference to confirm the accuracy of sound level meter. In this study, the possibility of maximum error that could occur was 0.4 dB.

The noise data were recorded at continuous 5 minute intervals with fast time response over 7 day periods. The collected data included measurement date and time, L_{max}, L_{min}, L_1, L_5, L_{10}, L_{50}, L_{90}, L_{95}, L_{99}, and L_{eq}. The loggers also recorded conditions of measurement consisting of: logger type; logger serial number; measurement title; start and stop time and date; pre-measurement reference value; post measurement reference value; frequency weighting; time response; range selection; statistical interval; engineering units and numbers of intervals.

The guidelines within Australian Standard AS 2702-1984 (Acoustic-Methods for the measurement of road traffic noise) were used for traffic measurement. The standard describes minimum instrument requirements, preferred scale of measurement, instrument positioning, and vehicle categorisation (Association's Committee on Community Noise, 1984).

Some historical daily traffic count data at Regent Street and Sandy Bay Road was provided by the Hobart City Council and the data for the Tasman Highway was obtained from the Department of Infrastructure, Energy and Resources. This data was used as an indication of the traffic levels that could be expected during manual counting and not included in the study. Half of the one-hour period was used for traffic volume measurement, this is in keeping with accepted statistical practice (Road System and Engineering Queensland, 2000). For each location traffic data was recorded for a minimum of 10 hours in each noise measurement period. The delineations car, medium size truck and heavy truck were used for traffic volume recording in order to meet the input requirements of the prediction models.

Site information was collected in the following manner:

- Site locations were recorded using a GPS 12 personal navigator GARMIN;
- Road gradients were measured using a clinometer;
- Road widths and all distance measurements were completed using a measuring tape;
- An anemometer was used for wind speed measurement; and
- A thermometer was used for temperature readings.

The site descriptions and measurement periods are described below.

3.2 Noise measurement sites

3.2.1 Site selection

There are many considerations associated with measurement site selection which have been taken into account, namely equipment security, observer safety, measurement procedure standards, and traffic density. It was also considered desirable to select sites with different types of traffic to better test the models. Safety of the monitoring equipment from vandalism and stealing was the first priority. Also, the procedure suggested in the Australian Standard

AS 2702-1984 Acoustic-Methods for the measurement of Road Traffic Noise was used for the measurement and data collection in this study. Furthermore, the sites were selected as a result of their location on roads with relatively high traffic volumes, perceived convenience and likelihood of creating traffic noise problems (Association's Committee on Community Noise, 1984).

3.2.2 Site descriptions

Site 1: Regent Street was selected as it represented a non-busy urban asphalt arterial road. Regent Street was a 2-way road with the total road width of 12 meters. The traffic volume was approximately 10,000 vehicles per day. The speed limit for this road was 60 kilometres per hour. The noise equipment was positioned inside the fence of the house at the corner of Regent Street and Lord Street at the Easterly 526355 E and the Northerly 5250153 N, in the suburb of Sandy Bay (as shown in Figure 3.2). The road conditions of Lord Street were similar to which were observed on Regent Street, despite the traffic volume was less than 1,000 vehicles per day.

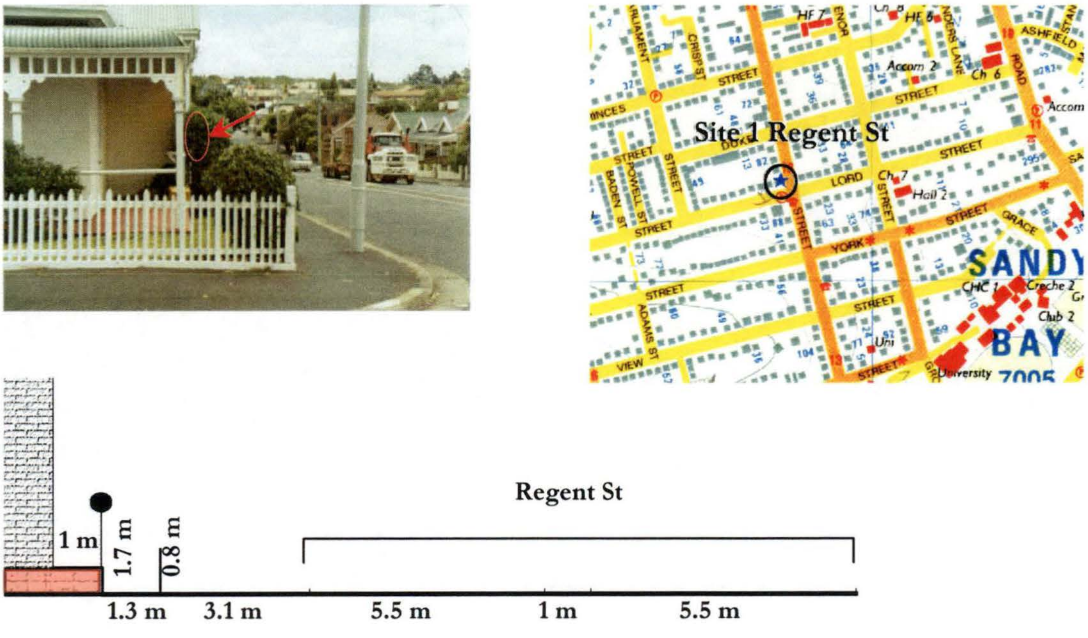


Figure 3.2 Site 1 Regent Street location information
Adapted from Department of Environmental and Land Management, 1998

The initial measurement:

- Noise measurements were recorded between 29th of November and 6th of December 2001.

- Traffic counts were conducted from 15.00 –22.00 on the 3rd, 12.00 – 15.00 on the 4th and 8.30 – 13.00 on the 5th of December.

The repeat measurement:

- Noise measurements were recorded between 2nd and 15th of January 2002.

- Traffic counts were conducted from 11.00 – 19.00 on the 3rd, 8.00 – 11.00 on the 4th of January.

Site 2: Sandy Bay Road was selected to represent an urban asphalt arterial road. Sandy Bay Road was a 2-way road with the total road width of 15 meters. The speed limit for this road was 60 kilometres per hour. The traffic volume was approximately 20,000 vehicles per day. The noise data logger was located at the Easterly 526840 E and the Northerly 5250112 N (as in Figure 3.3).

The initial measurement:

- Noise measurements were recorded between 10th and 17th of December 2001.

- Traffic counts were conducted from 13.00 –22.00 on the 13th and from 9.00 – 13.00 on the 14th of December.

The repeat measurement:

- Noise measurements were recorded between 2nd and 10th of January 2002, and again between 21st and 22nd of January. This second study interval was deemed necessary by the author due to the operation of a construction site close the study site on the 2nd and 10th of January. The author considered that the measurements on these days would not be reliable and conducted another noise measurement on 21st and 22nd to confirm and compare the reliability of the data.

- Traffic counts were conducted from 12.00 – 20.00 on the 21st and from 8.00 – 12.00 on the 22nd of January.

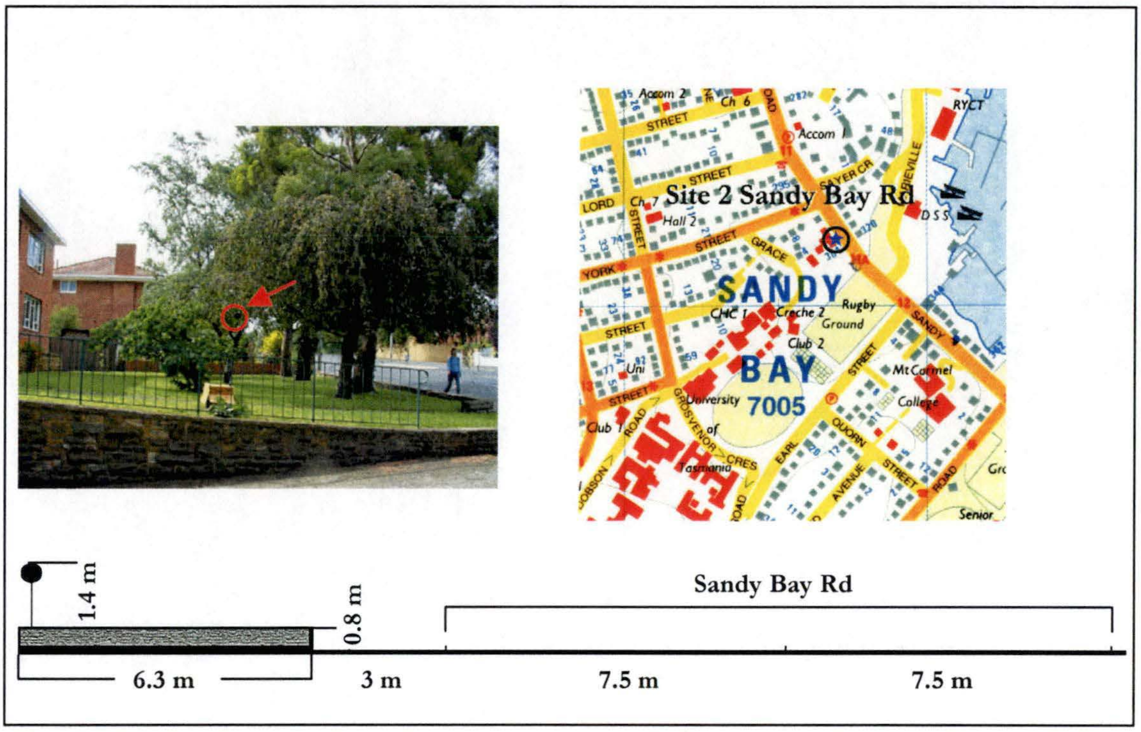


Figure 3.3 Site 2 Sandy Bay Road location information
Adapted from Department of Environmental and Land Management, 1998

Site 3: Tasman Highway was selected to represent an asphalt highway road. The Tasman Highway was a 2-way road with the total road width of 15 meters. The speed limit for this stretch of road was 70 kilometres per hour. The average traffic volume was 50,000 vehicles per day. The noise data logger was located at the Easterly 527148 E and the Northerly 5253305 N (as in Figure 3.4).

The initial measurement:

- Noise measurements were recorded between 17th and 24th of December 2001.

- Traffic counts were conducted from 8.00 –10.00 on the 20th and from 10.00 – 18.00 on the 21st of December.

The repeat measurement:

- Noise measurements were recorded between 24th and 31st of December 2001.

- Traffic counts were conducted from 9.00 –16.00 on the 27th and from 16.00 – 19.00 on the 28th of December.

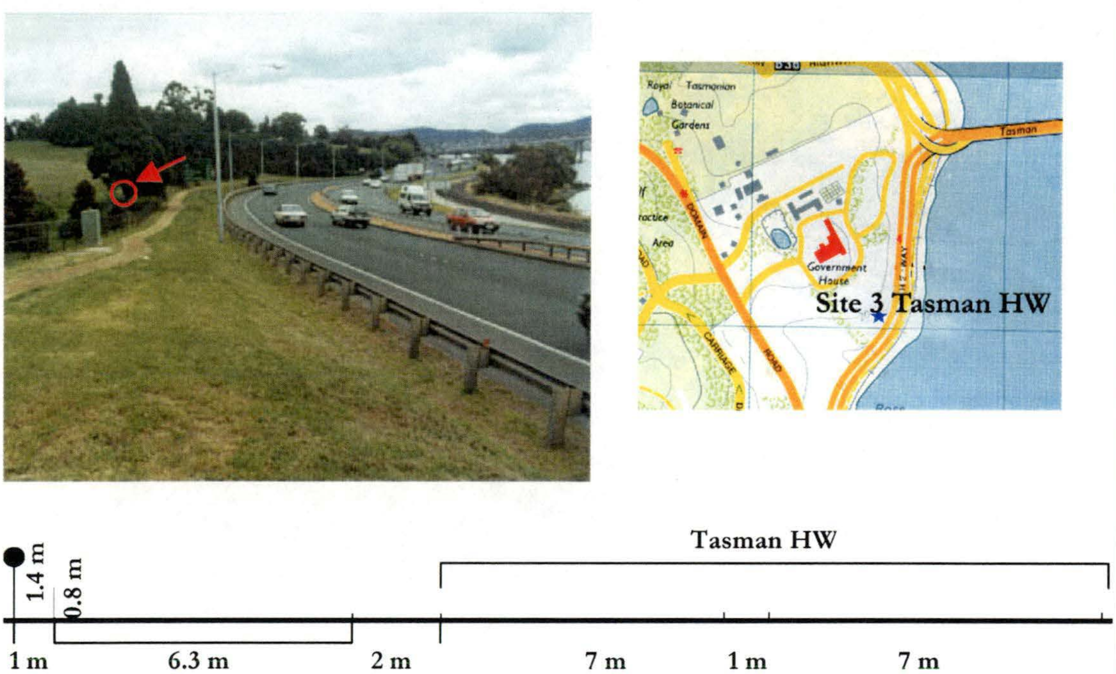


Figure 3.4 Site 3 Tasman Highway location information
Adapted from Department of Environmental and Land Management, 1998

3.3 ANALYSIS METHOD

After receiving both noise data and data from the prediction models, the noise values from actual noise measurements and the calculated noise values were compared. Since some models require different input and provide different output, the comparisons were conducted separately for each model.

An hour-by-hour comparison of the output from T-Noise and the actual figures measured was carried out using the L_{10} values. This approach was adopted due to this model originally being designed for L_{10} calculation. As the measured noise data has been operated to collect $L_{10\ (5\ min)}$, a representation of $L_{10\ (hourly)}$ must be gathered. The mode average was used in this study.

The comparison of ITFNS 1.1 output with the measured values was made in the same manner as the comparison of T-noise because ITFNS 1.1 also outputs L_{10} values.

Stamson4.1 provides output in $L_{eq\ 24\ hr}$ and $L_{eq\ day/night}$ values, therefore, L_{eq} figures were used for the comparison. As the L_{eq} values obtained from actual measurement were expressed in $L_{eq\ 5\ min}$ values these were converted to $L_{eq24\ hr}$ using the following equation.

$$L_{eq}\text{ average} = \frac{10\log\left[\sum_{n}^{i=1} 10^{\frac{SPL_i}{10}}\right]}{n}$$

Where: n = number of sound pressure level values

SPL = sound pressure level

After the comparisons the difference between actual measured noise level and noise level from numerical models were recorded. The spread of error gained from the comparisons were examined. Accuracy of each prediction model was explained by the percentage of error created by the prediction model and the magnitude of the majority of the errors when compared to the actual levels. This process involved the equations below.

Difference value = predicted noise level – actual measured noise level

Percentage of error = Difference value*100/predicted noise level

In adopting this method, the assumption has been made that the sound recording equipment provided an accurate measure of actual noise.

CHAPTER 4
RESULTS

This chapter presents the results gained from the study. The results include the explanation of traffic patterns and noise levels of each study site; the report of traffic counts conducted during the noise measurements; and the results of the noise levels comparison between actual noise measurement and prediction models.

4.1 TRAFFIC NOISE PATTERNS AND NOISE LEVELS

The traffic noise pattern is examined mainly by focusing on the time series of noise levels during the study period. The recorded noise level of each interval is plotted chronologically in order to clearly see any pattern of the changing noise levels. To understand the situation of traffic noise in the study sites, official and reliable traffic noise criteria are needed as a reference point. This research follows the criteria commenced in the NSW Environmental criteria for road traffic noise (Appendix D) and the Draft Environment Protection Policy (Noise) and Regulatory Impact Statement, Development of a Noise Policy for Tasmania (Appendix E). These documents have been used to determine whether the recorded noise levels exceed the acceptable levels. The criteria and guidelines contained within these documents were examined resulting in the conclusion that two readings would be taken, $L_{10(18\ hr)}$ and $L_{eq(5\ min)}$. Although the NSW criteria suggests that $L_{eq\ (15\ hr)}$ be used for the day period (7am to 10 pm) and $L_{eq(9\ hr)}$ for the night period, in this research, $L_{eq(5\ min)}$ has provided a clear picture of noise levels in comparison with these criteria. The author considered that L_{max} was also an important figure because the levels of L_{max} can be used to project the possibility of unusually high noise levels that could occur in each 5-minute interval. This characteristic can also be used to project the likelihood of community annoyance.

The noise data recorded during the field study indicate that traffic noise at every study site followed a similar pattern. Uniformly, the noise levels increased rapidly, starting from around 3:00 am at the $L_{eq(5\ min)}$ at the lowest point of approximately 50 to 55 dB(A) until the level reached the highest point of $L_{(5\ min)}$ varying from 70 to 75 dB(A) at around 8:30 am and this high level continued to 9:00 pm. After this time, the noise level declined by a few decibels.

The study indicated an almost steady noise level during the daytime at approximately 70 dB(A) of $L_{eq(5\ min)}$, after 9:00 pm noise levels declined. The lowest level typically occurred between 2:00 am and 4:00 am, however, some periods indicate a departure from this pattern. These departures were caused by uncommon events occurring during the measurement period. These may indicate the use of a horn or brake, the starting of a lawnmower, a car alarm signal, construction work or other human activity.

The details of each criterion contained in the NSW Environmental criteria for road traffic noise and the Draft Environment Protection Policy (Noise) and Regulatory Impact Statement, Development of a Noise Policy for Tasmania are explained below.

- NSW road traffic noise criteria for redevelopment of existing freeways and arterial roads state that noise levels for day-time (7:00 am to 10:00 pm) measured as $L_{eq(15\ hr)}$ should not exceed 60 dB(A). For night-time (10:00 pm to 7:00 am) measured as $L_{eq(9\ hr)}$, the noise levels should not exceed 55 dB(A). Although these criteria are classified with regard to redevelopment of existing freeways and arterial roads they are also applied to those not under redevelopment (EPA, 1999).

- Tasmania draft guidelines for road traffic noise recommend that the $L_{10(18\ hr)}$ measured between 6:00 am and 0:00 am should not rise above 63 dB(A)and the $L_{eq(1hr)}$ levels between 10:00 pm and 7:00 am should not exceed 55 dB(A). Although these guidelines apply only to new and upgraded road which are first opened to public traffic on or after the 1st of January 2004, the author considered that the guidelines provided a basic idea of traffic noise levels standard that will be used further in Tasmania (Department of Primary Industries, Water and Environment, 2002).

The delineation between day-time and night-time periods in this research followed the NSW example. This states that a day-time period spans 7:00 am to 10:00 pm and night-time 10:00 pm to 7:00 am. The noise levels recorded in each of the study sites were beyond the acceptable levels stated in the both the day-time NSW criterion and the Tasmania guidelines. Nevertheless, only approximately 50 percent of noise measured during night-time periods exceeded the NSW criterion. The details of noise pattern and levels are shown in Figures 4.1 to 4.6 and in Tables 4.1 to 4.3; the results of each study site are discussed below.

4.1.1 Site 1: Regent Street

The initial measurement at Site 1 was conducted between 29th of November and 6th of December 2001. $L_{eq(5\ min)}$ values were in the range of 50 to 60 dB(A) during night-time periods. The quietest period was from around 1:00 am until 5:30 am. The $L_{eq(5\ min)}$ increased rapidly in the morning and stayed steady from 10:00 am to 7:00 pm at approximately 70 dB(A). Observations on each day indicated noise levels beyond the acceptable levels stated in the NSW criteria. During a short period in the middle of each night the $L_{eq\ (5min)}$ dropped below 55 dB(A) (as in Figure 4.1). In similar fashion, $L_{10(18\ hr)}$ values exceeded the Tasmanian guidelines of 63 dB(A) on each day. The $L_{10(18\ hr)}$ values varied from 73 to 74 dB(A) indicating a level 9.5 to 11 decibels above the guideline (see Table 4.1). L_{max} values were normally between 75 and 90 dB(A) during the day and reduced to between 75 and 50 dB(A) in the evening.

The noise levels from the repeated measurements (Figure 4.2), recorded between the 2nd and 15th of January 2002, indicate the same pattern and range of noise levels as in the initial measurements. However, the noise pattern indicated on Monday was slightly different from the established trend. This is due to the noise interference created by the operation of a lawn mower in close proximity to the study site. The $L_{10(18\ hr)}$ figures gained from this test were between 70.5 and 77 dB(A). These levels exceeded the 63 dB(A) guideline by 7.5 to 14 dB(A) (see Figure 4.2 and Table 4.1).

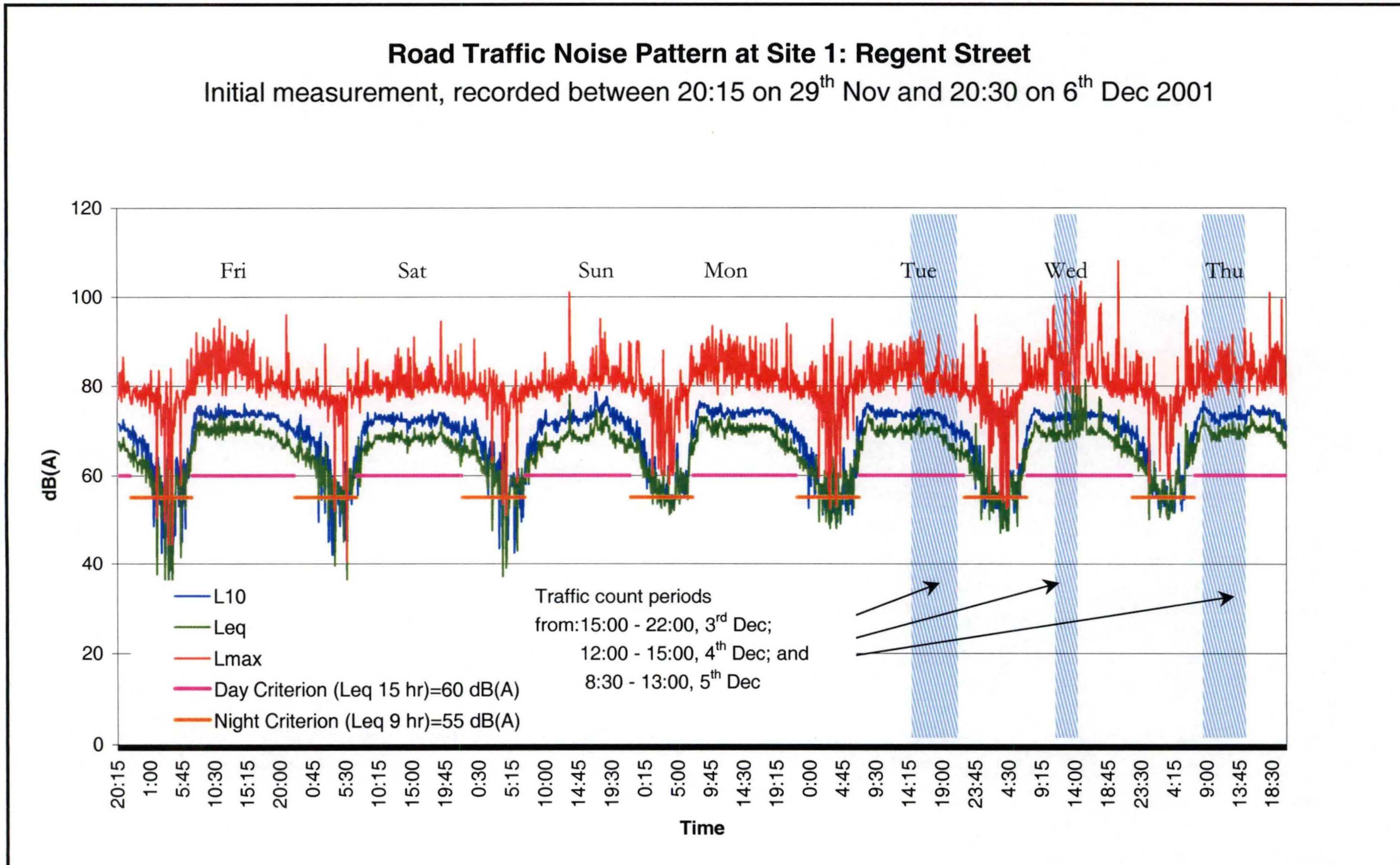


Figure 4.1 Road traffic noise pattern at Site 1: Regent Street, initial measurement

