

Converting the UK traffic noise index $L_{A10,18h}$ to EU noise indices for noise mapping

by P G Abbott and P M Nelson

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CONVERTING THE UK TRAFFIC NOISE INDEX $L_{A10,18h}$ TO EU NOISE INDICES FOR NOISE MAPPING

by P G Abbott & P M Nelson (TRL Limited)

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CONTENTS

| | Page |
|--|------|
| Executive summary..... | iv |
| Abstract..... | 1 |
| 1 Introduction..... | 1 |
| 2 Comparison of noise scales and indices..... | 3 |
| 2.1 Definitions of levels, scales and indices..... | 3 |
| 2.2 Relationships between different noise scales and indices..... | 5 |
| 2.3 Discussion of the comparison of noise scales and indices..... | 9 |
| 3 Methods for calculating EU noise indices..... | 10 |
| 3.1 L_{Aeq} traffic noise models..... | 10 |
| 3.2 Adapting the CRTN method..... | 12 |
| 3.3 Discussion of alternative methods of calculation..... | 14 |
| 4 Deriving an 'end correction' for CRTN..... | 16 |
| 4.1 Freely flowing traffic..... | 16 |
| 4.2 Non freely flowing traffic..... | 17 |
| 4.3 Combining free flow and non free flow data..... | 18 |
| 4.4 Relationships between measured hourly values of L_{Aeq} and L_{A10} | 19 |
| 4.5 Relationships between measured $L_{A10, 18h}$ and EU noise indices..... | 21 |
| 4.6 Procedure for calculating EU noise indices from CRTN derived noise levels..... | 26 |
| 5 Conclusions and recommendations..... | 31 |
| 6 Acknowledgements..... | 32 |
| References..... | 32 |

EXECUTIVE SUMMARY

The Commission of the European Communities has published proposals to establish a common EU framework for the assessment and management of exposure to environmental noise. It requires Member States to produce noise exposure information in the form of strategic noise maps that use common noise indicators that have also been proposed by the EU. An objective of this approach is to provide a means of assessing various noise control strategies on an area wide basis. It is intended that the strategic noise maps will be published, thereby allowing responsible authorities to compare the different noise control methods adopted. It is hoped that this exchange of information will encourage a greater understanding of the problem and will encourage the development of best practice across the community.

The Commission recognised that not all Member States have a noise prediction method for assessing environmental noise based on the EU noise indices. Therefore, it has made provisions to allow suitable interim computation methods to be used prior to the development of a common EU method. Two options have been recommended: Firstly, member states would be allowed to use existing national methods provided that they are adapted to compute the recommended EU noise indices. Secondly, if there is no suitable existing national method or an existing model that can be adapted, the EU recommends the French national computation method 'NMPB' for the assessment of road traffic noise.

In the UK, the environmental assessment of road traffic noise is normally based on the procedures described in the publication 'Calculation of Road Traffic Noise' (CRTN) (except for new or altered roads for the purposes of the Noise Insulation (Scotland) Regulations 1975). The noise index derived from this prediction method is very different from the indices proposed by the EU. A decision has to be made therefore whether to attempt to adapt the CRTN method to produce the required noise indices or whether to adopt the proposed French method or a similar new method in the UK for noise mapping purposes. In order to inform this decision the AEQ Division of DEFRA and the devolved administrations have commissioned TRL to examine the options available.

In this study the various options are reviewed and compared to establish advantages and disadvantages of each approach. In addition, a particular objective is to determine correction formulae to CRTN to produce outputs in the form of the EU indices and to establish the potential accuracy of this approach. The analysis does not consider how barrier attenuation or varying wind speed and direction may influence noise levels and the subsequent effects on the relationship between L_{Aeq} and L_{A10} . However, it is pointed out that the relative effect of screening on the different noise indices is likely to be small in practice. Consequently, it is reasonable to expect that the relationships derived for open site conditions can also be applied to sites where screening is involved. The EU requirement to predict long-term average noise levels based on average wind conditions rather than the moderately adverse conditions implicit in the CRTN formulation will tend to overestimate EU indices, particularly at locations where negative wind vectors predominate.

It was found that using either the French 'NMPB' method or a similar method derived by the Noise Advisory Council as an interim computation method would pose significant problems. The main limitation is the lack of appropriate vehicle noise input data particularly for roads where vehicle speeds fall below 80 km/h.