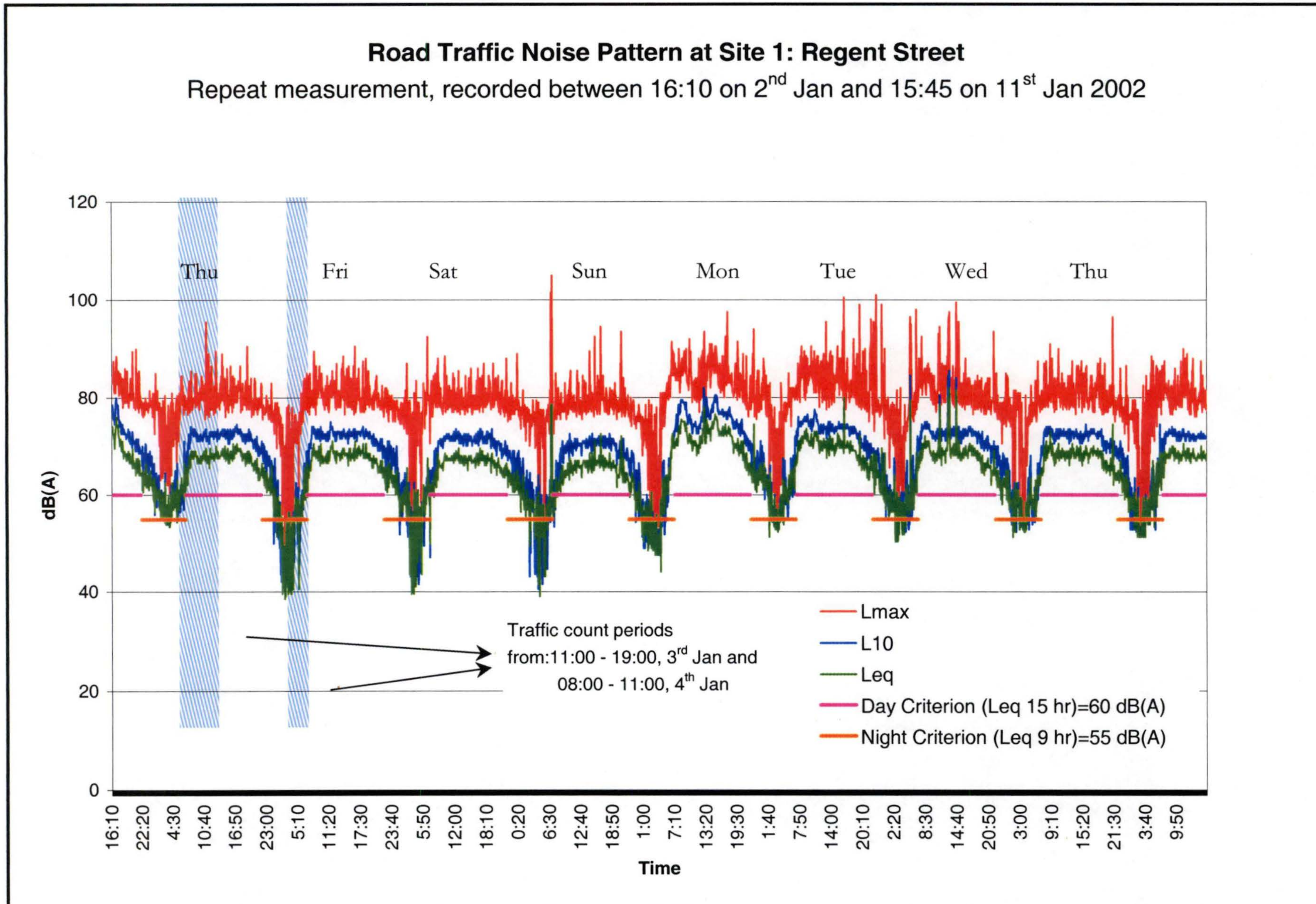


Figure 4.2 Road traffic noise pattern at Site 1: Regent Street, Repeat measurement

Table 4.1 $L_{10(18\,hr)}$ at Site 1: Regent Street compared with Tasmania Road Traffic Noise Guideline

Date	Day	$L_{10(18\,hr)}$	Decibels above guideline
Initial measurement			
30 Nov 01	Fri	73.5	10.5
01 Dec 01	Sat	72.5	9.5
02 Dec 01	Sun	73	10
03 Dec 01	Mon	74	11
04 Dec 01	Tue	74	11
05 Dec 01	Wed	73	10
Repeat measurement			
03 Jan 02	Thu	72	9
04 Jan 02	Fri	72	9
05 Jan 02	Sat	71.5	8.5
06 Jan 02	Sun	70.5	7.5
07 Jan 02	Mon	77	14
08 Jan 02	Tue	74	11
09 Jan 02	Wed	73	10
10 Jan 02	Thu	72.5	9.5

4.1.2 Site 2: Sandy Bay Road

The noise levels for Sandy Bay Road were initially recorded between the 10th and 17th of December 2001. Although the noise pattern is similar to that of Site 1, the noise levels at Site 2 show less difference between night-time and day-time. The quietest period usually occurred between 3:00 and 5:30 am, however, the noise level went up until it reached around 70 dB(A) at approximately 8:30 to 9:00 am on each day. This remained stable during the day and declined at around 10:00 pm. On Friday and Saturday the noise level remained high for approximately 6 hours longer than the established trend. The acceptable NSW noise criteria were exceeded for both day-time and night-time periods (see Figure 4.3). All of the $L_{10(18\ hr)}$ were also above the Tasmanian guidelines (as in Table 4.2).

Noise levels obtained from the repeat measurement, recorded between 2nd and 10th of January 2002, indicate a similar trend to that established in the initial measurement. However, the noise level fluctuated on day sixth, seventh and eighth. This was due to noise interference created from construction that was carried out in close proximity to the noise recording equipment. Also, a signboard set up between the road and the microphone caused interference resulting in the night-time noise levels declining below the normal trend. Most of the noise levels were higher than the NSW criteria (Figure 4.4) and $L_{10(18\ hr)}$ exceeded 63 dB(A) almost every day except on Tuesday the 8th of Jan (the seventh amplitude in Figure 4.4 and detail as in Table 4.2).

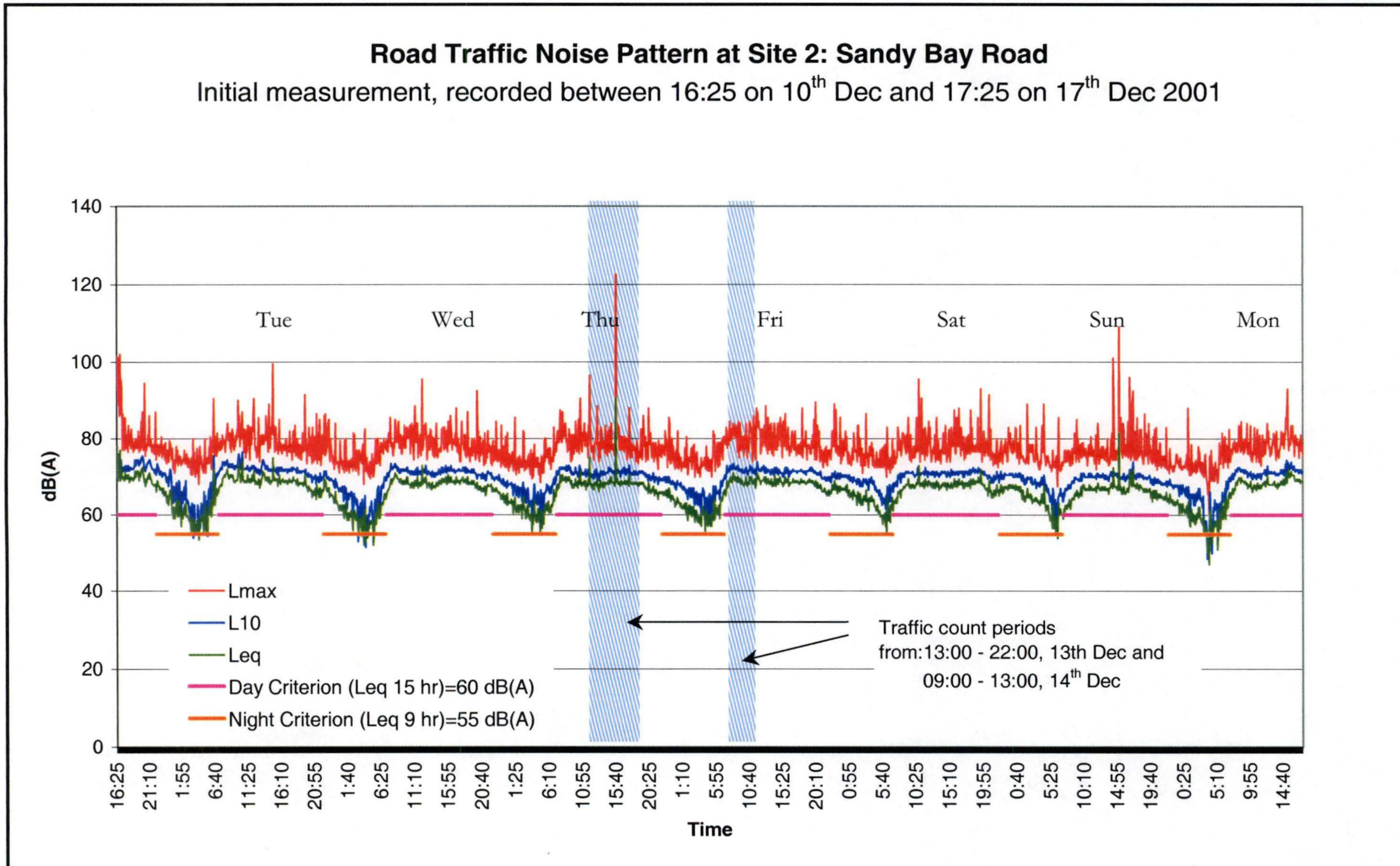


Figure 4.3 Road traffic noise pattern at Site 2: Sandy Bay Road, initial measurement

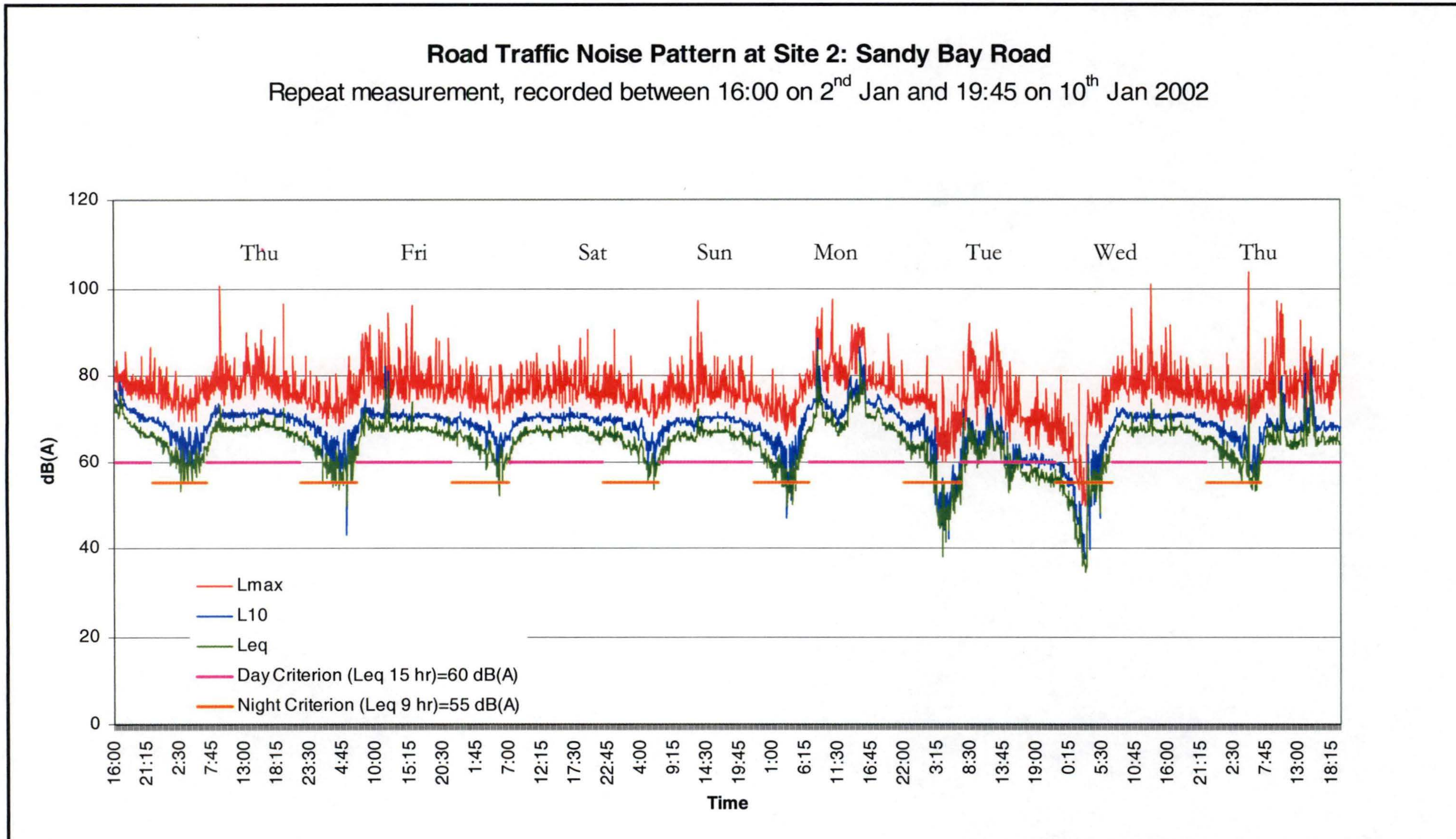


Figure 4.4 Road traffic noise pattern at Site 2: Sandy Bay Road, Repeat measurement

Table 4.2 $L_{10(18\ hr)}$ at Site 2: Sandy Bay Road compared with Tasmania Road Traffic Noise Guideline

-

Date	Day	$L_{10(18\ hr)}$	Decibels above guideline
Initial measurement			
11 Dec 01	Tue	72	9
12 Dec 01	Wed	71.5	8.5
13 Dec 01	Thu	71	8
14 Dec 01	Fri	71.5	8.5
15 Dec 01	Sat	71	8
16 Dec 01	Sun	70	7
Repeat measurement			
03 Jan 02	Thu	71	8
04 Jan 02	Fri	70.5	7.5
05 Jan 02	Sat	70	7
06 Jan 02	Sun	70	7
07 Jan 02	Mon	72	9
08 Jan 02	Tue	59.5	-3.5
09 Jan 02	Wed	70.5	7.5

4.1.3 Site 3: Tasman Highway

The noise pattern at Site 3 showed a similar trend to that established at the previous study sites, however, the correlation between noise levels and time of the day was slightly different. The first noise measurement was conducted between the 17th and 24th of December 2001. $L_{eq\ (5\ min)}$ was below 55 dB(A) between 2:00 and 4:00 am. The noise levels increased rapidly prior to steadying at the level of approximately 70 dB(A) during the period 11:00 am to 7:00 pm, this culminated in the level quickly declining after 7:00 pm. The pattern is slightly different in the last five days of the data recording. This interference was caused by an influx of human activity in a house located close to the noise recorder (Figure 4.5). $L_{eq(5\ min)}$ varied between approximately 50 dB(A) and 70 dB(A) in each cycle. $L_{10(18\ hr)}$ were between 69.5 and 72 dB(A). However, in general, the noise levels were higher than both the NSW criteria and Tasmanian guidelines (see Figure 4.5 and Table 4.3).

The repeat measurement was conducted immediately after the initial measurement. This involved the period from the 24th to 31st of December 2001. The noise pattern resembled that pertaining to the previous measurement. Noise levels were around 1 to 2 dB(A) lower than the initial data. The fluctuation of noise levels on the first and second day was attributed to the same human influx as in the initial measurement. This is likely to be the cause of the very high level of L_{max} appearing on the second study day. The noise pattern and $L_{10(18\ hr)}$ are illustrated in Figure 4.6 and Table 4.3.

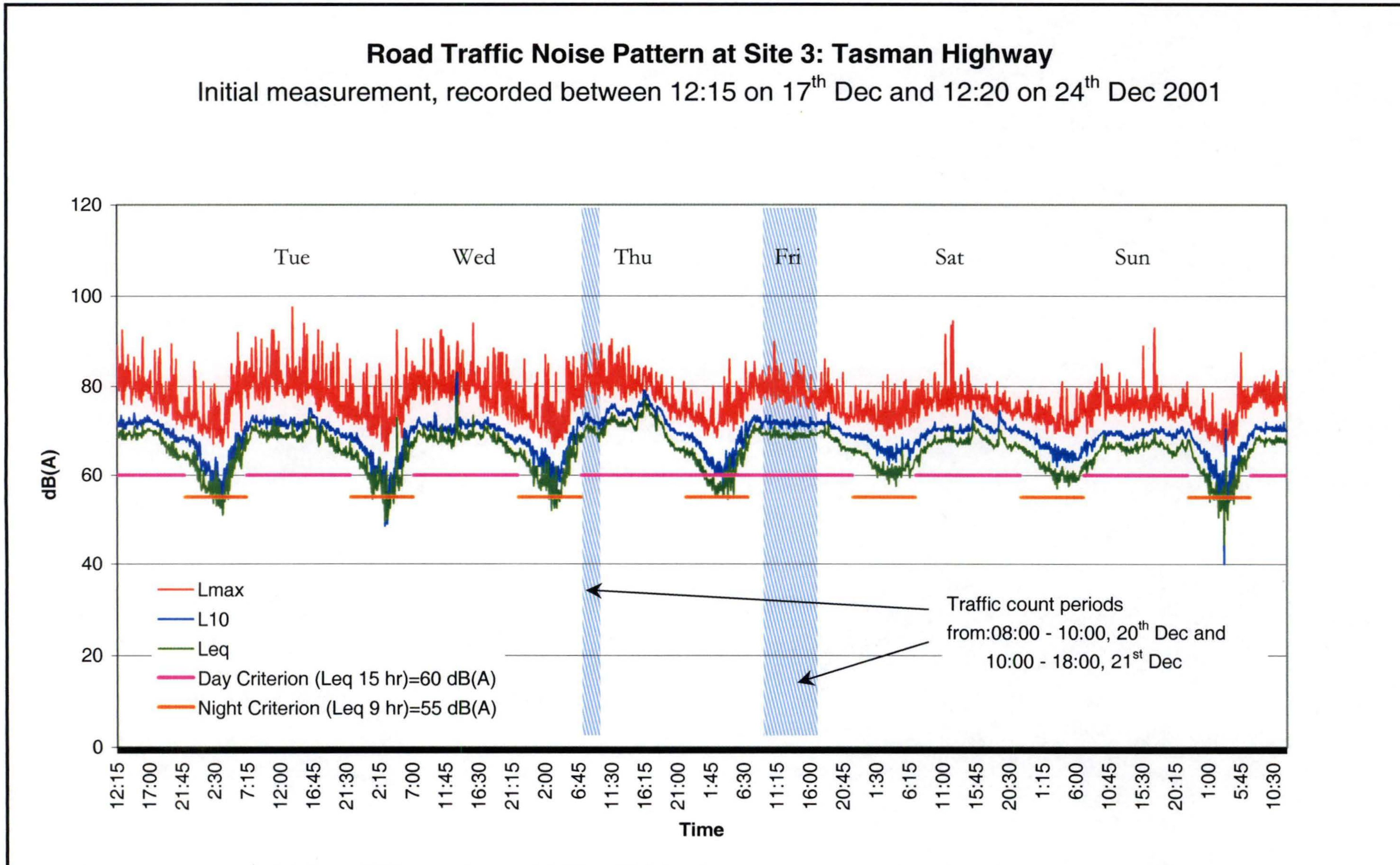


Figure 4.5 Road traffic noise pattern at Site 3: Tasman Highway, initial measurement

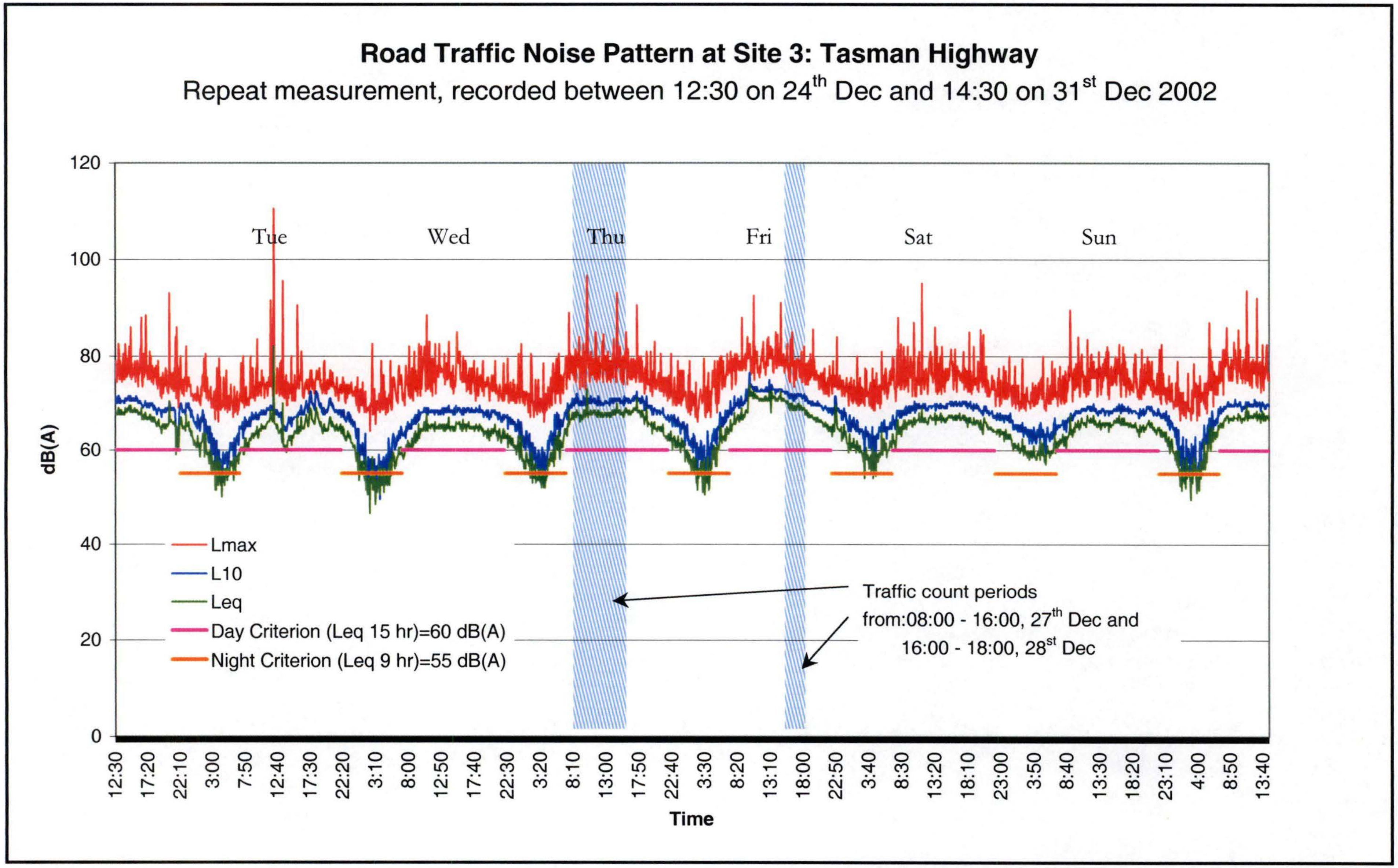


Figure 4.6 Road traffic noise pattern at Site 3: Tasman Highway, Repeat measurement

Table 4.3 $L_{10(18\ hr)}$ at Site 3: Tasman Highway compared with Tasmania Road Traffic Noise Guideline

Date	Day	$L_{10(18\ hr)}$	Decibels above guideline
Initial measurement			
18 Dec 01	Tue	72	9
19 Dec 01	Wed	71.5	8.5
20 Dec 01	Thu	72	9
21 Dec 01	Fri	72	9
22 Dec 01	Sat	70	7
23 Dec 01	Sun	69.5	6.5
Repeat measurement			
25 Dec 01	Thu	68.5	5.5
26 Dec 01	Wed	68	5
27 Dec 01	Thu	70	7
28 Dec 01	Fri	72.5	9.5
29 Dec 01	Sat	69.5	6.5
30 Dec 01	Sun	68.5	5.5

4.2 TRAFFIC VOLUME

The traffic volume studies were conducted during traffic noise measurements to examine the number of vehicles that travelled past each site. The vehicles were categorised into three groups following the guideline suggested by the Noise Assessment and Systems Support (1989). These include categories of heavy truck, medium truck and car. The traffic volume of each measurement, with the combination of the three categories of vehicles, shown hourly in Figure 4.7 to Figure 4.12.

The study found that Regent Street shows the smallest vehicle population per hour while the Tasman Highway has the greatest traffic volumes in the same period of time. At Site 1: Regent Street, the traffic volume varied from 234 to 1,280 vehicles per hour, the busiest time was between 5:00 and 6:00 pm. At Site 2: Sandy Bay Road, the number of vehicles varied from 940 to 2,210 vehicles per hour, the busiest hour of the initial measurement was between 2:00 and 3:00 pm and from 5:00 to 6:00 pm during the repeat measurement. At Site 3: Tasman Highway, the total vehicles per hour changed from 2,506 to 5,210. The busiest hour of the initial measurement was between 5:00 and 6:00 pm, while the hour from 4:00 to 5:00 pm of the repeat measurement had the greatest vehicle population. The results of each site are detailed below.

4.2.1 Site 1: Regent Street

At Site 1: Regent Street, 13 hours of traffic counting, from 8:00 am to 7:00 pm and from 9:00 pm to 11:00 pm, was carried out during the initial measurement (Figure 4.7 and Table 4.4). A total number of vehicles of 11,179 was recorded. This number is comprised: 513 heavy trucks; 905 medium size trucks; and 9,761 cars. Trucks accounted for 11.7 percent of total vehicles. The majority of totals fell between 750 and 1,100 vehicles per hour. However, the traffic volume during the periods 9:00 to 10:00 am, 3:00 to 4:00 pm and 5:00 to 6:00 pm showed higher numbers of, 1,084, 1,235 and 1,280 vehicles per hour respectively. The road was found to be less busy in the early morning and during the night. Noticeably, the percentage of trucks counted hourly remained relatively constant between 9:00 am and 5:00 pm, this occurred within the range of 13.7 and 16.4 percent.

The traffic count, conducted as part of the repeat measurement (Figure 4.8 and Table 4.4), was taken over an 11-hour period from 8:00 am to 7:00 pm. A total number of 9, 296 vehicles was recorded consisting of 374 heavy trucks, 830 medium trucks, and 8,292 cars. The average percentage of trucks was 10.8, 0.9 percent lower than the previous measurement. The total volume changed between 1,360 and 2,210 vehicles per hour. The majority of hourly traffic-count figures were in the range of 800 to 1,000 vehicles per hour. The maximum was recorded during the period between 5:00 and 6:00 pm, as in the initial measurement. The minimum was recorded from 6:00 to 7:00 pm. Generally, hourly traffic volumes exhibited relatively little change during the traffic counting period.

In general, at Site 1: Regent Street, the number of vehicles travelling past the study site was approximately within the range of 800 to 1,000 vehicles per hour during normal work time (9:00 am – 5:00pm). The busiest time of the day was from 5:00 to 6:00 pm, this correlates with the usual times at which people finish work. The number of trucks traveling on the road during the counting time was approximately 11 percent of the total vehicles.

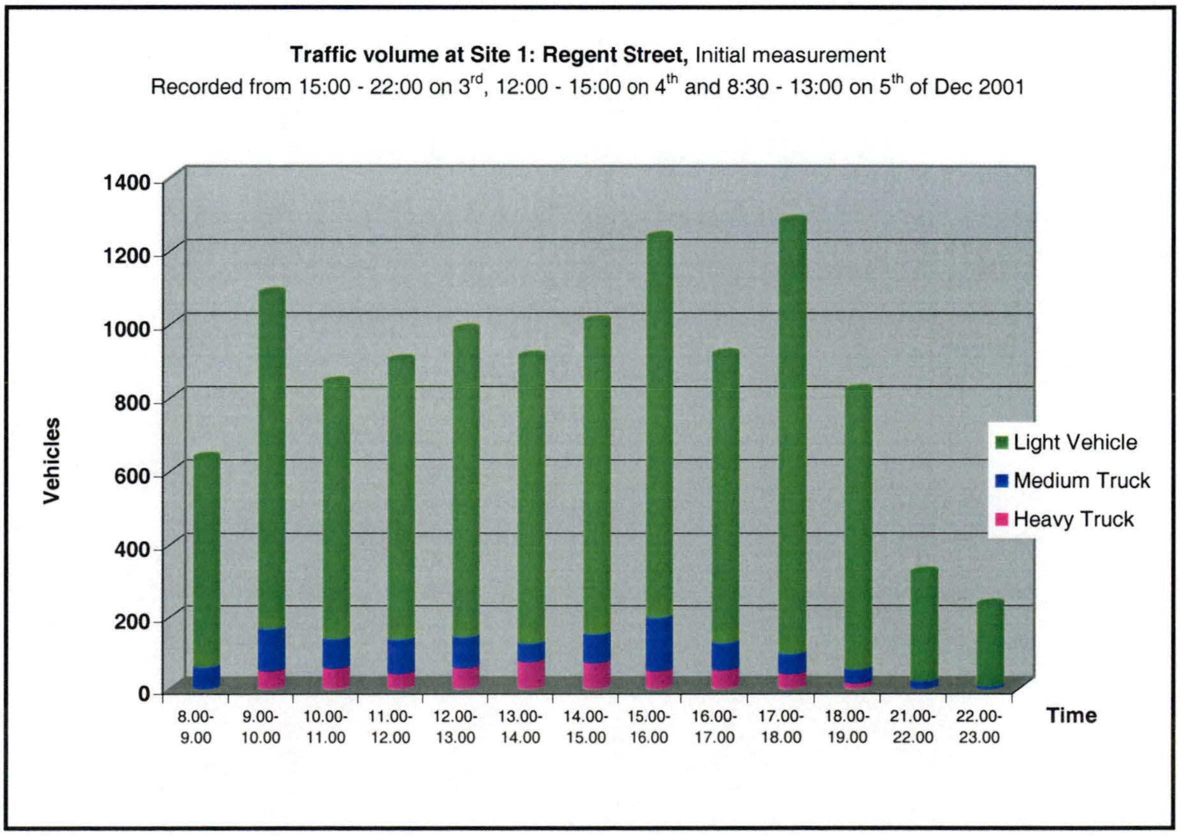


Figure 4.7 Traffic volume at Site 1: Regent Street, initial measurement

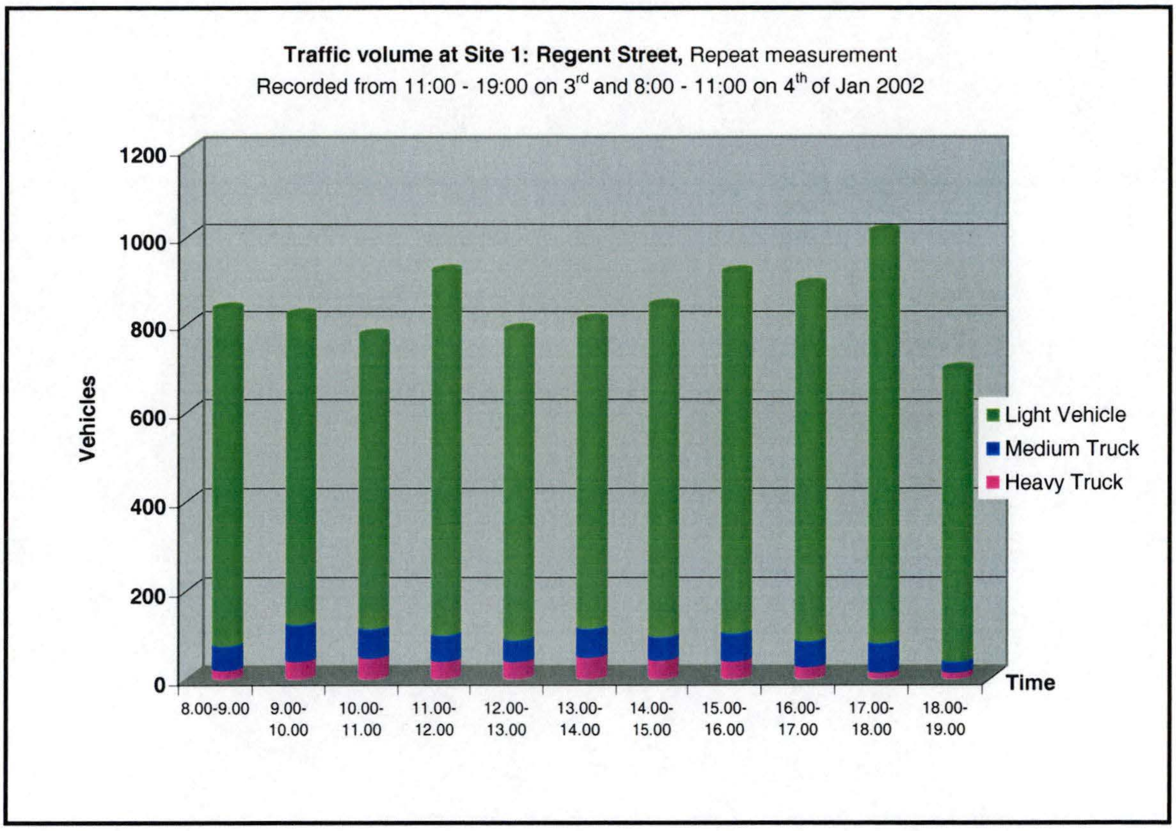


Figure 4.8 Traffic volume at Site 1: Regent Street, Repeat measurement

Table 4.4 Hourly traffic volume and percentage of trucks recorded at Site 1: Regent Street

Time	Heavy truck	Medium truck	Light vehicle	Percent truck
Initial Measurement				
8.00-9.00	1	59	576	9 4
9.00-10 00	49	117	918	15 3
10.00-11.00	57	81	704	16 4
11.00-12.00	42	94	766	15 1
12.00-13.00	58	85	842	14.5
13 00-14.00	75	50	787	13 7
14.00-15.00	72	79	857	15 0
15.00-16.00	49	148	1039	15.9
16 00-17.00	52	75	791	13.8
17.00-18.00	41	55	1184	7 5
18.00-19.00	16	37	767	6 5
21.00-22 00	1	19	302	6.2
22.00-23.00	0	6	228	2 6
Total	**513**	**905**	**9761**	**Average = 11.7**
Total Traffic Volume			**11,179.0**	
Repeat Measurement				
8.00-9.00	20	54	760	8.9
9.00-10.00	40	82	698	14.9
10.00-11.00	47	65	662	14.5
11.00-12.00	40	58	822	10.7
12.00-13.00	39	48	699	11.1
13.00-14.00	49	64	695	14 0
14.00-15.00	42	52	748	11.2
15.00-16.00	40	62	816	11.1
16.00-17.00	27	57	804	9.5
17.00-18.00	15	65	930	7.9
18.00-19.00	15	23	658	5.5
Total	**374**	**630**	**8292**	**Average 10.8**
Total Traffic Volume			**9,296.0**	

4.2.2 Site 2: Sandy Bay Road

During the initial measurement a traffic count was conducted over a 13-hour period (Figure 4.9 and Table 4.5). During this count a total of 21,238 vehicles were recorded. This number is comprised of 662 heavy trucks, 2,159 medium trucks and 18,417 cars. In each hour approximately 13.1 percent of the total vehicles consisted of trucks. The volume generally fluctuated at around 1,500 to 2,000 vehicles per hour. Clearly, the road was found to be busier during the afternoon period (1:00 pm to 6:00 pm) than during the morning (9:00 am to 1:00 pm). The busiest hour was between 3:00 and 4:00 pm with a maximum number of 2,210 vehicles per hour. The lowest count occurred during the last hour of observation being 838 vehicles. The number of trucks that travelled past each hour remained relatively constant between 9:00 am and 5:00 pm in the range of 254 to 315 vehicles per hour. The number of vehicles counted dropped quickly after 5:00 pm.

In the repeat measurement (Figure 4.10 and Table 4.5), 18,274 vehicles were counted during 12 hours of study carried out between 8:00 am and 8:00 pm. This number consisted of 931 heavy trucks, 1,511 medium trucks and 15,832 cars. The hourly average percentage of trucks during the study period was 13.4, 0.3 percent lower than the figure from the initial measurement. Similar to the previous observation, the number of vehicles travelling during the afternoon period was higher than the number discovered during the morning. The number of vehicles using this road was approximately between 1,500 to 2,000 vehicles per hour between 12:00 am and 6:00 pm, and 1,000 to 1,500 vehicles per hour between 8:00 am until noon. The busiest hour was between 5:00 and 6:00 pm, again correlating with a typical finishing time for city workers. The study found that there were two distinct phases of trucks during this investigation. The number of trucks slightly increased from 200 vehicles in the first hour to a maximum of 278 vehicles at the end of the 10:00 to 11:00 am period. Following this, the numbers slowly decreased to the minimum of 178 vehicles from 12:00 am to 1:00 pm. After this, the number of trucks increased again. It gradually rose from 206 vehicles in the following hour to 222 vehicles between 2:00 and 3:00 pm; this number then fell to 212 vehicles from 4:00 to 5:00 pm. The truck volume augmented again to 226 vehicles in the next one-hour period and dropped sharply afterward.

In summary, the Sandy Bay traffic volume indicates approximately 1,000 to 2,000 vehicles traveling hourly comprising a truck percentage of around 13. People were more likely to use this road in the afternoon than in the morning. Although the busiest hour in the initial measurement was the 3:00 to 4:00 pm period, the busiest hour in the repeat measurement occurred in the same period as that of Regent Street, being between 5:00 and 6:00 pm. Since counting for the initial measurement was conducted on a Friday it is assumed that work-finishing times may have skewed the data.

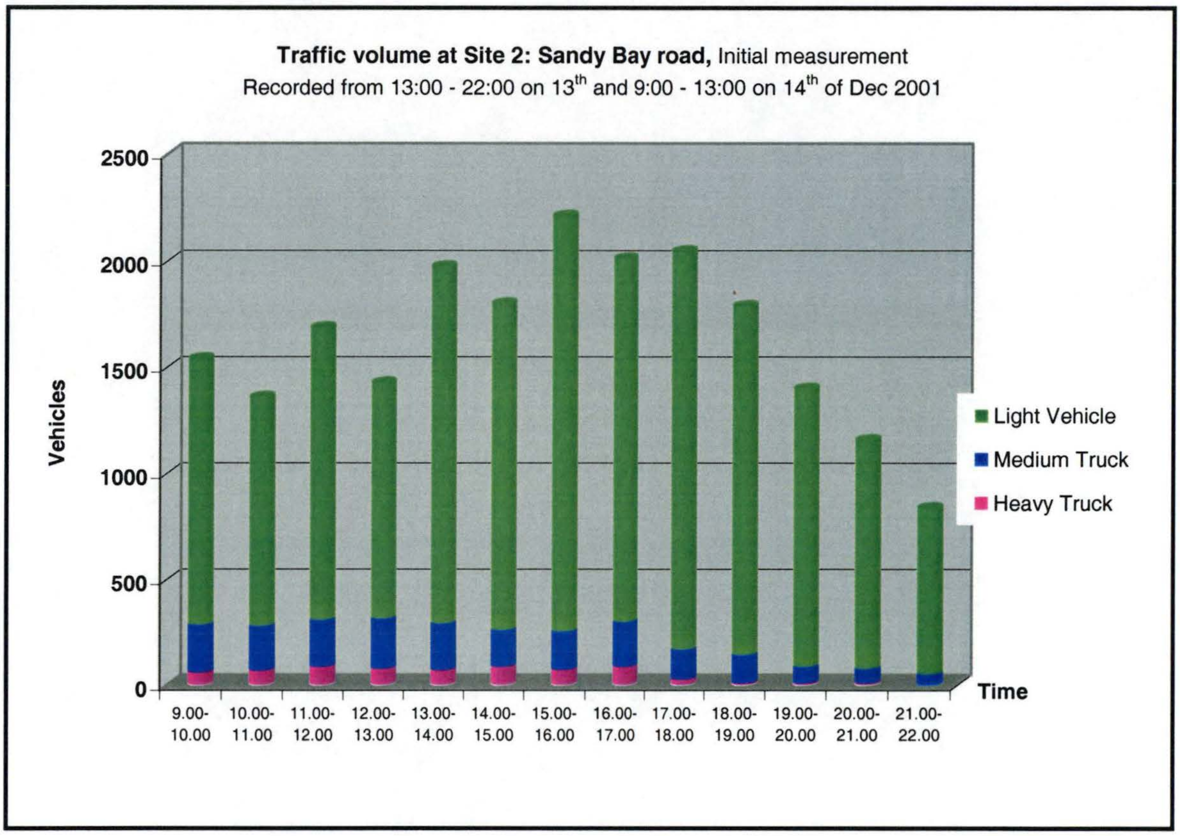


Figure 4.9 Traffic volume at Site 2: Sandy Bay Road, initial measurement

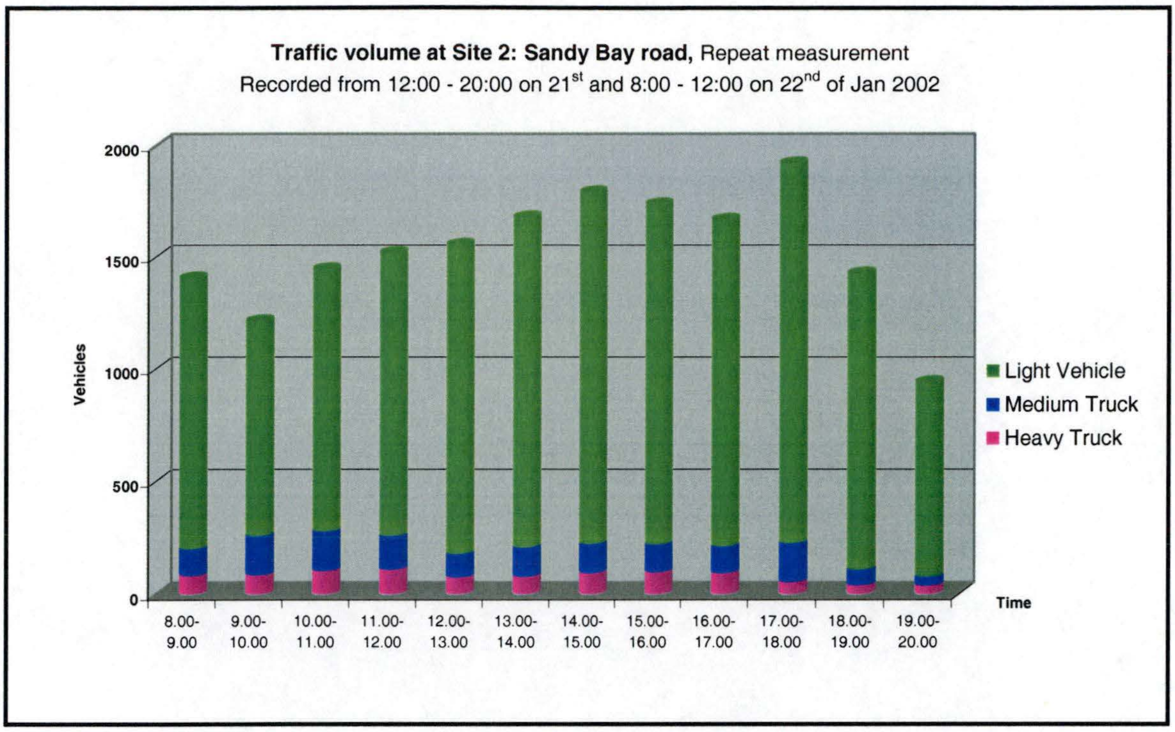


Figure 4.10 Traffic volume at Site 2: Sandy Bay Road, Repeat measurement

Table 4.5 Hourly traffic volume and percentage of trucks recorded at Site 2: Sandy Bay Road

Time	Heavy truck	Medium truck	Light vehicle	Percent truck
Initial Measurement				
9.00-10.00	60	226	1256	18.5
10.00-11.00	68	212	1080	20.6
11.00-12.00	86	222	1380	18.2
12.00-13.00	77	238	1113	22.1
13.00-14.00	70	222	1680	14.8
14.00-15.00	87	173	1540	14.4
15.00-16.00	71	183	1956	11.5
16.00-17.00	87	213	1710	14.9
17.00-18.00	27	141	1876	8.2
18.00-19.00	9	133	1646	7.9
19.00-20.00	10	76	1314	6.1
20.00-21.00	10	68	1080	6.7
21.00-22.00	0	52	786	6.2
Total	**662**	**2159**	**18417**	**Average 13.1**
Total Traffic Volume			**21,238**	
Repeat Measurement				
8.00-9.00	81	119	1204	14.2
9.00-10.00	83	175	954	21.3
10.00-11.00	102	176	1166	19.3
11.00-12.00	108	150	1258	17.0
12.00-13.00	73	105	1376	11.5
13.00-14.00	77	129	1470	12.3
14.00-15.00	92	130	1566	12.4
15.00-16.00	96	124	1514	12.7
16.00-17.00	92	120	1452	12.7
17.00-18.00	53	173	1692	11.8
18.00-19.00	38	70	1316	7.6
19.00-20.00	36	40	864	8.1
Total	**931**	**1,511**	**15,832**	**Average 13.4**
Total Traffic Volume			**18,274**	

4.2.3 Site 3: Tasman Highway

The traffic on the Tasman Highway was counted twice, for 10 hours during the initial noise measurement and 10 hours during the repeat measurement. The two studies were conducted in the same period of time, between 8:00 am to 6:00 pm. Conspicuously, the studies show a substantial difference between the former and the later observations. While the first count provided the number of 40,214 for the total volume with 8.8 percent trucks, the later gave only 31,404 vehicles with 2.2 percent trucks. This difference may be due to the timing of the second traffic count during the Christmas holiday period.

With regard to the above, the total traffic volume in the initial measurement was 40,214 in the 10-hour counting time (Figure 4.11 and Table 4.6). This figure consisted of 1,596 heavy trucks, 1,735 medium trucks and 36,883 cars. The volumes were between 3,324 and 5,210 vehicles per hour. The maximum number of 5,210 vehicles per hour was collected during the period between 5:00 and 6:00 pm. The busiest period in the morning was between 8:00 and 9:00 am with 4,320 vehicles. The number of vehicles dropped by 1,000 per hour in the next two-hour periods then rose to the level of 3,952 vehicles per hour from 11:00 to 12:00 am. The number went down again in the hour between 12:00 am and 1:00 pm at the level of 3,512 vehicles. The volume gradually increased by around 200 vehicles each hour from 1:00 to 4:00 pm and increased by approximately 400 vehicles per hour until it reached the highest volume of 5,210 during the last hour of the study. The hourly numbers of trucks that travelled past the study site showed, in contrast to the trend of the total traffic volume, the greatest number (459 vehicles per hour) was during the first hour of the observation, then the volumes continuously fell, although there were some small fluctuations in between. Of note, during the last two hours, the number of trucks dropped significantly from 297 vehicles per hour in the period of 3:00 to 4:00 pm to 105 vehicles per hour and the lowest number of 37 vehicles per hour occurred during the periods 4:00 to 5:00 pm and 5:00 to 6:00 pm respectively. The truck percentages, of the total number of vehicles, varied from 7.2 to 13.2 hourly between 8:00 am and 4:00 pm, and 2.2 to 0.7 percent from 4:00 to 6:00 pm.

Traffic volume during the repeat measurement was considerably lower than in the previous measurement (Figure 4.12 and Table 4.4). The total number of vehicles was between 2,506 vehicles per hour and 3,644 vehicles per hour. The maximum occurred during the hour from 4:00 to 5:00 pm, while the minimum was measured during the next one-hour period. The traffic during the study period was relatively consistent, although there was a significant difference between the second last and the last hour. The number of trucks varied between 91 and 42 vehicles per hour and comprised only 2.2 percent of the total number of vehicles. The nature of the volume changes were similar to the previous measurement in that the greatest number occurred during the first hour period and the smallest during the last hour. The traffic volume during the repeat measurement, compared to the data gained during the initial measurement, shows that the numbers of vehicles in the repeat measurement were consistently lower than the numbers in the initial measurement. The biggest difference in hourly traffic volume from the previous to the latter measurement was during the 5:00 to 6:00 pm time slot in which the latter volume was 51.4 percent lower than the former. In contrast, the number of trucks in the repeat measurement was 13.5 percent higher than the earlier study. The traffic volumes are similar during the 10:00 to 11:00 am period with the second measurement only 4.9 percent lower than the previous study.

In general, the traffic volume on the Tasman Highway was relatively high during the study period. However, the traffic decreased during the Christmas holiday period, particularly the numbers of trucks.

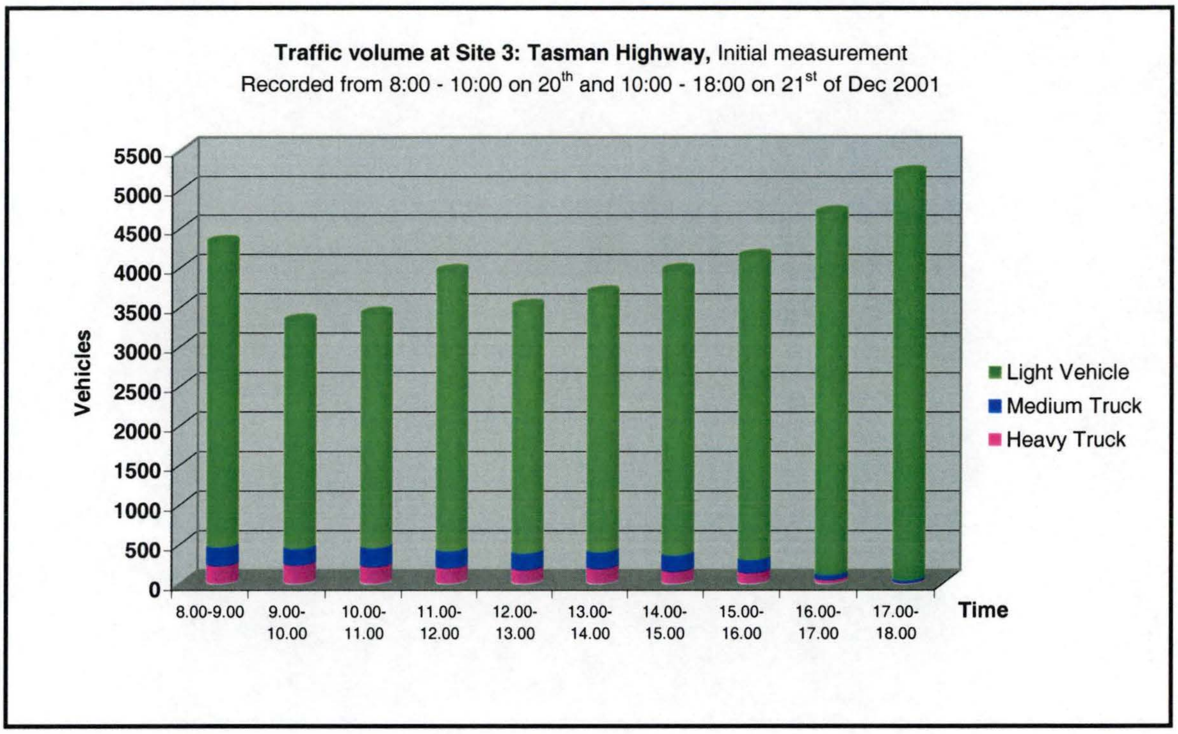


Figure 4.11 Traffic volume at Site 3: Tasman Highway, initial measurement

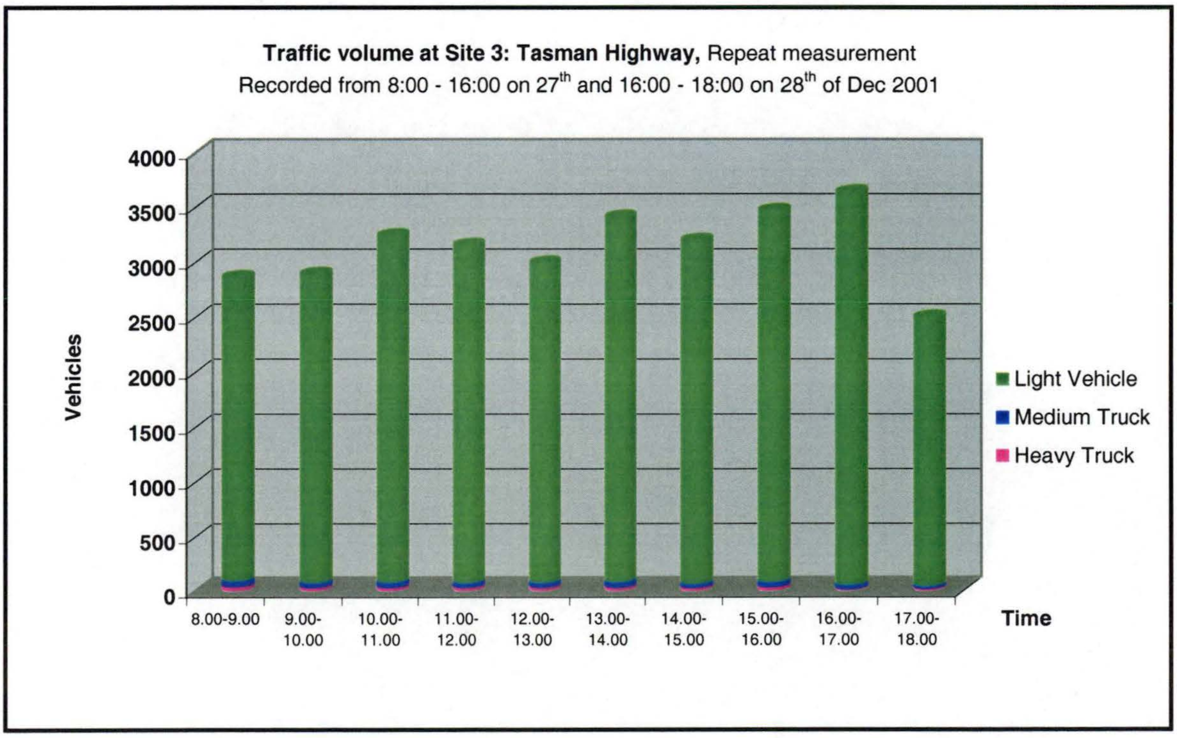


Figure 4.12 Traffic volume at Site 3: Tasman Highway, Repeat measurement

Table 4.6 Hourly traffic volume and percentage of trucks recorded at Site 3: Tasman Highway

Time	Heavy truck	Medium truck	Light vehicle	Percent truck
Initial Measurement				
8.00-9.00	227	232	3861	10.6
9.00-10.00	234	205	2885	13.2
10.00-11.00	213	238	2961	13.2
11.00-12.00	200	209	3543	10.3
12.00-13.00	175	205	3132	10.8
13.00-14.00	192	207	3283	10.8
14.00-15.00	156	199	3609	9.0
15.00-16.00	139	158	3845	7.2
16.00-17.00	47	58	4591	2.2
17.00-18.00	13	24	5173	0.7
Total	**1,596**	**1,735**	**36,883**	**8.8**
Total Traffic Volume			**40,214**	
Repeat Measurement				
8.00-9.00	37	54	2775	3.2
9.00-10.00	29	45	2820	2.6
10.00-11.00	28	48	3170	2.3
11.00-12.00	28	42	3088	2.2
12.00-13.00	28	45	2925	2.4
13.00-14.00	28	52	3336	2.3
14.00-15.00	26	34	3142	1.9
15.00-16.00	33	46	3395	2.3
16.00-17.00	12	39	3593	1.4
17.00-18.00	16	26	2464	1.7
Total	**265**	**431**	**30,708**	**2.2**
Total Traffic Volume			**31,404**	

4.3 THE COMPARISON OF THE TRAFFIC NOISE LEVEL FROM ACTUAL MEASUREMENTS AND PREDICTION MODELS

The comparison between predicted and actual noise for each site was separately studied in order to explain the variation of the differences between noise levels from the actual measurements and the prediction models over the three different traffic environments at the study sites. Following this, the accuracy of each model was investigated.

The comparisons of the traffic noise measurements and the outcomes from T-Noise were achieved using L_{10} hourly figures, while L_{eq} hourly figures were used to compare with the values predicted by STAMSON4.1. The noise level data, both gained from actual measurements and calculated from the prediction models, were plotted to show the variations of the predicted values against the actual noise levels.

The results calculated by ITFNS1.1 were explained separately due to: the limitations of using this model and the large difference between its prediction and the actual noise levels.

The examination of the accuracy of the prediction models focused on two components, namely: the comparison of the absolute noise values between the actual noise levels and the predicted noise levels; and the correlation test. The first study explained the degree of difference between the predicted levels and the actual levels in an hour by hour comparison; and also indicated the error frequencies categorised into groups designated by 3 percent increments. The difference between actual and predicted noise levels was converted to a percentage error value. These values were then categorised into groups starting with 0 to ± 3 percent, ± 3 to ± 6 percent, until the maximum percentage of error was classified. The frequency contained in each group indicated the percentage of variation between the actual noise levels and the calculated noise levels. The frequency values were then converted to percentage values in order to facilitate examining the distribution of the errors created by the prediction models. The correlation tests were conducted to discover the relationship between changes in actual noise levels and changes in predicted noise levels. These studies use the R^2 values as indicators. R^2 value represents the possibility of the prediction model providing the accurate value, the higher the R^2 value, the more accuracy the model provided.

Correlation tests between traffic volumes and the differences of predicted noise levels and actual noise levels were conducted to discover their relationship.

4.3.1 Site 1: Regent Street

The result gained from the initial measurement showed that the noise levels calculated by T-Noise and STAMSON4.1 exhibited a similar trend, except in the first hour, to the noise levels obtained from the actual measurement (see Figure 4.13). In this test, the noise levels calculated by T-Noise and STAMSON were similar to the noise levels that actually occurred, although there were differences in some figures.

On average, T-Noise calculated values were 0.52 dB in average above the actual levels (Table 4.7). The largest difference, 3.1 dB above the actual noise levels, was found from 9:00 to 10:00 am, while the least variation of 0.6 dB above the actual noise level occurred between 4:00 and 6:00 pm. Sixty two percent of the differences were between –2 and +2 dB, while 23 percent were more than 2 dB over predicted and 15 percent were more than 2 dB under predicted.

On average, STAMSON4.1 under predicted by 2.32 dB compared to the actual figures (see Table 4.8). The biggest difference occurred between 8:00 to 9:00 am, 7.68 dB less than the actual value. The least difference was 0.07 dB under predicted, which occurred during the period 13:00 to 15:00. Fifty four percent of the total predicted values showed less than 1 dB difference from the actual noise levels and 15 percent showed differences that varied between 1 and 3 dB.

Table 4.7 $L_{10(1\,hr)}$ gained from the initial noise measurement at Site 1: Regent Street compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
8 00-9 00	74 5	72 2	-2.3	-3 12
9.00-10 00	72 5	75.6	3.1	4 10
10.00-11.00	72	74.8	2.8	3 74
11 00-12 00	72 5	74.7	2.2	2 94
12 00-13.00	74	75	1	1 33
13 00-14.00	73.5	74.7	1 2	1 61
14 00-15.00	73.5	74.9	1 4	1.87
15 00-16.00	74 5	76 4	1.9	2 49
16 00-17 00	74	74 6	0 6	0 80
17 00-18.00	74	74 6	0 6	0 80
18 00-19.00	74	72 4	-1 6	-2.21
21.00-22 00	70	68	-2	-2 94
22.00-23.00	68	65.8	-2 2	-3 34

Table 4.8 $L_{eq(1\,hr)}$ gained from the initial noise measurement at Site 1: Regent Street compared with $L_{eq(1\,hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
8.00-9.00	70.63	62.95	-7.68	-12.20
9.00-10.00	68.67	69.24	0 57	0.82
10 00-11.00	69.67	69.2	-0 47	-0.68
11.00-12.00	69 08	68.54	-0.54	-0 79
12.00-13.00	70	69.34	-0.66	-0 95
13.00-14.00	69.83	69 9	0.07	0.10
14.00-15.00	70.04	69.97	-0.07	-0.10
15 00-16.00	70.45	69.65	-0 8	-1 15
16 00-17.00	70.54	68.92	-1 62	-2 35
17.00-18.00	70.45	68.33	-2.12	-3 10
18.00-19.00	69.42	65.28	-4 14	-6.34
21.00-22.00	65 54	59 44	-6 1	-10.26
22.00-23 00	63.29	56.33	-6.96	-12 35

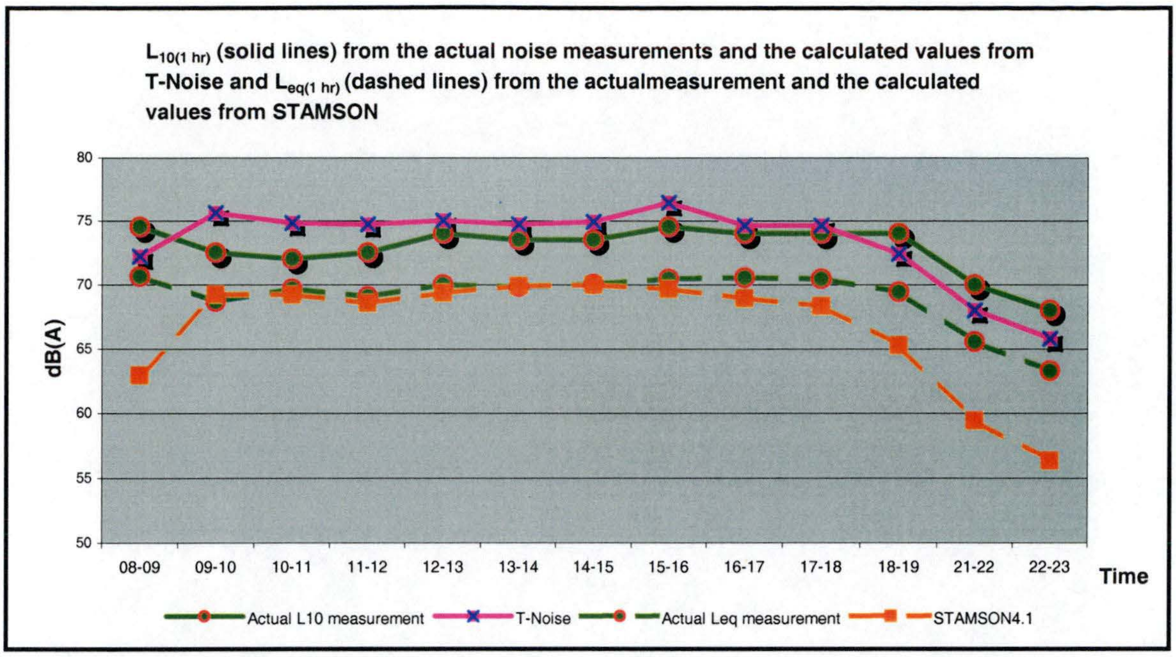


Figure 4.13 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 1: Regent Street, initial measurement

In the repeat measurement, T-Noise and STAMSON4.1 predictions were again slightly different from the actual measurement (see Figure 4.14). In this test, the majority of noise values obtained from T-Noise were slightly over predicted. However, the predicted noise levels in the first and the last hour showed the opposite. In contrast, STAMSON4.1 provided under predicted levels for every hour, compared to actual noise levels.

Noise levels predicted by T-Noise were, on average, 1 dB higher than the actual levels (see Table 4.9). The differences between the predicted and the actual levels were between 0.5 and 2.9 dB. Ninety one percent of the difference between predicted and actual levels varied in the range of –2 to +2 dB, while the rest of the calculations were more than 2 dB over predicted. The largest variation of 2.9 dB occurred from 9:00 to 10:00 am. The smallest difference of 0.5 dB was found during the first and the second last hour.

STAMSON4.1 under predicted by 1.38 dB on average. The biggest difference of 3.65 dB under predicted occurred during the last hour. While the smallest difference of 0.3 dB under prediction was found from 9:00 to 10:00 am (see Table 4.10). Forty five percent of the total predicted values showed less than 1 dB difference from the actual noise levels, which is 9 percent less than found in the initial measurement. Eighteen percent of the calculated values were between 1 and 2 dB below the actual levels and 36 percent were more than 2 dB below the actual levels.

The hourly L_{10} values calculated from ITFNS1.1 were between 9 and 15.5 dB below the values gained from actual measurement. This result indicates that the prediction using ITFNS1.1 should be considered unreliable (see Table 4.19).

Table 4.9 $L_{10(1\,hr)}$ gained from the repeat noise measurement at Site 1: Regent Street compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
8.00-9 00	73 5	73	-0.5	-0 68
9.00-10 00	71 5	74.4	2 9	3 90
10 00-11.00	72.5	74.3	1 8	2 42
11.00-12.00	72	73.9	1 9	2 57
12.00-13.00	73	73 6	0 6	0 82
13 00-14.00	72.5	74 1	1 6	2 16
14.00-15.00	73	73 8	0.8	1.08
15.00-16 00	72	74	2	2.70
16.00-17 00	73	73.6	0.6	0.86
17.00-18 00	73	73.5	0 5	0 68
18.00-19.00	72.5	71.3	-1 2	-1.68

Table 4.10 $L_{eq(1\,hr)}$ gained from the repeat noise measurement at Site 1: Regent Street compared with $L_{eq(1\,hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
8 00-9.00	68.5	65.76	-2.74	-4 17
9 00-10 00	68.04	67.71	-0.33	-0 49
10.00-11.00	67.42	67.93	0.51	0.75
11 00-12.00	67.71	67.34	-0.37	-0 55
12 00-13.00	68 08	67.15	-0.93	-1 38
13.00-14 00	68.21	68.03	-0.18	-0 26
14.00-15 00	68 58	67.42	-1.16	-1 72
15.00-16 00	68 04	67.48	-0.56	-0.83
16 00-17.00	68.67	66.49	-2.18	-3 28
17 00-18.00	69 29	65.73	-3.56	-5 42
18.00-19.00	67.79	64.14	-3.65	-5.69

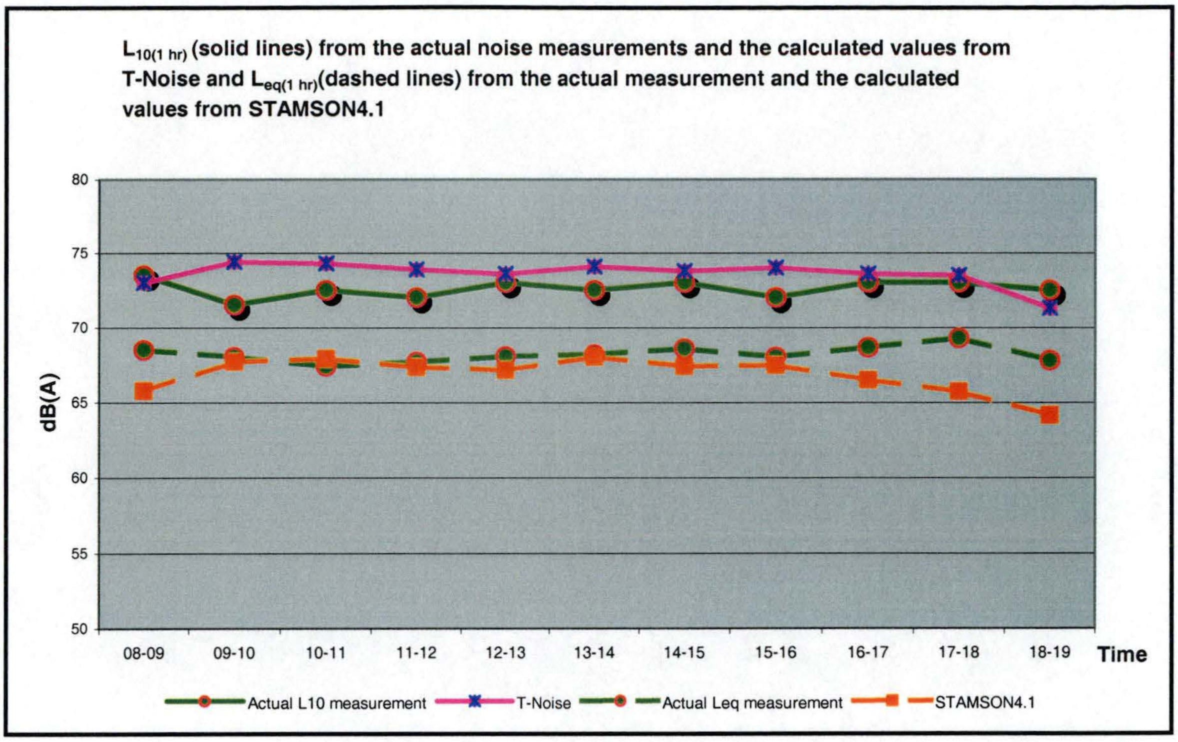


Figure 4.14 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 1: Regent Street, repeat measurement

The study of the accuracy of the prediction models has shown that at site 1: Regent Street, T-Noise provided the best accuracy compared to the other models (see Figure 4.15). T-Noise generally over predicted noise levels, compared with the actual noise levels. Sixty two percent of predicted levels varied from the actual noise levels from 0 up to 3 percent. Seventeen percent were found between 0 and 3 percent under prediction. Twelve percent of all data showed that the predicted levels were between 3 and 6 percent over estimation, while another 8.3 percent were from 3 to 6 percent lower than the actual noise levels.

The calculated noise levels provided by STAMSON4.1 showed that 50 percent of all predicted levels were 0 to 3 percent lower than the actual levels. 12.5 percent of all data were between 0 and 3 percent higher than the actual levels. Approximately 20 percent of calculated levels were ranged from 3 to 6 percent below the actual values.

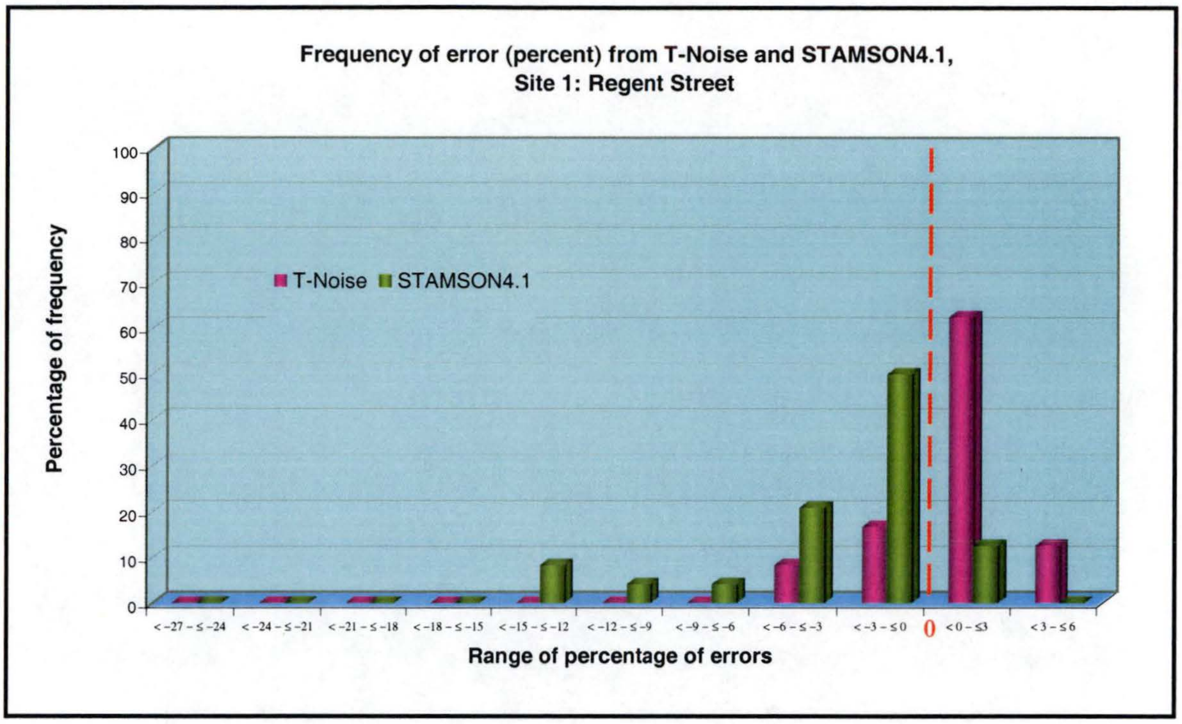
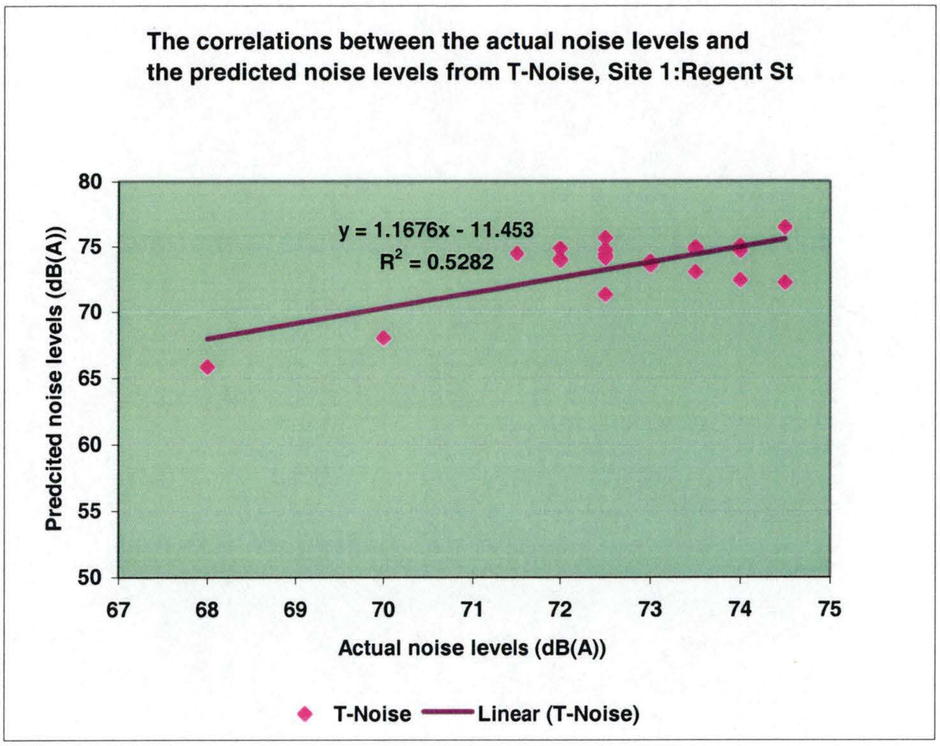


Figure 4.15 The distribution of errors from the comparisons of actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 1: Regent Street

Correlation tests at Site 1 showed that STAMSON4.1 calculated higher correlation figures with R^2=0.5599 (Figure 4.16b), while T-Noise provided R^2=0.5282 (Figure 4.16a). Although STAMSON4.1 showed the highest correlation, the result was only an acceptable accuracy. For absolute noise level prediction, T-Noise proved very accurate, however, its result in correlation tests provided only acceptable accuracy.

a



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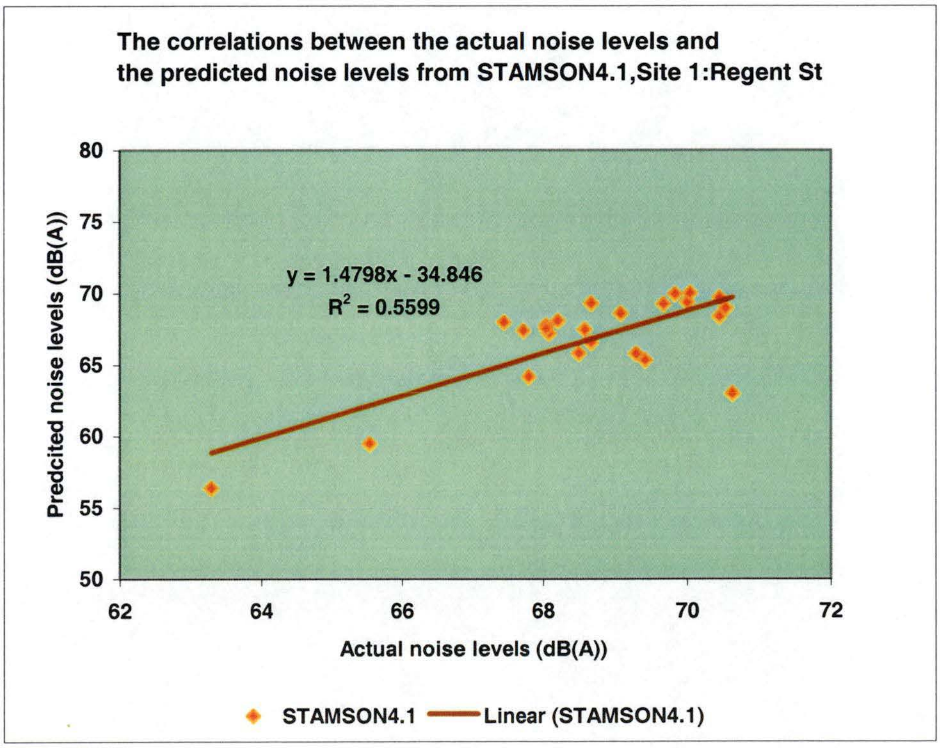


Figure 4.16 The correlation tests between the actual noise levels and predicted noise levels, Site 1: Regent Street

4.3.2 Site 2: Sandy Bay Road

The results gained from the initial measurement period showed (Figure 4.17) that the noise levels calculated by T-Noise followed a similar trend to the noise levels obtained from the actual measurement, although it showed a quick decline in the last three hours. STAMSON4.1 provided very close prediction during the first six hours period and the eighth hour period. There was a significant under prediction during the seventh hour and in the last five hours. In this test, T-Noise showed the best similarity of the predicted noise levels and the actual noise levels.

T-Noise calculated 0.9 dB on average under the actual noise levels (Table 4.11). The differences between calculated noise levels and actual noise levels were in the range of –3.8 and 1.2 dB. The largest difference was found during the last hour, the smallest variation of 0.1 dB over predicted noise level appeared during 2:00 to 3:00 pm. Seventy seven percent of the differences varied between –2 and 2 dB, while the rest of 23 percent showed more than 2 dB under prediction.

STAMSON4.1 under predicted by 3.52 dB on average, compared to the actual figures (Table 4.12). The biggest different occurred in the last hour, with the predicted level 17.12 dB lower than the actual noise level. The least difference was 0.15 dB under predicted, which occurred at the period of 11:00 to 12:00 pm. Fifty four percent of the total predicted values showed less than 2 dB different from the actual noise levels and 69 percent indicated the variation up to 4 dB.

Table 4.11 $L_{10(1\,hr)}$ gained from the initial noise measurement at Site 2: Sandy Bay Road compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
9.00-10.00	72	71.1	-0 9	-1 27
10 00-11.00	72	70.8	-1.2	-1.69
11 00-12.00	72	71.5	-0.5	-0 70
12 00-13.00	71.5	71.2	-0 3	-0 42
13.00-14.00	70.5	71.7	1.2	1.67
14.00-15 00	71	71 1	0 1	0 14
15.00-16 00	71	71.4	0.4	0 56
16.00-17 00	71	71.7	0.7	0 98
17.00-18.00	71	70 2	-0 8	-1.14
18.00-19.00	70.5	69 8	-0 7	-1 00
19.00-20.00	71	67 7	-3 3	-4.87
20.00-21.00	69.5	66.9	-2 6	-3.89
21 00-22.00	69.5	65.7	-3 8	-5.78

Table 4.12 $L_{eq(1\,hr)}$ gained from the initial noise measurement at Site 2: Sandy Bay Road compared with $L_{eq(1\,hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
9 00-10.00	68 58	67.94	-0 64	-0 94
10 00-11.00	69	68 12	-0 88	-1 29
11.00-12.00	69.08	68.93	-0.15	-0 221
12.00-13 00	69 08	68 61	-0.47	-0 69
13.00-14.00	67.63	68 48	0 85	1.24
14.00-15 00	68.63	68.79	0.16	0.23
15.00-16 00	70.37	68 42	-1.95	-2.85
16 00-17.00	68 42	69 04	0 62	0 90
17 00-18.00	68 43	65.94	-2.49	-3.78
18 00-19.00	68.13	64.22	-3.91	-6.09
19 00-20.00	67 71	63 07	-4.64	-7 36
20 00-21 00	66.63	51.46	-15 17	-29.48
21 00-22.00	65.58	48.46	-17 12	-35 33

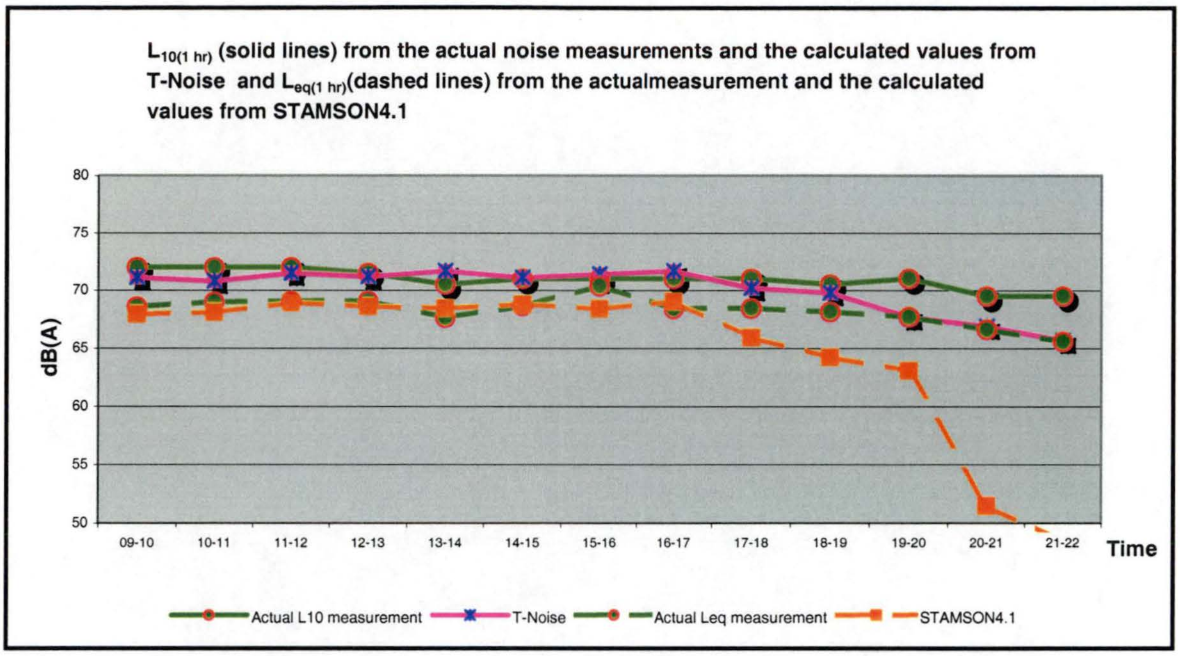


Figure 4.17 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 2: Sandy Bay Road, initial measurement

In the repeat measurement, T-Noise and STAMSON4.1, except in the first hour, predicted similar trends but in absolute values they were relatively different from the actual measurement (Figure 4.18). In this test, it is clear that the majority of the calculated noise levels from all prediction models were below the actual noise levels.

Noise levels predicted by T-Noise were, on average, 1.34 dB lower than the actual levels, which was worse than 0.44 dB in the initial measurement (Table 4.13). The differences between the predicted and the actual levels ranged from 0 to 2.8 dB. The model calculated exactly the same noise value that was recorded from the actual measurement from 10:00 to 11:00 am. Eighty three percent of all calculated values were under estimated. Fifty percent of the errors were in the range of –2 to -0.5 dB and 43 percent were more than 2 dB under the actual noise levels. The largest variation of -2.8 dB occurred during 6:00 to 7:00 pm.

STAMSON4.1 under predicted 1.60 dB on average from the actual figures (Table 4.14). This is about half the error of the original test. The biggest different of 3.37 dB under prediction occurred between 6:00 and 7:00 pm, the same period that showed the largest variation created from T-Noise. The smallest difference of -0.05 dB compared to the actual noise level appeared during 9:00 to 10:00 am. Fifty percent of the total predicted values showed less than 2 dB difference from the actual noise levels, which is 4 percent lower than found in the initial test. The other 50 percent showed a difference greater than –2 dB.

Table 4.13 $L_{10(1\,hr)}$ gained from the repeat noise measurement at Site 2: Sandy Bay Road compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
8 00-9 00	71 5	74.1	2 6	3.51
9 00-10.00	71	70.5	-0 5	-0 71
10.00-11 00	71	71	0	0
11.00-12.00	72	70.8	-1 2	-1.69
12.00-13.00	71	69.9	-1 1	-1 57
13.00-14.00	73	70.4	-2 6	-3 69
14.00-15.00	73	70.8	-2 2	-3.11
15.00-16.00	73 5	70.8	-2.7	-3 81
16.00-17.00	72 5	70.6	-1 9	-2 69
17.00-18.00	72.5	70.8	-1.7	-2 4
18.00-19.00	71.5	68.7	-2 8	-4.08
19.00-20.00	69	67	-2	-2 99

Table 4.14 $L_{eq(1\,hr)}$ gained from the repeat noise measurement at Site 2: Sandy Bay Road compared with $L_{eq(1\,hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
8.00-9 00	70.5	68.17	-2 33	-3 42
9 00-10 00	68.5	68.45	-0.05	-0.07
10.00-11.00	68.5	69.18	0 68	0 98
11.00-12.00	69.5	69 28	-0 22	-0 32
12 00-13.00	68	67 83	-0.17	-0 25
13.00-14.00	71	68 17	-2 83	-4 15
14 00-15.00	71.5	68.77	-2 73	-3 97
15 00-16 00	71.5	68.86	-2 64	-3.83
16.00-17.00	70 5	68.68	-1 82	-2 65
17 00-18.00	70.5	67 51	-2 99	-4 43
18 00-19.00	69	65.63	-3 37	-5 13
19.00-20 00	65.5	64.79	-0 71	-1.10

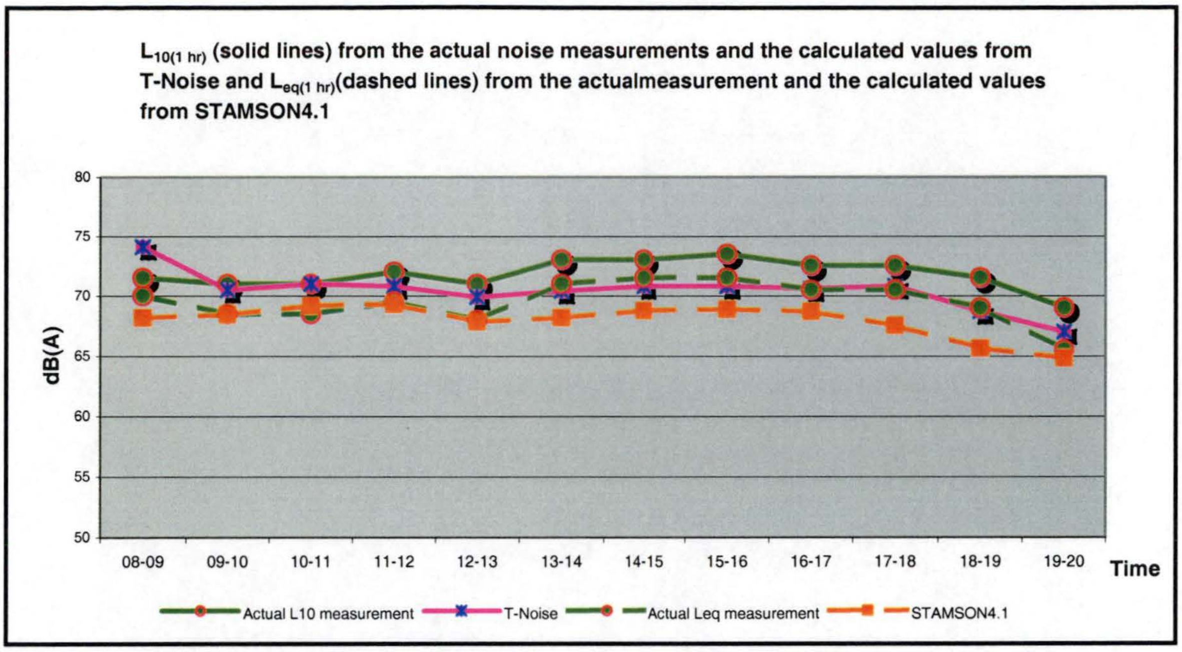


Figure 4.18 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 2: Sandy Bay Road, repeat measurement

At Site 2: Sandy Bay Road, T-Noise, again, showed the greatest accuracy among the models. However, STAMSON4.1 was only slightly less accurate.

The comparison between calculated noise levels provided by T-Noise and the actual noise levels showed that 68 percent of all data showed errors up to 3 percent, 52 percent were under predicted and 16 percent over predicted (Figure 4.19). Twenty eight percent of all values were 3 to 6 percent under estimated. Only 4 percent appear 3 to 6 percent over prediction.

The calculated noise levels provided by STAMSON4.1 showed that 56 percent of all predicted levels varied from the actual levels by ±3 percent. Thirty six percent of the total data gained from this model showed further negative bias. This proportion included 24 percent of error between 3 and 6, and 12 percent in the 6 to 12 percent range. Eight percent of the compared levels were 30 to 36 percent lower than the actual noise level.

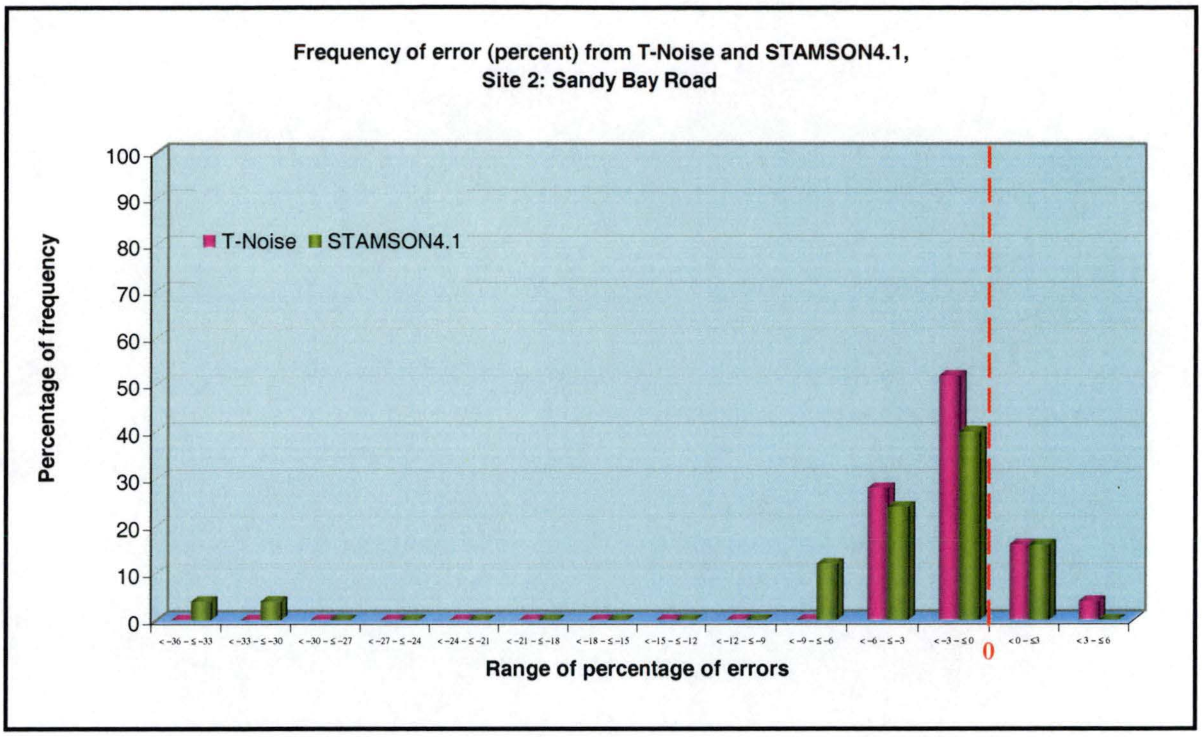
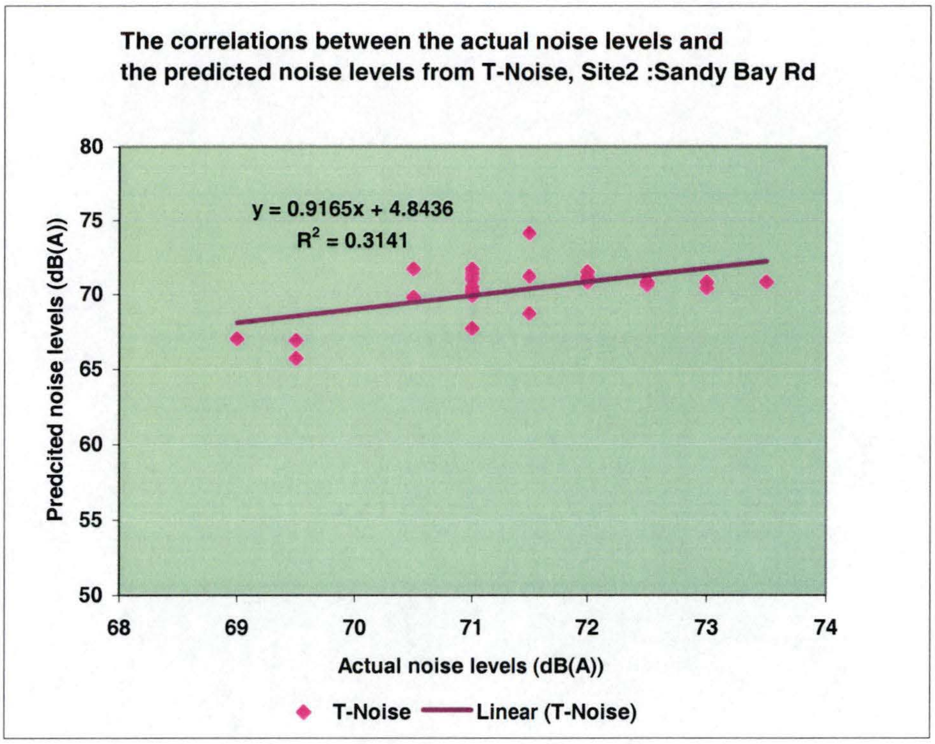


Figure 4.19 The distribution of errors from the comparisons of actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 2: Sandy Bay Road

The correlation test at site 2 showed that STAMSON4.1 provided the highest correlation coefficient of the three models with a value of R^2=0.4034 (Figure 4.20b), while T-Noise accounted R^2=0.3141 (Figure 4.20a). All prediction models provided poor calculations at Site 2 when compared with the predictions achieved at Site 1. Although, STAMSON4.1 and T-Noise provided reliable predictions for the comparison of absolute levels, the correlation test between the predicted noise levels and the measured noise level proved inaccurate.

a



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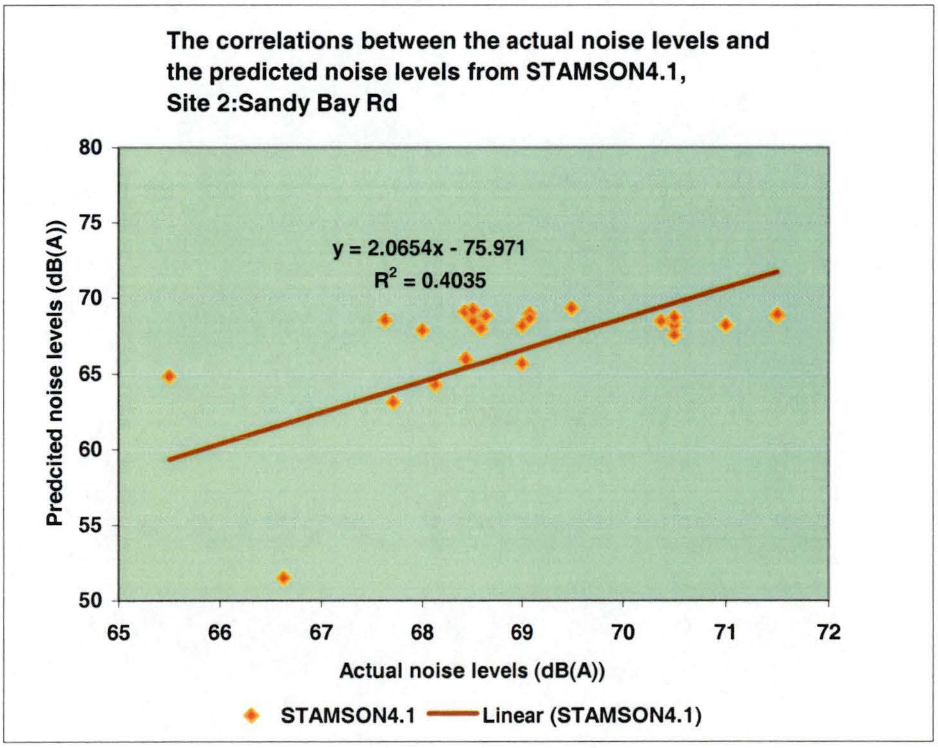


Figure 4.20 The correlation tests between the actual noise levels and predicted noise levels, Site 2: Sandy Bay Road

4.3.3 Site 3: Tasman Highway

The results from the initial measurement showed that all predicted noise levels from both models were higher than the actual levels (see Figure 4.21). In this test, the predictions produced by T-Noise and STAMSON4.1 were considered, by the author, to be too high.

T-Noise calculated 6.48 dB, on average, above the actual levels (Table 4.15). The largest difference of 7.4 dB above actual noise was found from 1:00 to 2:00 pm and 3:00 to 4:00 pm, while the smallest variation of 5.5 dB above actual noise occurred between 10:00 and 11:00 am. Eighty percent of the calculated values showed errors between 5.5 and 6.9 dB, and 20 percent were above 7 dB over prediction.

STAMSON4.1 over predicted by 5.53 dB on average compared to the actual figures, 0.95 dB better than T-Noise prediction (Table 4.16). The largest difference occurred from 1:00 to 2:00 pm, 6.83 dB higher than the actual value. The least difference was 1.97 dB above the actual level, which occurred during the last hour. Similar to the levels calculated by T-Noise, 80 percent of the total numbers of predicted values were between 5.53 and 6.83 dB higher than the actual noise values. The other 20 percent were less than 5 dB over prediction.

Table 4.15 $L_{10(1\,hr)}$ gained from the initial noise measurement at Site 3: Tasman Highway compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
8 00-9.00	72	78 4	6.4	8 16
9.00-10.00	72	78.3	6.3	8.046
10.00-11.00	73	78.5	5.5	7.01
11.00-12.00	72	78 6	6.6	8 40
12.00-13.00	72	78.1	6.1	7 81
13.00-14.00	71	78.4	7.4	9.44
14.00-15.00	71.5	78 4	6.9	8.80
15.00-16.00	71	78.4	7.4	9 44
16 00-17.00	71.5	77 8	6.3	8.10
17.00-18.00	72	77.9	5.9	7 57

Table 4.16 $L_{eq(1\,hr)}$ gained from the initial noise measurement at Site 3: Tasman Highway compared with $L_{eq(1\,hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
8.00-9 00	70.25	76.3	6.05	7.93
9.00-10.00	69 29	76 06	6.77	8.9
10.00-11.00	70.46	75 92	5.46	7 19
11.00-12 00	69.13	75.81	6.68	8.81
12.00-13.00	69.04	75.32	6.28	8.34
13.00-14.00	68.79	75.62	6.83	9.03
14.00-15.00	69.13	75 16	6 03	8 02
15.00-16 00	68.96	74.79	5 83	7 8
16.00-17.00	69 21	72 57	3.36	4.63
17.00-18 00	69.63	71.6	1.97	2.75

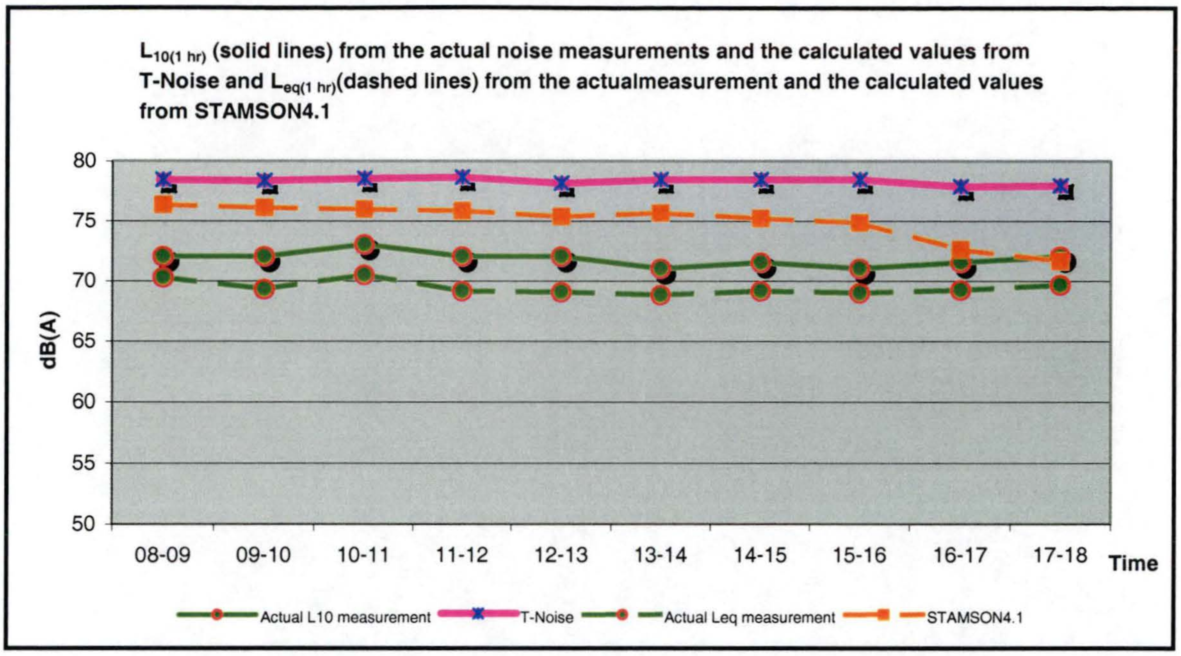


Figure 4.21 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 3: Tasman Highway, initial measurement

In the repeat measurement, similar to the initial measurement, all of the results gained from both T-Noise and STAMSON4.1 were over-prediction. T-Noise showed a parallel trend to the actual noise levels, while noise levels predicted by STAMSON4.1 were slightly different (Figure 4.22). In Figure 4.20, it is clearly seen that the gap between the actual trend and the predicted trend created by STAMPSON4.1 is approximately half the gap produced by T-Noise. In this test, STAMSON4.1 clearly showed better results than T-Noise.

T-Noise calculated 5.49 dB on average above the actual levels, which was 0.99 dB closer to the actual levels than found in the initial measurement (Table 4.17). The largest difference of 6.1 dB above actual noise occurred during 12:00 am to 1:00 pm, while the smallest variation of 4.3 dB was found in the last hour. Ninety percent of the calculated values showed at least 5 dB over prediction, and only 10 percent were less than 5 dB variation.

STAMSON4.1 over predicted by 2.57 dB on average compared to the actual figures, 2.92 dB better than T-Noise and 2.96 dB better than it previously showed at this site (Table 4.18). The biggest different occurred during the first study hour, 3.77 dB higher than the actual value. The least difference was 1.19 dB, which occurred during the period 4:00 to 5:00 pm.

Fifty percent of the total predicted values were less than 3 dB higher than the actual noise values, while the rest were more than 3 dB higher.

Table 4.17 $L_{10(1\ hr)}$ gained from the repeat noise measurement at Site 3: Tasman Highway compared with $L_{10(1\ hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from T-Noise		
		Predicted values	Differences of estimation	% Error
8.00-9.00	69.5	75.4	5.9	7 82
9.00-10 00	70.5	75.6	5 1	6.75
10.00-11.00	70	76	6	7 89
11.00-12.00	70	76.1	6 1	8 02
12 00-13.00	70	75.8	5.8	7.65
13.00-14.00	70.5	76 3	5 8	7 6
14.00-15.00	70	75.9	5 9	7 77
15 00-16.00	71.5	76.5	5	6.54
16.00-17.00	71.5	76 5	5	6.54
17.00-18.00	70 5	74.8	4 3	5.75

Table 4.18 $L_{eq(1\ hr)}$ gained from the repeat noise measurement at Site 3: Tasman Highway compared with $L_{eq(1\ hr)}$ calculated from STAMSON4.1

Time	Values from actual measurement	Values from STAMSON4.1		
		Predicted values	Differences of estimation	%Error
8.00-9.00	67.2	70.97	3.77	5.31
9.00-10.00	68.2	70 57	2.37	3.36
10.00-11.00	67.83	70.86	3 03	4 28
11.00-12.00	67 54	70.73	3.19	4.51
12.00-13.00	67.54	70 62	3 08	4 36
13 00-14.00	68.25	71.04	2 79	3.93
14.00-15.00	67.91	70.6	2 69	3.81
15.00-16.00	69	71.22	2 22	3.12
16.00-17.00	69.25	70.44	1.19	1.69
17.00-18.00	67.9	69.28	1.38	1 99

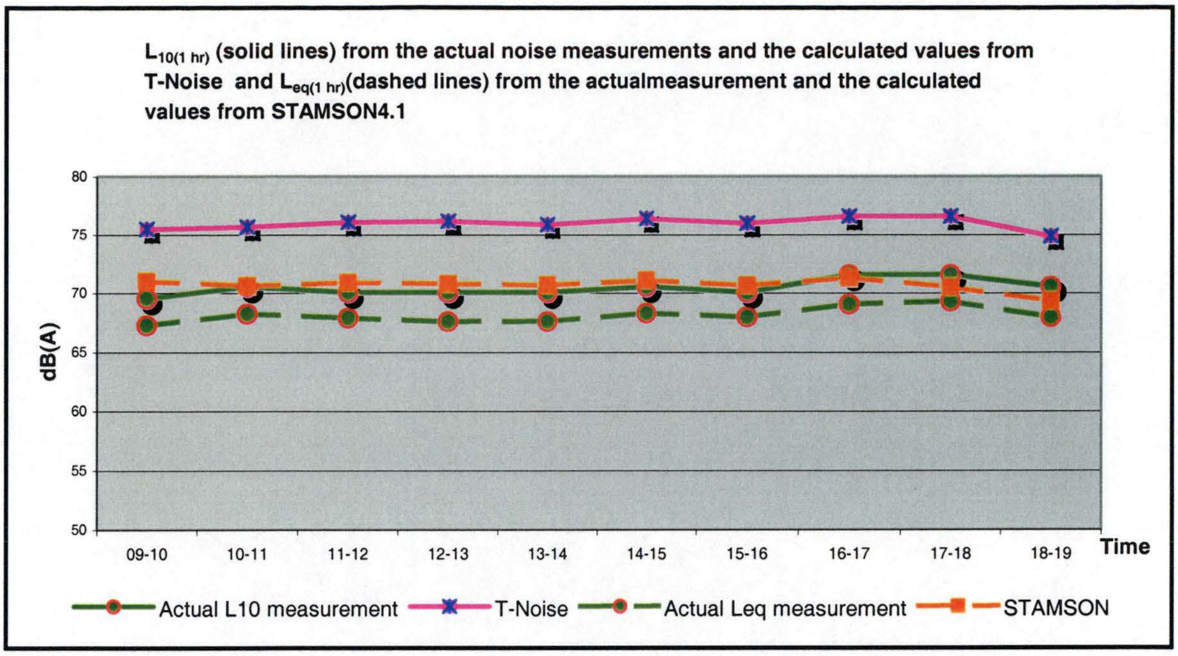


Figure 4.22 Actual noise levels and predicted noise levels calculated from T-Noise and STAMSON4.1, Site 3:Tasman Highway, repeat measurement

At site 3: Tasman Highway, although both T-Noise and STAMSON4.1 over predicted levels for all calculations, STAMSON4.1 provided more accurate prediction than T-Noise (Figure 4.23). Fifteen percent of all predicted levels provided by STAMSON4.1 were up to 3 percent over prediction and 45 percent of its prediction was between 3 and 6 percent higher than the actual values. This model showed that only 40 percent of its prediction was between 6 and 12 percent higher than the actual values, while T-Noise showed 95 percent in this range. Only 5 percent of the levels predicted by T-Noise showed between 3 and 6 percent over prediction, and none of them were in the range of less than 3 percent error.

The majority of the estimates distribution provided by STAMSON4.1 was between 3 and 6 percent over prediction, while the largest population of the predicted levels calculated by T-Noise was between 6 and 9 percent over prediction. This led to STAMSON4.1 being considered as a better predictor for this study site.

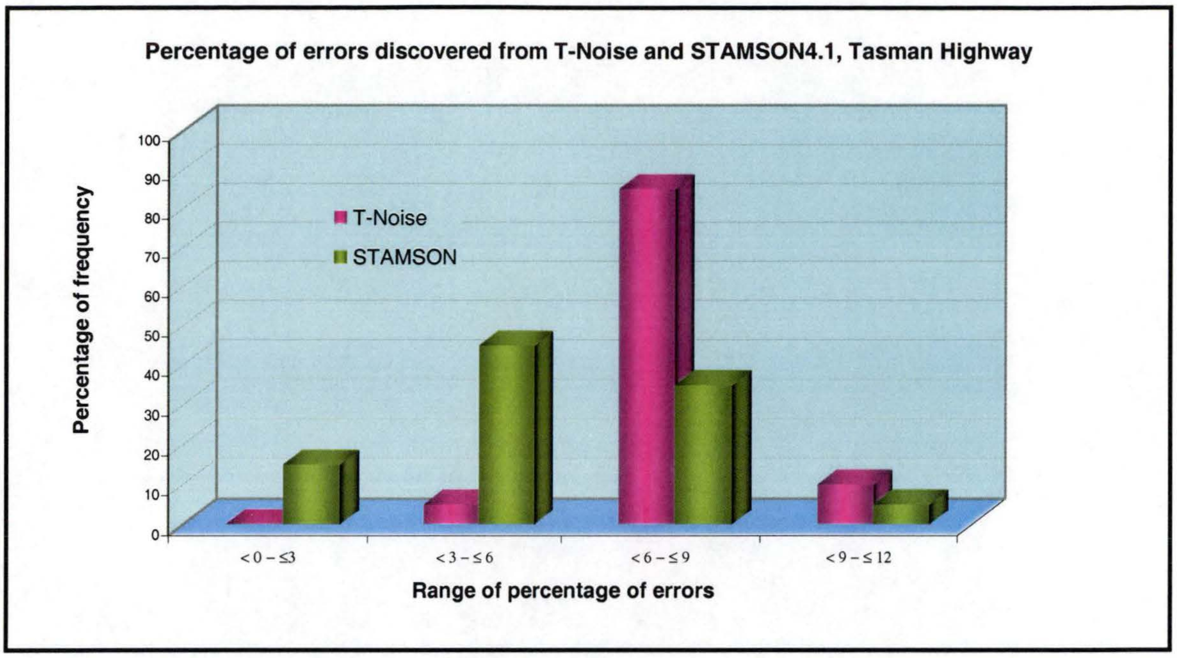
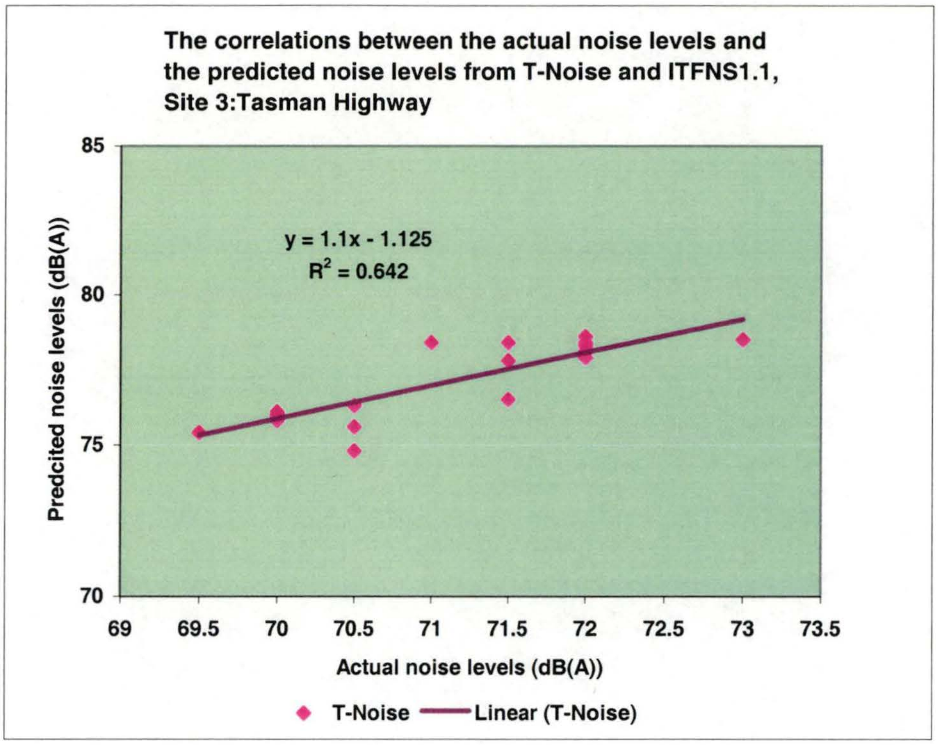


Figure 4.23 The distribution of errors from the comparisons of actual noise levels and predicted noise levels calculated from T-Noise STAMSON4.1, Site 3: Tasman Highway

The correlation test for site 3 showed a more accurate result using T-Noise of $R^2=0.6420$ (Figure 4.24a), while STAMSON4.1 illustrated the result of $R^2=0.4909$ (Figure 4.24b). It is to be pointed out that although STAMSON4.1 showed slightly closer predictions for the absolute values at this site than the others, T-Noise provided a better correlation with the changes in noise.

a



b

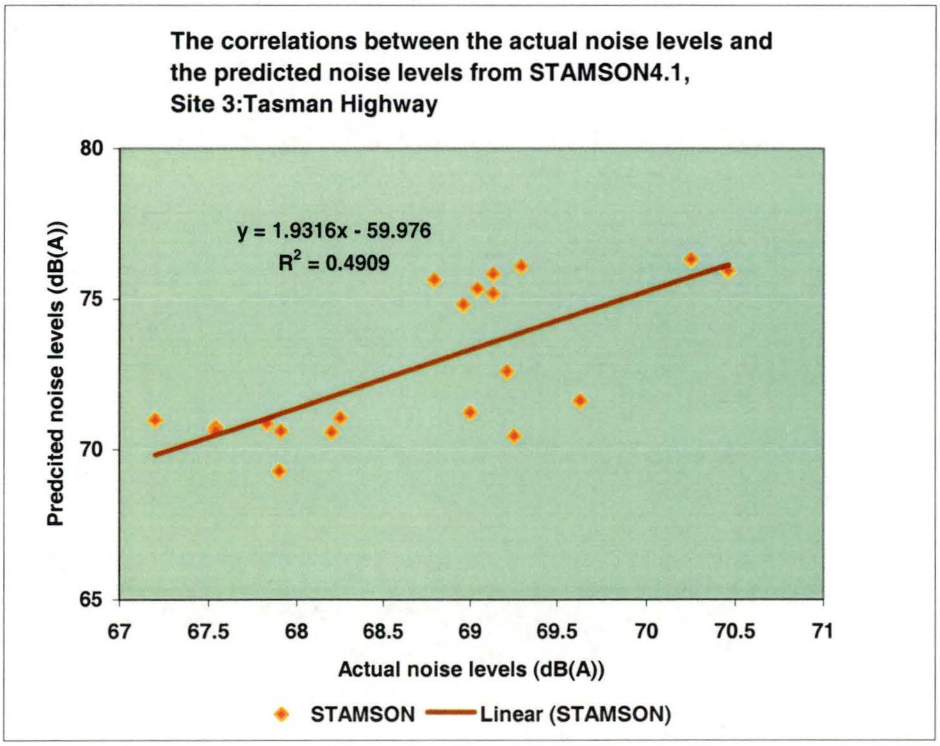


Figure 4.24 The correlation tests between the actual noise levels and predicted noise levels, Site 3: Tasman Highway

4.3.4 The comparison of actual noise levels and predicted noise levels calculated by ITFNS1.1

The following paragraphs explain the results gained form ITFNS1.1. The results are explained separately due to limitations found in using ITFNS1.1 which significantly underestimated noise levels.

At Site 1: Regent Street, the calculated values were significantly lower than the actual noise. Analysis of the ITFNS1.1 predictions showed underestimation of between 9 and 15 dB (Table 4.19) for the initial measurement and between 10 and 14 dB for the repeat measurement (Table 4.20). The noise trend calculated from this model during both initial and repeat measurements showed no clear relation to the actual noise levels (Figures 4.25 and 4.26).

Table 4.19 $L_{10(1\,hr)}$ gained from the initial noise measurement at Site 1: Regent Street compared with $L_{10(1\,hr)}$ calculated from T-Noise

Time	Values from actual measurement	Values from ITFNS1.1		
		Predicted values	Differences of estimation	%Error
8 00-9.00	74.5	59	-15 5	-26.27
9.00-10.00	72.5	62	-10.5	-16.94
10.00-11.00	72	59	-13	-22 03
11 00-12.00	72.5	61	-11.5	-18.85
12.00-13.00	74	61	-13	-21.31
13 00-14.00	73 5	61	-12.5	-20.49
14.00-15.00	73.5	62	-11 5	-18.55
15.00-16.00	74 5	59	-15.5	-26.27
16.00-17.00	74	59	-15	-25.42
17.00-18.00	74	63	-11	-17.46
18.00-19.00	74	59	-15	-25 42
21.00-22 00	70	61	-9	-14.75
22.00-23.00	68	59	-9	-15.25

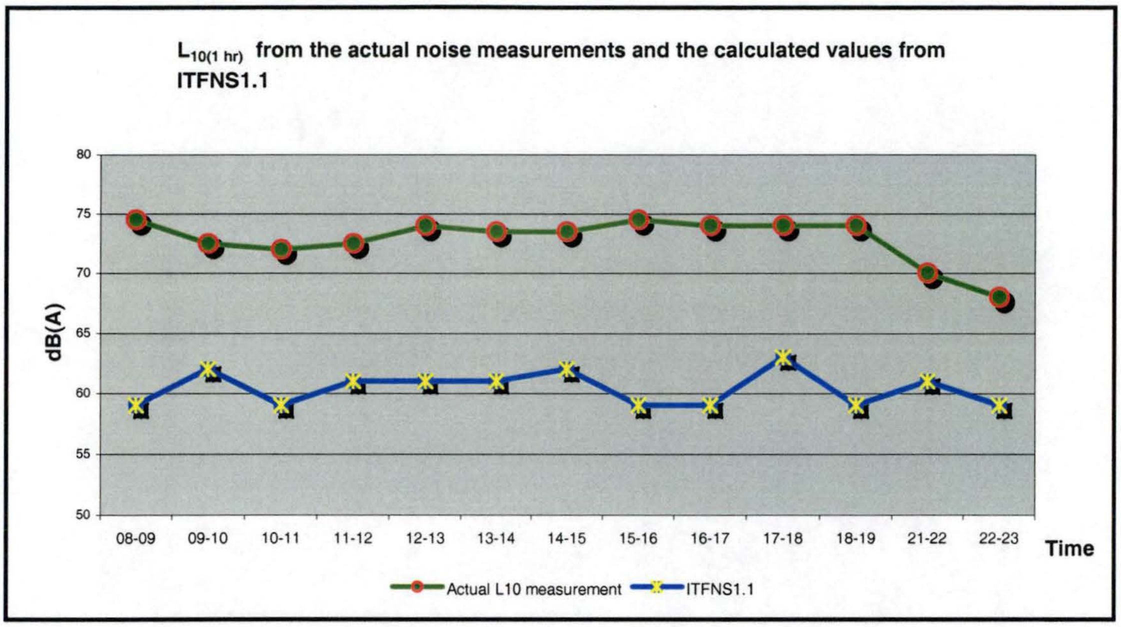


Figure 4.25 Actual noise levels and predicted noise levels calculated from ITFNS1.1 , Site 1: Regent Street, initial measurement

Table 4.20 $L_{10(1\ hr)}$ gained from the repeat noise measurement at Site 1: Regent Street compared with $L_{10(1\ hr)}$ calculated from ITFNS1.1

Time	Values from actual measurement	Values from ITFNS1.1		
		Predicted values	Differences of estimation	%Error
8.00-9.00	73.5	61.5	-12	-19.51
9.00-10.00	71.5	61.5	-10	-16.26
10.00-11.00	72.5	61.5	-11	-17.89
11.00-12.00	72	59	-13	-22.03
12.00-13.00	73	59	-14	-23.73
13.00-14.00	72.5	61.5	-11	-17.89
14.00-15.00	73	59	-14	-23.73
15.00-16.00	72	61.5	-10.5	-17.07
16.00-17.00	73	59	-14	-23.73
17.00-18.00	73	62.5	-10.5	-16.80
18.00-19.00	72.5	59	-13.5	-22.88

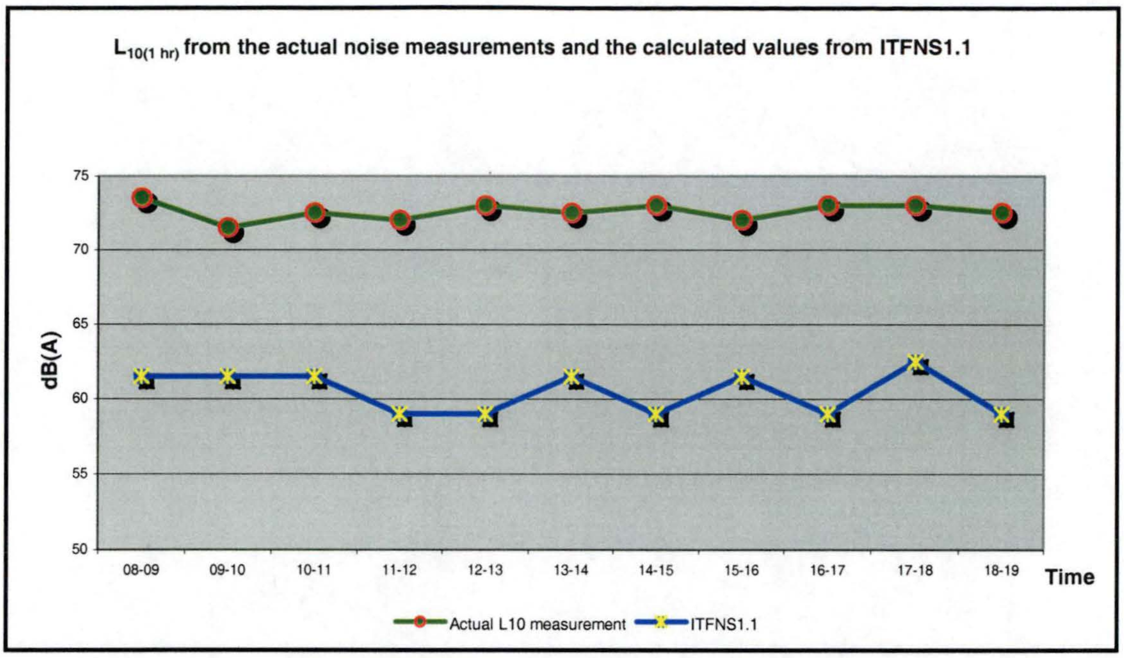


Figure 4.26 Actual noise levels and predicted noise levels calculated from ITFNS1.1, Site 1: Regent Street, repeat measurement

Accuracy analysis shows that ITFNS1.1 provided the lowest accuracy compared to the other models. The predicted values were between 27 and 12 percent lower than the actual values. The majority of calculated levels were between 15 and 18 percent under prediction (Figure 4.27).

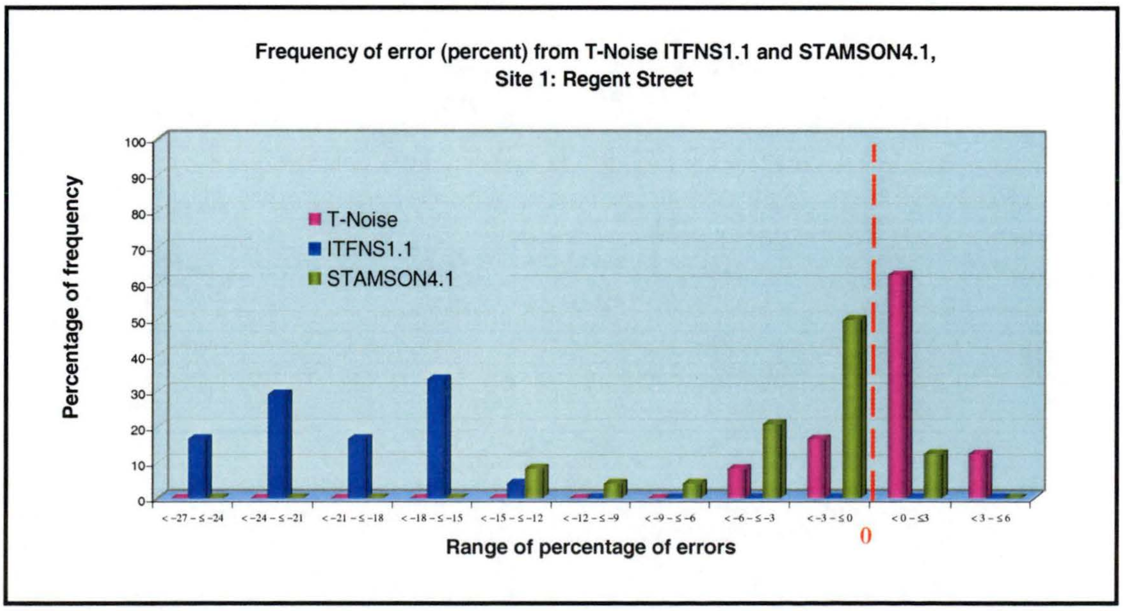


Figure 4.27 The distribution of errors from the comparisons of actual noise levels and predicted noise levels calculated from T-Noise, ITFNS1.1 and STAMSON4.1, Site 1: Regent Street

Correlation test shows that ITFNS1.1 provided inaccurate results with R^2=0.0031 (Figure 4.28).

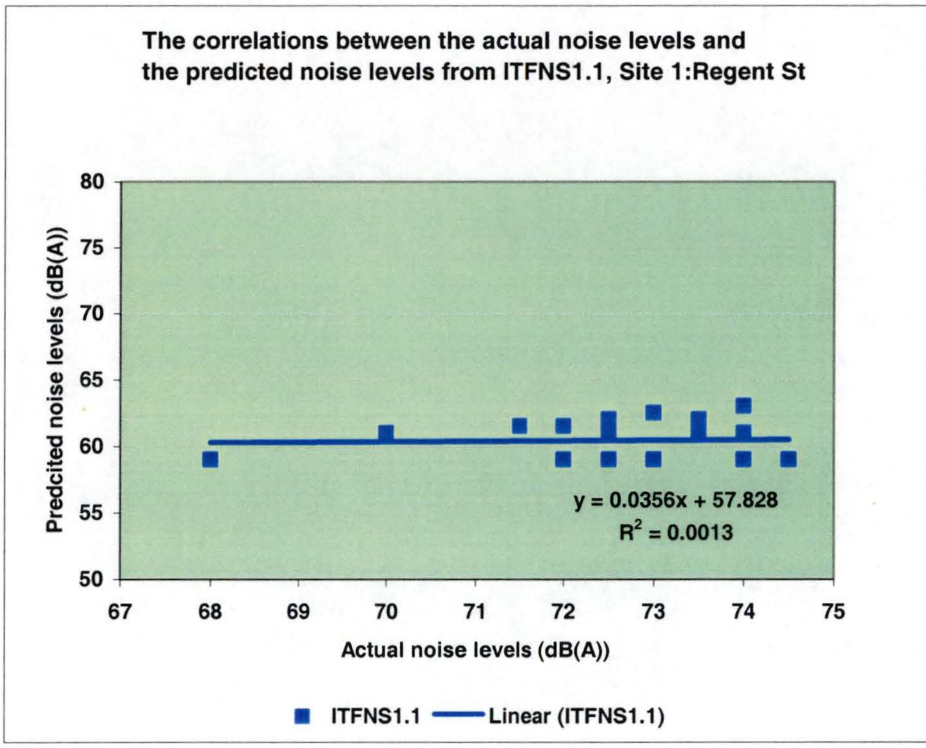


Figure 4.28 The correlation tests between the actual noise levels and predicted noise levels, Site 1: Regent Street

At Site 2: Sandy Bay Road, ITFNS1.1, again showed little relation to the actual noise values. Although it showed a relatively parallel trend as established by the actual measurement in the initial test, the calculated noise levels were much too low to be trusted (Figure 4.29) and it also indicated little correspondence to the actual noise levels in the repeat measurement (Figure 4.30).

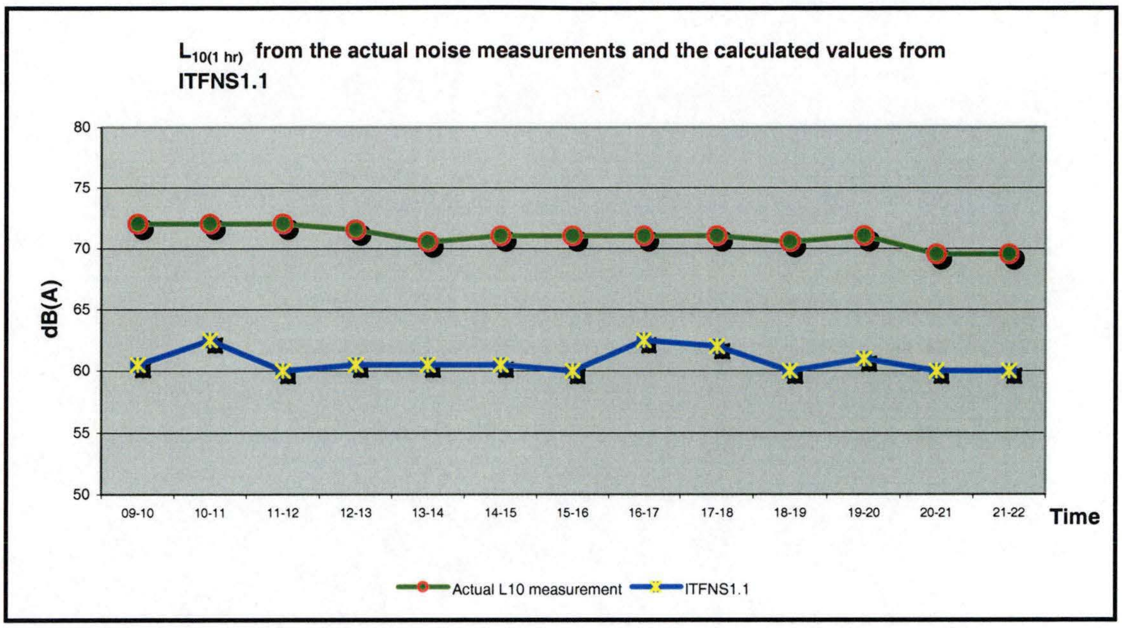


Figure 4.29 Actual noise levels and predicted noise levels calculated from ITFNS1.1, Site 2: Sandy Bay Road, initial measurement

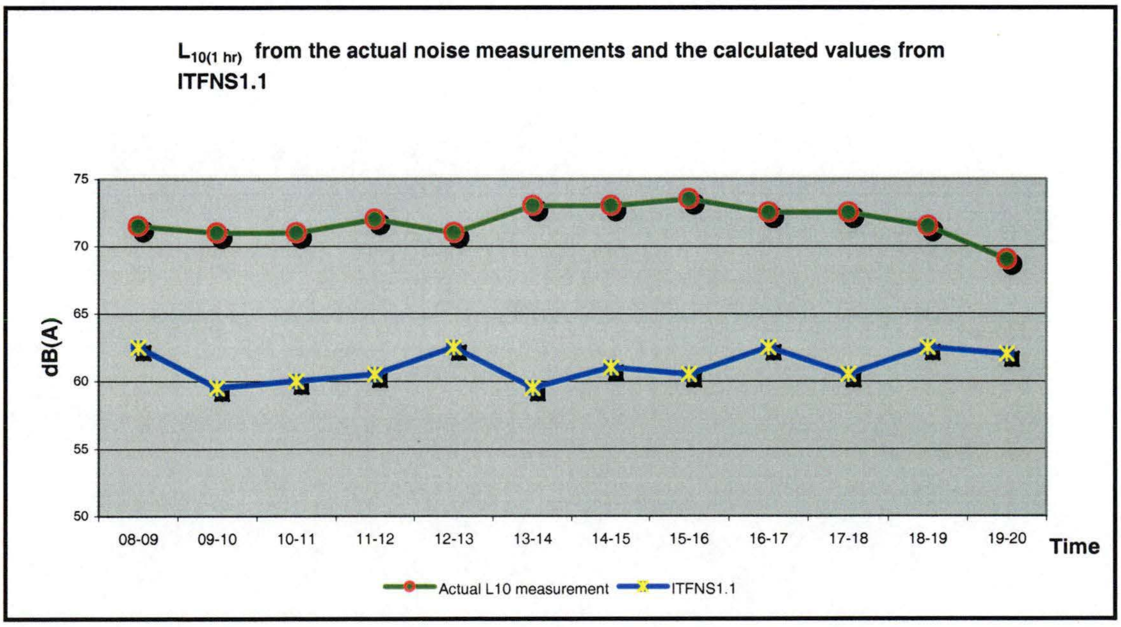


Figure 4.30 Actual noise levels and predicted noise levels calculated from ITFNS1.1 and, Site 2: Sandy Bay Road, repeat measurement

The absolute noise levels calculated by ITFNS1.1 were under predicted within the range of –12 and –8.5 dB in the initial measurement (Table 4.21) and between -13.5 and -7 dB in the repeat measurement (Table 4.22). This demonstrates that the noise levels provided by ITFNS1.1 were less reliable.

Table 4.21 $L_{10(1\,hr)}$ gained from the initial noise measurement at Site 2: Sandy Bay Road compared with $L_{10(1\,hr)}$ calculated from ITFNS1.1

Time	Values from actual measurement	Values from ITFNS1.1		
		Predicted values	Differences of estimation	%Error
9.00-10.00	72	60 5	-11 5	-19.01
10.00-11.00	72	62 5	-9.5	-15.20
11.00-12 00	72	60	-12	-20 00
12.00-13 00	71.5	60.5	-11	-18 18
13.00-14 00	70.5	60.5	-10	-16 53
14 00-15.00	71	60.5	-10 5	-17 36
15.00-16.00	71	60	-11	-18 33
16.00-17 00	71	62.5	-8 5	-13.60
17.00-18 00	71	62	-9	-14.52
18.00-19.00	70 5	60	-10.5	-17 50
19.00-20.00	71	61	-10	-16 39
20.00-21 00	69 5	60	-9.5	-15.83
21.00-22.00	69.5	60	-9.5	-15 83

Table 4.22 $L_{10(1\,hr)}$ gained from the repeat noise measurement at Site 2: Sandy Bay Road compared with $L_{10(1\,hr)}$ calculated from ITFNS1.1

Time	Values from actual measurement	Values from ITFNS1.1		
		Predicted values	Differences of estimation	%Error
8 00-9.00	71 5	62 5	-9	-14 40
9.00-10.00	71	59.5	-11.5	-19 33
10 00-11.00	71	60	-11	-18 33
11.00-12.00	72	60 5	-11.5	-19 01
12 00-13 00	71	62 5	-8 5	-13.60
13.00-14.00	73	59.5	-13.5	-22.69
14 00-15.00	73	61	-12	-19 67
15 00-16.00	73 5	60.5	-13	-21.49
16.00-17 00	72.5	62 5	-10	-16 00
17.00-18 00	72.5	60 5	-12	-19.83
18.00-19 00	71 5	62 5	-9	-14 40
19.00-20 00	69	62	-7	-11.29

In accuracy analysis, ITFNS1.1 provided the lowest accuracy compared to the other models. The percentage of frequency of errors spread between –24 and –9 percent. The highest frequency of errors occurred between -21 and -18 percent (see Figure 4.31).

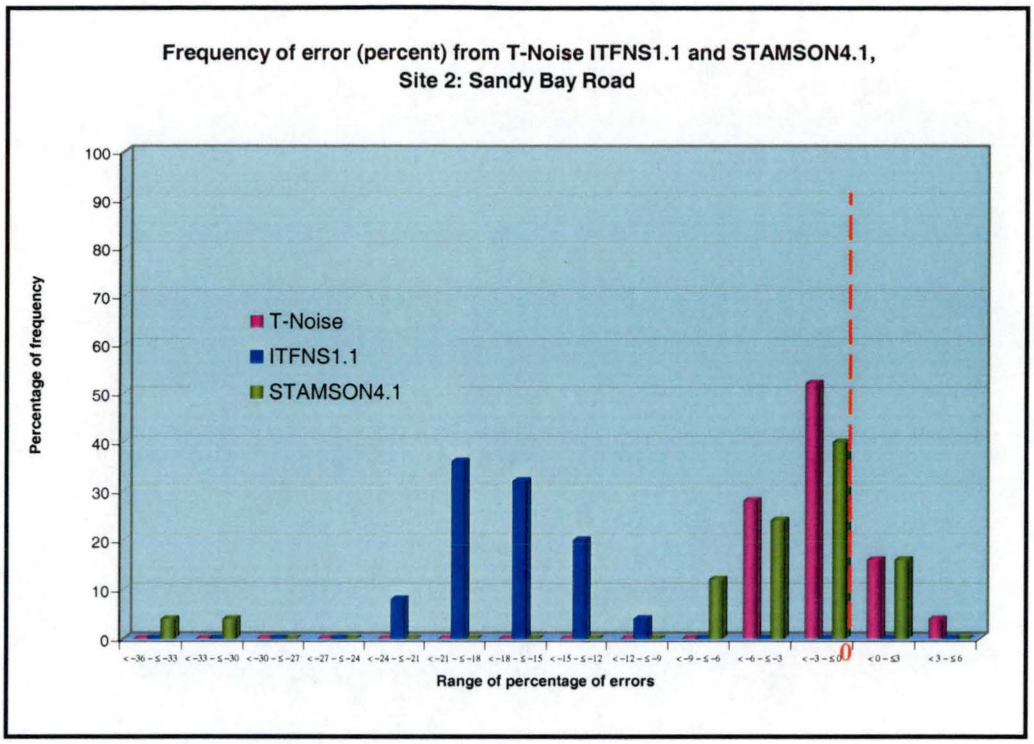


Figure 4.31 The distribution of errors from the comparisons of actual noise levels and predicted noise levels calculated from T-Noise, ITFNS1.1 and STAMSON4.1, Site 2: Sandy Bay Road

Correlation test shows that ITFNS1.1 showed the least correlation compared to the other models, with its correlation coefficient of R^2=0.0001 (Figure 4.32).

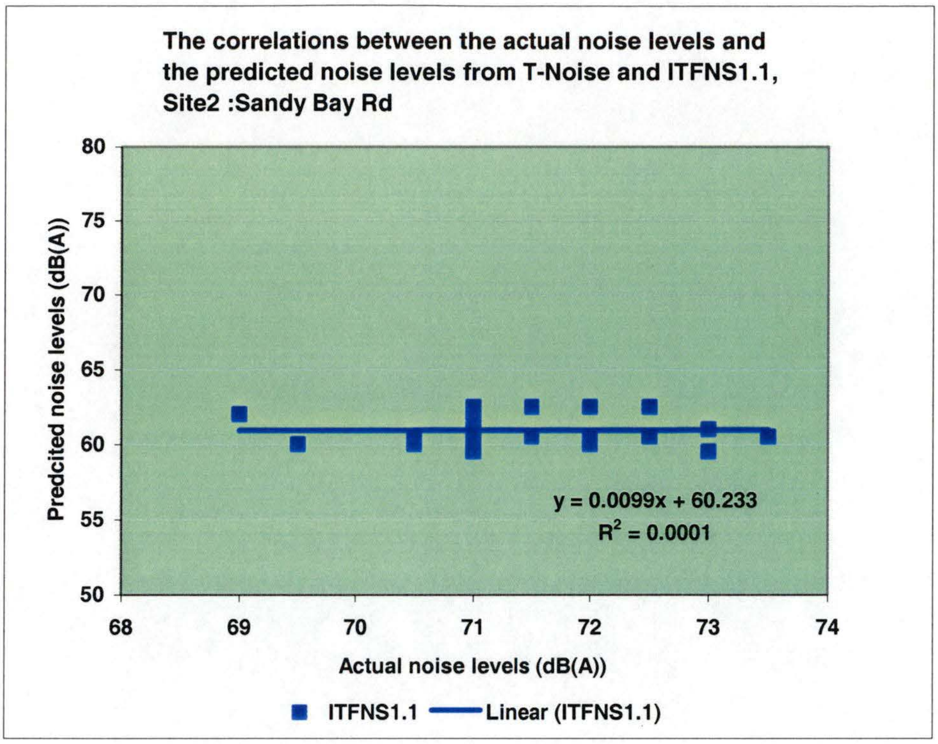


Figure 4.32 The correlation tests between the actual noise levels and predicted noise levels, Site 2: Sandy Bay Road

ITFNS1.1 was not analysed for the Tasman Highway because it would not calculate noise levels where the traffic volume in each vehicle category was higher than the maximum limit (760 vehicles per hour) of vehicle input for this model.

Table 4.23 shows the raw traffic data used for ITFNS1.1. The results from Regent Street were only slightly different from the other sites despite the discrepancy between the data format required by ITFNS1.1 and the raw data. This further indicates an inaccuracy in the predictions made by this model. For example, for the traffic volumes higher than 760 vehicles per hour observed at Sandy Bay site, the author put-in traffic volume of 760 vehicles per hour to run the model due to this being the maximum number of vehicles permitted per hour for this software. Even during the time intervals when actual traffic counts were used (e.g. all the Regent Street calculations) the predicted noise levels were well below the observed noise levels.

Table 4.23 Input traffic information for ITFNS

Site / Time	Regent Street								Sandy Bay Road							
	Initial measurement				Repeat measurement				Initial measurement				Repeat measurement			
	Direction				Direction				Direction				Direction			
	W/E	E/W	S/N	N/S	W/E	E/W	S/N	N/S	W/E	E/W	S/N	N/S	W/E	E/W	S/N	N/S
8-9	144	432	18	42	440	342	36	16	-	-	-	-	360	760 1044*	0	0
9-10	504	490	48	42	350	428	24	18	618	760 934*	0	0	494	718	0	0
10-11	376	398	24	44	334	394	24	22	590	760 770*	0	0	628	760 816*	0	0
11-12	426	404	40	32	448	396	36	40	760	760 960*	0	0	670	760 846*	0	0
12-13	468	450	41	26	376	350	20	40	734	694	0	0	760	760 762*	0	0
13-14	444	412	30	26	418	330	28	32	708	760 1264*	0	0	754	760 922*	0	0
14-15	566	354	44	44	428	352	26	36	760	760 1028*	0	0	760	760 1006*	0	0
15-16	630	512	38	56	480	356	42	40	760	760 1046*	0	0	738	760 996*	0	0
16-17	466	366	30	56	482	346	24	36	760	760 1028*	0	0	760	760 870*	0	0
17-18	704	462	56	58	584	320	50	56	760	760 796*	0	0	760	760 828*	0	0
18-19	444	306	28	42	410	214	34	38	760	760 798*	0	0	750	674	0	0
19-20	-	-	-	-	-	-	-	-	602	602	0	0	494	446	0	0
20-21	-	-	-	-	-	-	-	-	556	462	0	0	-	-	-	-
21-22	202	98	8	14	-	-	-	-	376	380	0	0	-	-	-	-
22-23	132	90	6	6	-	-	-	-	-	-	-	-	-	-	-	-

W/E = direction of traffic from West to East   S/N = direction of traffic from South to North

E/W = direction of traffic from East to West   N/S = direction of traffic from North to South

* = actual traffic volumes

4.3.5 The comparison of the accuracy provided by each prediction model over the study sites

With regard to the above results, when considering the absolute noise levels, T-Noise and STAMSON4.1 provided relatively reliable results for urban arterial road conditions, while ITFNS1.1 produced too low a prediction. For the highway conditions, none of the models presented reliable predictions. In comparing T-Noise and STAMSON4.1, the results provided by T-Noise were better than the predictions calculated using STAMSON4.1 The majority of the predicted noise levels calculated by T-Noise were higher than the actual levels in a situation of low traffic density (Regent Street), while it regularly showed under-predicted levels on busier arterial roads (Sandy Bay Road). STAMSON4.1, alternatively, usually provided under-estimation of noise levels for both conditions.

In contrast, the correlation studies indicated that all of the study prediction models presented a poor relationship between their calculations and the observed changes in noise levels. However, T-Noise showed the greatest correlation coefficient in both urban and highway conditions. STAMSON4.1 provided the second best correlations for both road conditions. It is also clear that ITFNS1.1 provided particularly unreliable results, accordingly the author decided not to further discuss the results from this model.

Figures 4.33 and 4.34 show the correlation coefficients gained form the predictions of T-Noise and STAMSON4.1 respectively. T-Noise provided better results with $R^2 = 0.5678$ while STAMSON4.1 provided $R^2=0.4271$.

The equation calculated from the urban sites data showed underestimation that could be obtained from T-Noise and STAMSON4.1. However, better results would be achieved with the use of T-Noise. For example, if the actual noise is 70 dB(A), by using the equation illustrated in Figures 4.33 and 4.34, the T-Noise calculation would be approximately 69 dB(A) while the STAMSON4.2 prediction would be approximately 68.7 dB(A).

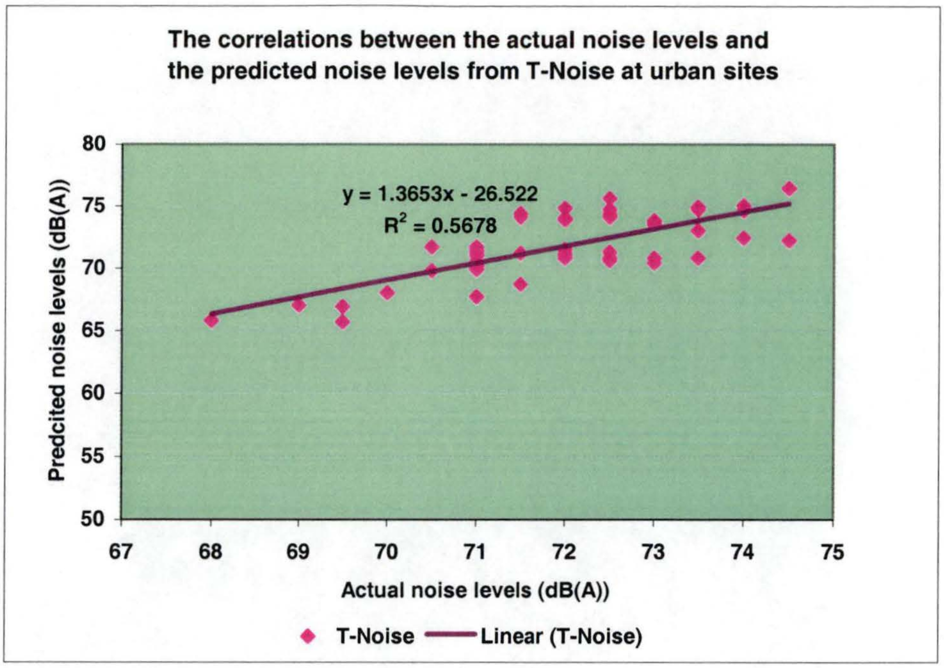


Figure 4.33 The correlation tests between the actual noise levels and predicted noise levels from T-Noise at urban sites

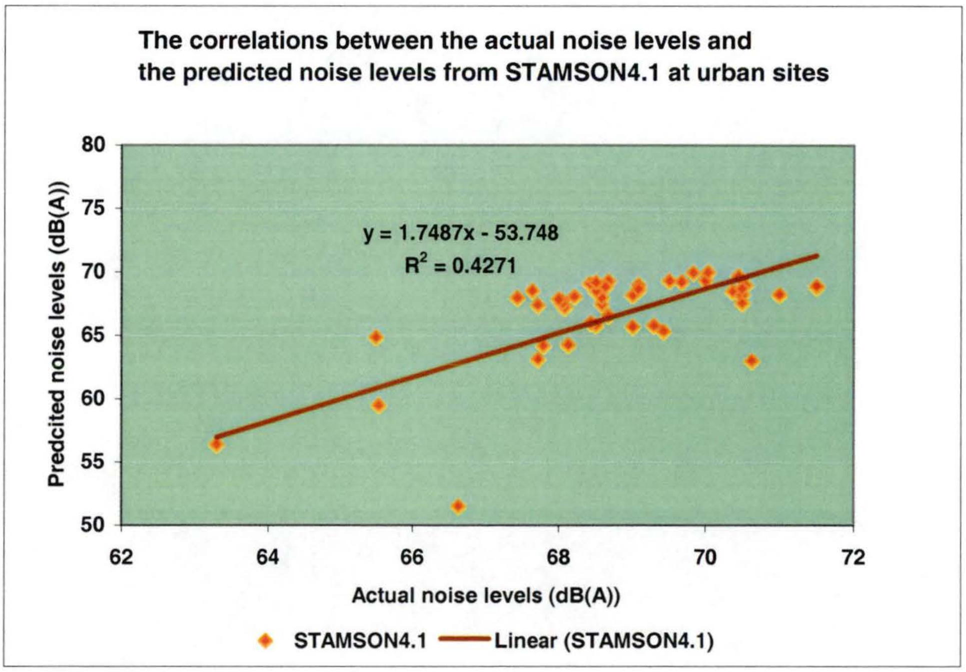


Figure 4.34 The correlation tests between the actual noise levels and predicted noise levels from STAMSON4.1 at urban sites

In the correlation test for both urban and highway conditions combined both models show very little correspondence with the actual noise levels (Figure 4.35 and 4.36). These results indicate that even if changes or improvements in the equations used for each model were introduced the separate study of urban and highway conditions would bring about better predictions.

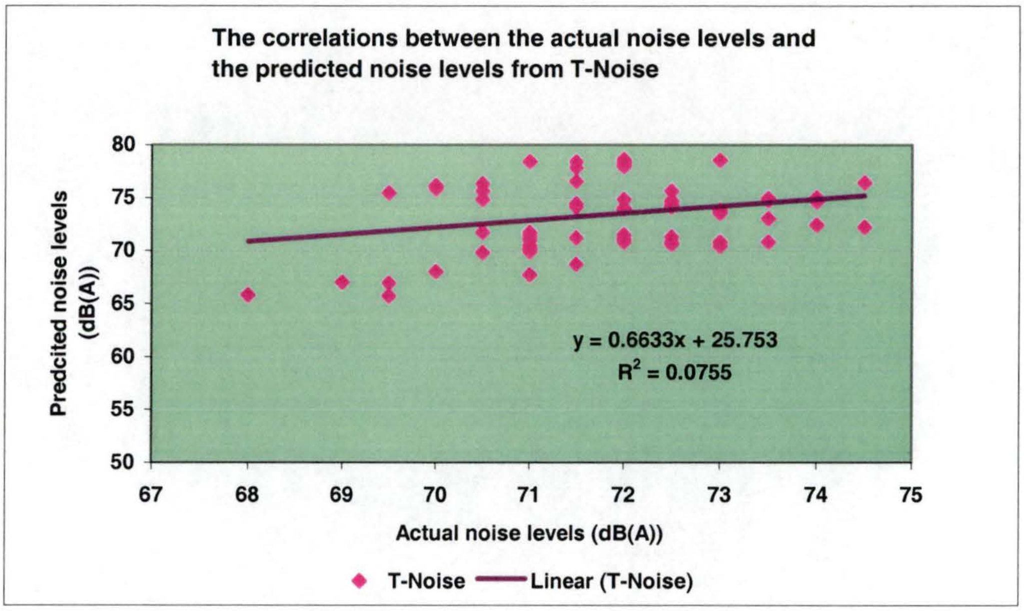


Figure 4.35 The correlation tests between the actual noise levels and predicted noise levels from T-Noise at all sites

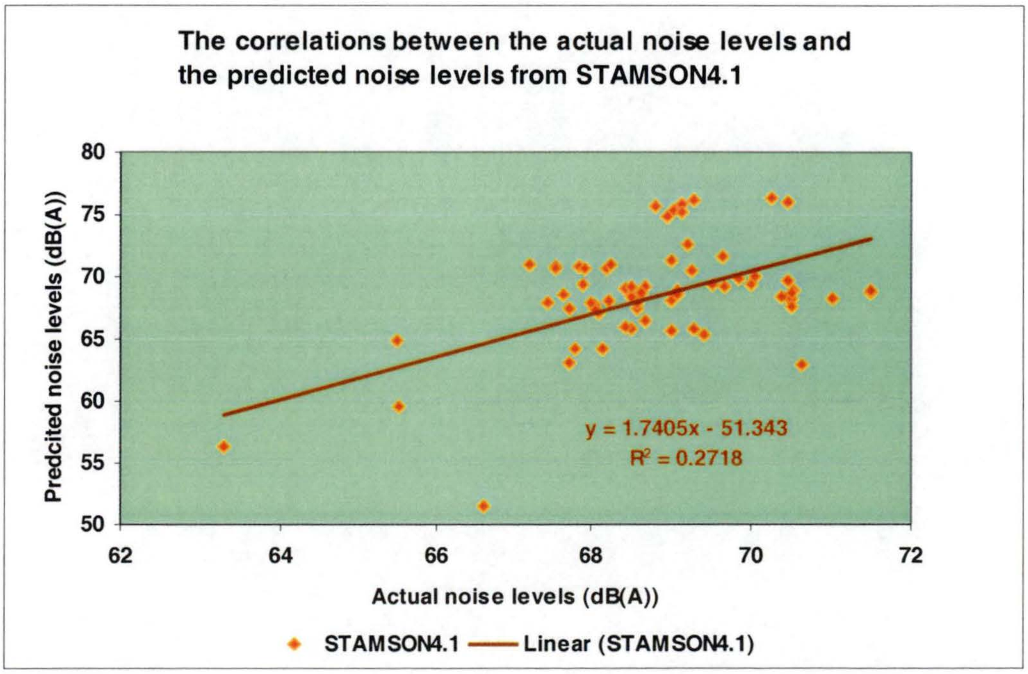


Figure 4.36 The correlation tests between the actual noise levels and predicted noise levels from STAMSON4.1 at all sites

4.3.6 The comparison of errors from the prediction models and traffic volumes

The correlation studies between errors from prediction models and traffic volumes show that T-Noise (R^2=0.59) provided better correlation than STAMSON4.1 (R^2=0.05). These results imply that the observed errors from T-Noise show some relationship with traffic volumes; therefore a propensity for improvement of the systematic underestimation of noise in cases where lower numbers of vehicles are recorded exists. For STAMSON4.1, there is a very small link between error and number of vehicles (Figure 4.37).

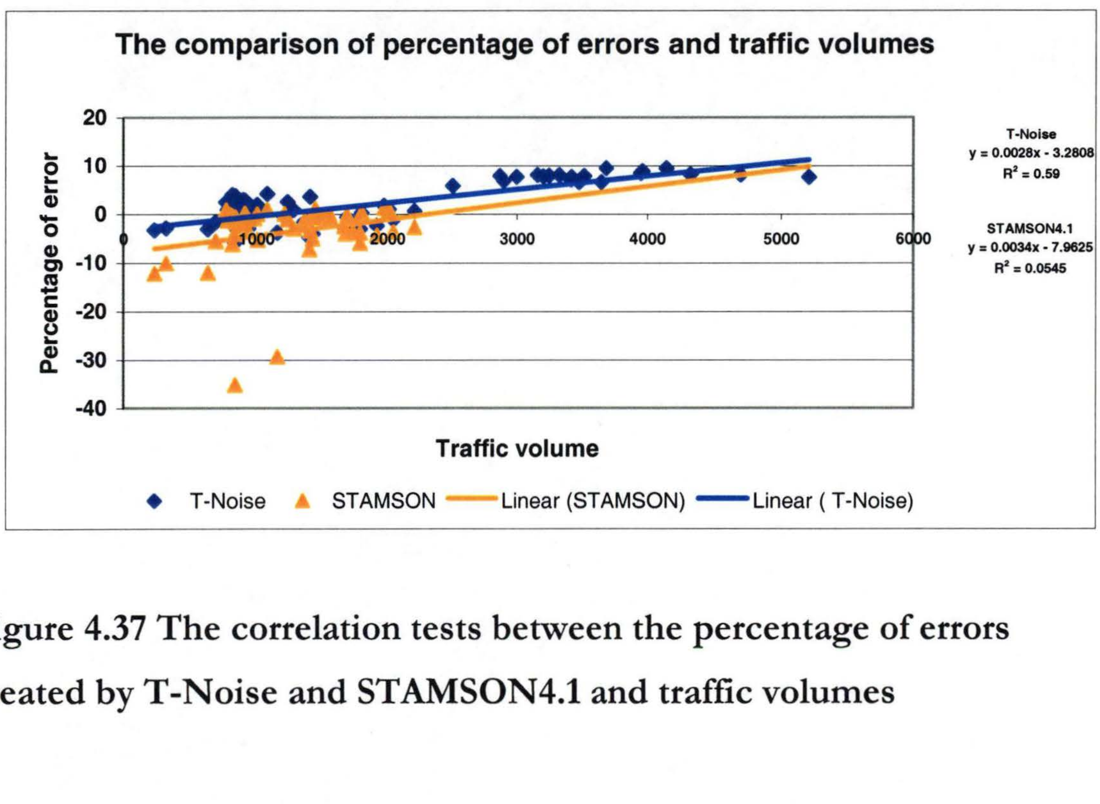


Figure 4.37 The correlation tests between the percentage of errors created by T-Noise and STAMSON4.1 and traffic volumes

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 DISCUSSION

5.1.1 The benefits of using models

Traffic noise prediction models have been proved to provide a range of benefits for traffic noise planning. The outcomes from the models are not only useful for decision making with regard to new infrastructure and any traffic changes, but they also suggest suitable alternatives for use with noise problems with existing roads. However, there are limitations with the use of prediction models. For example, the prediction models are limited in their application to a range of circumstances and environmental conditions. Although there are sophisticated prediction models that provide complicated calculations with a variety of databases and take into account various environmental conditions, errors from calculations have still occurred. This is a result of some conditions where the complexity of environmental influences outweighs the capability of their calculations. In addition, some traffic characteristics, such as traffic structures, weather conditions, road conditions, vehicle capacity, and newly established noise emission laws, have changed from the time at which these models were created. For example, the Hobart City Council reported that there were approximately 400 vehicles per day on Regent Street in 1988. Whilst the traffic counts shown in this thesis were approximately 12,000 vehicles per day on the same street. This obviously shows that traffic volume on Regent Street has increased by 3,000 percent within 14 years (HCC, 2002). Subtle changes, such as construction of new roads and buildings or new vehicle technology, can cause variations in prediction outcomes. As a consequence, the accuracy of the prediction models for each area considered should be regularly quantified, or at least tested in order to be certain that the prediction models that are going to be used for those areas will bring about reliable predictions.

This thesis introduced the idea of testing prediction models in real conditions through drawing on the currently used prediction models and testing the outcomes with the use of actual data collection (using T-Noise, which is in used in Hobart and STAMSON4.1, which is in used in Canada) and the old prediction model (ITFNS1.1) that is no longer in use.

Amongst those prediction models, T-Noise was the most user-friendly model whereas STAMSON4.1 and ITFNS1.1 were slightly less convenient for the user. This convenience related to T-Noise being updated to run on the Windows2000 computer operating system, hence proving ease of access to many users, while the others were run using DOS mode. In addition, the process of input and making databases was found to be easiest using T-Noise, with the hardest model being ITFNS1.1. T-Noise also presented the most convenient software for the process of calculation and output display.

Nevertheless, all studied prediction models contained limitations within themselves, as explained below.

T-Noise, although proving to be the most sophisticated of the three prediction models, denied the traffic input of less than 50 vehicles per hour. Furthermore, T-Noise calculated L_{eq} by subtracting 3.5 dB from each $L_{10\ (24\ hr)}$ result and 3 dB from each $L_{10(1\ hr)}$ result. As a result, the possibility of providing an incorrect prediction was likely to be high because a range of factors in the real situation that caused an influence over the variation of noise levels are not considered in the statistical prediction of L_{10}. Hence, the fixed values that were used for converting the value of L_{10} to L_{eq} would provide inflexibility in the prediction. In addition, a further limitation of T-Noise relates to the distance at which it can predict noise levels, being between 4 and 500 metres. For distance inputs outside of this range, the model would either not process the calculations or would produce an inaccurate result. Furthermore, the most recent information on traffic noise used for establishing the model was produced in or before 1988. At the present stage, this model would be considered quite old.

There were several limitations using ITFNS1.1 and as a result, although it was produced two years after T-Noise, it is still considered an old model. Firstly, the model allowed for a maximum of 760 vehicles in each vehicle input cell at each carriageway. Secondly, the distance between source and receiver was determined using grid co-ordinates provided by the model, however, the distance between each grid line was not specified and hence the information on distances from the carriageways to the study locations were not clear. This also caused incorrect predicted levels because the exact locations were not taken into account. Even with selection of the nearest grid coordinate to the source the predicted levels were very low. ITFNS1.1 was similar to T-Noise calculation in that it calculated $L_{eq(1\ hr)}$ by subtracting 3 dB form $L_{10(1\ hr)}$ values and hence subjected the prediction results to the same inaccuracies described above.

STAMSON4.1 is also considered an old prediction model due to it being based on methods and data dating back prior to 1990. The limitations that cause inaccurate prediction making with the use of this model mainly stem from poor input requirements. There were several input figures that were already set within the model. Instead of putting in the actual environmental characteristics such as topography and types of intermedia to surface, users had to select from simplified situational scenarios and the software would determine the input variables for these conditions prepared by the model. This meant that the figures provided within the software only partly matched the real conditions. Also, the distance between source and receiver was limited to a minimum of 15 metres, this also caused an increased propensity for incorrect calculations for distances less than this minimum.

The above limitations, coupled with the fact that each model used different equations, provides an explanation as to why the noise level predictions vary even though the models used the same input data.

From the results of this study, T-Noise and STAMSON4.1 showed some potential for predicting traffic noise levels for urban roads, while ITFNS1.1 always provided unreliable data. Accordingly, discussion on ITFNS1.1 will not be further presented. Although the comparisons of the absolute noise levels gained from the actual measurements and the noise levels calculated by T-Noise and STAMSON4.1 were only slightly different, the correlation tests indicated only marginally acceptable correlations with the actual noise, with their $R^2=0.57$ by T-Noise and $R^2=0.43$ by STAMSON4.1. Therefore, users of these prediction models must be aware of the possibility for variation. Also, the predictions of both T-Noise and STAMSON4.1 were not significantly different, and hence it is hard to point out which one is more appropriate for use on Hobart urban roads. However, in terms of the convenience offered to prediction model users, T-Noise is recommended. For highway conditions, although the results showed none of the models provided good predictions when the absolute levels were considered, the correlation tests showed that T-Noise provided better correlation with the actual trend. In this case, the use of T-Noise for Hobart highway traffic noise prediction would be suggested. In this thesis, although the studied models did not show any excellent predictions, the author would suggest T-Noise as the most appropriate. Furthermore, the correlation test between errors from T-Noise prediction and traffic volume showed that there was an apparent relation between these figures. This could infer that further study to improve T-Noise accuracy could be achieved by considering traffic characteristics. However, there are few points to be considered using T-Noise. Firstly, Although T-Noise provided better results in both urban road and highway conditions, the correlation test results when both highway and urban roads were combined were unreliable. Therefore, the use of this model should be calibrated separately between urban road and highway conditions. Secondly, due to the equations of the best-fit lines gained from correlation studies, these results suggest the user should expect slightly underestimated results in urban condition and overestimated results in highway conditions.

5.1.2 The important parameters that affected the predictions

There are some factors that affected the predictions of the models used in this thesis. Apart from the differences of the equations used and the background information of each model, the important factors that affected the predictions in this study involved the environment and the traffic information relating to each study site. The models focused mainly on the road conditions, the location of receivers, traffic volumes and speed, but were not concerned with some minor effects from temperature, wind-speed and wind direction, driving behaviour, which sometimes could contribute changes in usual traffic noise levels (Hood, 1987).

Research by Hood (1987), conducted to test the accuracy of CoRTN (the basic method of calculation of road traffic noise in T-Noise), stated that within the London region it provided an over-prediction of traffic noise by approximately 0.7 dB(A) with an rms error of 2.1 dB(A). This infers that there were errors in the basic method before it was used in T-Noise leading to errors with its use.

The correction value is one of the key factors that can affect the accuracy of the prediction models. The correction values in the models were calculated from empirical theory of the effect of the environment on noise levels at the receiver. It would be possible to alter these correction values based on local conditions. These modified values assist in decreasing errors caused by environmental factors in that area. Therefore, in different study areas, the correction values would be different. In this thesis, only T-Noise provided a choice for users between the built-in correction values or values determined by the user. This means that T-Noise provided more flexible and adjustable calculations for different study sites. If the correction values given by users are deemed suitable, this makes it more likely that T-Noise will provide a good result. However, this thesis used the correction values that were provided by the model.

The comparison tests and the absolute noise levels predicted by T-Noise and STAMSON4.1 were, on average, less than 2.5 dB different to the actual levels while the correlation tests indicated a slight contrast with the correlation coefficient, R^2, only about 0.5 when actual noise measurements were compared to model predictions, there remains considerable uncertainty when using the models to predict changes in noise when traffic numbers change.

5.1.3 Guidelines and noise levels

The results showed that all the day-time and most of night-time noise levels exceeded NSW road noise criteria along with the Tasmanian guidelines. This raises the question; is the road noise situation in Hobart problematic? Therefore, clarification of the appropriateness of use of the criteria and guidelines should be undertaken.

NSW criteria apply to arterial roads, and so should be expected to apply to the sites in this study. However, the Tasmania guidelines apply only to new and upgraded roads that are first opened to public traffic on or after the 1st of January 2004, which means the newly built and newly upgraded roads should not create noise louder than that indicated in the guidelines (Department of Primary Industries, Water and Environment, 2002).

In realistic situations, the NSW criteria might not be applicable to Hobart, because it has been proven in this study that the desired noise levels are always below the usual traffic noise. For the same reason, the Tasmanian guidelines, although aimed at new and new upgraded roads, may prove difficult in implementation. This means that noise levels from the new roads have a propensity for exceeding the guidelines. Therefore, in reality, success is not assured if the guidelines are implemented in Hobart. Or on the other hand, the desired noise levels suggested in the criteria and guidelines might be unrealistically low.

This raises the question of whether good predictions are helpful if the noise criteria are considered impractical. For example, if the prediction outcomes show the noise levels from the new or new upgraded roads are beyond the desired levels, should the projects be continued? On the other hand, prediction models can bring about suitable guidelines by providing predictions that describe general noise levels that could occur in the considered areas. This process would be more likely to bring about guidelines that are better related to realistic situations.

5.2 CONCLUSION

5.2.1 Limitations

There were three main limitations to this study: site selection and interference during noise measurement; traffic count periods; and the use of prediction models. When selecting study sites, instead of primarily focusing on the most appropriate conditions to test the prediction model, safety from vandalism and stealing was the first priority. This led to some parameters being beyond control of the project. For example, at the Tasman Highway study site, which was located in the Hobart City Council hostel, interference introduced by people who stayed in the hostel was often observed. This caused the measured noise levels to vary from the levels attributed to traffic alone. Interference was also encountered at the Regent Street study site with the measured noise levels being altered by a lawn mower and alarm signal in close proximity. At the Sandy Bay site, vandalism was a major problem when conducting noise measurements. The noise measuring equipment was found relocated many times and sometimes knocked over. Construction was in progress in and around the security building located just behind the site, and also occurred on the adjacent road approximately twenty metres from the site. However, these phenomena affected only part of the noise pattern study; this influence was avoided in evaluating the accuracy through the comparison tests.

Traffic count study periods were limited by factors relating to safety of the observers. Ideally, the traffic counts should be conducted over at least one week, for 24 hours continuously, and at the same time as the noise measurements to increase the accuracy of the comparison tests. However, the author chose the least number of study hours that could provide reliable results for safety reasons.

There was also a limitation relating to the use of the prediction models. STAMSON4.1 often stopped working when the number of vehicles equalled zero (for example, sometimes there were no heavy trucks in the study period). Sometimes it allowed every number to be put in, but often it stopped when traffic volume was less than 100. This limitation was not indicated in the user manual; therefore, the author assumed that it might be a problem within the model programming. For ITFNS1.1, some bugs were found in the software programming relating to the command for inputting data and the command for describing input data. In this case, the author had to improvise to make the model work. Nevertheless, the commands used in ITFNS1.1 were simple providing an advantage in improving the potential of its predictions.

5.2.2 Conclusion

Noise pollution from traffic has been considered as one of the major noise problems due to its annoyance and health effects on people that are exposed to the noise. There are various means to deal with this problem, using a traffic noise prediction model was found an appropriate approach. Traffic prediction models can predict noise levels, particularly for planning, before constructing a new infrastructure or any actions that lead to a change of traffic characteristics. The models can help designing noise reduction means in an area that finds noise a problem. However, the use of a prediction model must take into account its accuracy within the investigated area. This thesis was conducted to test the accuracy of prediction models using Hobart arterial roads and a highway. Three prediction models were used in this study: T-Noise, ITFNS1.1 and STAMSON4.1. In order to complete this test, the study of current noise levels and traffic volume in the study area were necessary.

On each measurement day, the traffic noise at the study sites generally increased quickly in the morning, stayed steady during the day at the L_{eq} range 70 to 75 dB, then the levels dropped quickly in the evening to L_{eq} between 50 to 60 dB(A) in the late night. When compared to the NSW road traffic noise criteria and the Tasmanian guidelines, all day-time noise data exceeded both recommendations and only few hours during the night were below both criteria and guidelines.

Traffic volume at the Regent Street site was approximately between 800 and 1000 vehicles per hour from 8:00 am to 7:00 pm. Sandy Bay Road site was found busier with a range approximately between 1500 and 2000 vehicles per hour in the same observed period. Tasman Highway was found as the busiest site with approximately 3000 to 5000 vehicles per hour from 8:00 am to 6:00 pm.

The results in the comparison tests showed that T-Noise and STAMSON4.1 provided close predictions for the absolute noise levels on arterial road conditions. The average variations created by T-Noise and STAMSON4.1 predictions were 0.91 dB(A) and -1.57 dB(A) respectively. While ITFNS1.1 created errors of -11.34 dB(A), which is considered an unreliable prediction. For highway conditions, none of them showed reliable results. The result gained from correlation tests from T-Noise and STAMSON4.1 were fairly acceptable with the correlation coefficient of approximately 0.57 and 0.43 respectively for urban roads.

For highway condition, T-Noise provided the greatest correlation coefficient of approximately 0.64, while STAMSON4.1 provided correlation coefficient of approximately 0.43. Low correlation coefficient of 0.08 and 0.27 were found from T-Noise and STAMSON4.1 respectively in combined urban and highway correlation tests. ITFNS1.1 showed poor results on this test with the correlation coefficient at urban road sites of approximately 0.006 and it was not able to predict under highway conditions.

5.2.3 Further study

Further study is required to improve the efficiency of T-Noise for predicting traffic noise levels in the Hobart area. Particularly, research is needed to find out suitable correction values to adjust the calculations so that predictions are more reliable. More data collection and comparisons, including the study of the empirical theory of this area, are necessary.

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APPENDIX A

List of Specifications in Accordance with AS 1259 (1982)

Clause	Description	Performance
(a)	The type of microphone and method of mounting in order to attain the tolerances required for Type 2	1/2" piezoelectric ceramic mounted vertically on a telescopic microphone support post
(b)	The reference direction of incidence.	0° of incidence (frontal / vertical).
(c)	The range of weighted sound pressure levels which the instrument is designed to measure within the tolerances of this standard.	33 to 113dBA 43 to 113dBC.
(d)	The reference value of sound pressure level.	104dB.
(e)	The nominal frequency weighting characteristics.	A weighting and C weighting.
(f)	The detector-indicator characteristics.	FAST.
(g)	The effect of vibration on the operation of the sound level meter.	1ms^{-2} will give an output of less than 80dBC, for vibrations in any direction.
(h)	The effect of magnetic fields.	80 $A_{/M}$ at 50Hz gives a reading of less than 35dB.
(j)	The effects of temperature.	Error is less than 0.5dB for the range -10°C to +50°C.
(k)	The effect of the presence of the operator on a free field measurement.	Not applicable for normal unattended operation.
(l)	The effects of humidity.	The unit meets the specification for a relative humidity of 0 to 90%.
(m)	The limits of temperature and humidity beyond which permanent damage to the sound level meter may result	70°C and saturation
(n)	The correction to be added to the pressure response of the microphone to obtain the free field frequency response of the complete instrument.	Refer to microphone data sheet
(o)	The correction to be added to the actuator response of the microphone to obtain the free field frequency response of the complete instrument.	Not applicable for a piezoelectric microphone.
(p)	The correction to be added to the electrical response of the instrument with an equivalent electrical network substituted for the microphone to obtain the free field frequency response of the complete instrument.	None.
(q)	Any correction to calibration required when a microphone extension cables used.	Less than 0 25dB for a cable length of 10m or less
(r)	The effect on the performance of the instrument caused by the use of recommended microphone accessories such as windscreens etc.	No effect
(s)	The calibration procedure necessary to maintain instrument accuracy	See calibration procedure in user manual
(t)	The position of the instrument case and observer relative to the microphone in order to minimise their influence on the measured sound field.	Not applicable for normal unattended operation. See operating instructions in user manual
(u)	A procedure to ensure optimum operating conditions when the Sound Level Meter is used with external filters or analysers if applicable.	Not applicable
(v)	The limitations on the electrical impedance that may be connected to the output connector if applicable.	Not applicable
(w)	The reference frequency used for calibration	1000Hz
(x)	The reference range for calibration purposes.	Not applicable.
(y)	The warm-up time before valid readings can be made	5 minutes
(z)	For Type 0 instruments, continuous frequency response curves.	Not applicable.
(aa)	Correction information between the sensitivity in a diffuse field and that in the reference direction as a function of frequency.	Refer to microphone data sheet.
(bb)	The directional response of the sound level meter at various frequencies:	Refer to microphone data sheet
(cc)	The electrical network(s) which shall be substituted for the microphone for testing purposes.	Refer to calibration and servicing manual.
(dd)	The primary indicator range as required by Sub-clause 9.6	64dB - 84dB.
(ee)	For sound level meters with automatic range control, the settling time.	N/A
(ff)	The lowest frequency for which the error resulting from non-linear distortion is less than 1 dB	31.5Hz