It is suggested that for UK conditions the best interim approach is to adapt CRTN by applying an 'end correction' to obtain the relevant EU indices from calculated values of L_{A10} . The preferred approach

relies on determining hourly values of L_{A10} using the CRTN¹ method and then converting these values to equivalent values of L_{Aeq} using the relationship

$$L_{Aeq,1h} = 0.94 \times L_{A10,1h} + 0.77 \text{ dB}$$

except for *non-motorway roads when hourly traffic flows are below 200 vehicles per hour during the period 24:00 to 06:00 hours*, when the relationship

$$L_{Aeq,1h} = 0.57 \times L_{A10,1h} + 24.46 \text{ dB}$$

should be used.

The converted values obtained for the full 24 hours can then be used to derive the values of L_{den} and L_{night} as required by the EU.

For situations where hourly values cannot be determined, due to the absence of detailed hourly traffic information but where traffic data for the required period indices is known or can be determined, an alternative method is provided. This allows CRTN to be used to produce values of $L_{A10,18h}$ which are then converted to $L_{Aeq,18h}$ and then subsequently to the component EU noise indices using the relevant period traffic data. L_{den} is then determined from these component values.

A third method is provided that can be used to determine the EU indices where additional traffic information is not available. The method allows CRTN to be used to produce values of $L_{A10,18h}$ which are then converted directly to the EU indices. However, this method relies on the assumption that different road types will, on average, produce a reasonably consistent diurnal flow pattern. For roads where significant deviations in the average conditions occur then errors in conversion may result.

It is concluded that adapting CRTN in the manner described provides the basis for an interim computation method that will comply with the EU Directive relating to the assessment and management of environmental noise.

¹ For the purposes of noise mapping, the EU Directive assumes the assessment point is at 2 m in front of the most exposed façade and 4 m above the ground and that reflection effects from the façade are ignored.

CONVERTING THE UK TRAFFIC NOISE INDEX $L_{A10,18h}$ TO EU NOISE INDICES FOR NOISE MAPPING

ABSTRACT

The Commission of the European Communities has published a proposal to establish a common EU framework for the assessment and management of exposure to environmental noise. It requires Member States to publish noise exposure information in the form of strategic noise maps that use the common indicators recommended by the EU. The AEQ Division of DEFRA and the devolved administrations have commissioned TRL to advise on the development of an interim computation method for possible use in the UK which would comply with the proposed Directive for noise mapping purposes. This Report examines the various options and makes recommendations.

1 INTRODUCTION

The Commission of the European Communities has published a proposal to establish a common EU framework for the assessment and management of exposure to environmental noise (Commission of the European Communities, 2000). The objectives of the proposed Directive are to harmonise noise indicators and assessment methods for environmental noise. It requires Member States to produce noise exposure information in the form of strategic noise maps using the common indicators recommended by the EC (Commission of the European Communities, 1996). An objective is to provide a means of assessing various noise control strategies on an area wide basis. It is intended that noise maps will be published, thereby allowing responsible authorities to compare the different approaches adopted. It is hoped that this exchange of information will encourage a greater understanding of the problem and will encourage the development of best practice across the community.

The proposed Directive states that all Member States shall provide strategic noise maps approved by competent authorities for all agglomerations with more than 250,000 inhabitants and for all major roads, railways and airports. Recent European Council negotiations suggest that the date for completion of the maps under the proposed Directive may be set for 2007, however, DEFRA intends to complete a first round of mapping by the end of 2004.

The Commission recognised that not all Member States have a noise prediction method for assessing environmental noise based on the EU noise indices. Therefore, it has made provisions to allow suitable interim computation methods to be used prior to the development of a common EU method. Two options are included:

(a) Adaptation of existing national methods. Member States would be allowed to use existing national methods providing they are adapted to compute the recommended EU noise indices.

(b) Temporary computation methods. If there is no suitable existing national method or an existing model that can be updated, the Directive recommends the French national computation method 'NMPB' for the assessment of road traffic noise (CETUR, 1996). This recommendation followed a review of national prediction methods carried out by TRL for the Commission (Morgan et al, 2000). For input data to this method concerning source emission levels, reference is made to an earlier prediction method (CETUR, 1980).

In the UK, the environmental assessment of road traffic noise is based on the procedures described in the publication 'Calculation of Road Traffic Noise' (CRTN) (Department of Transport et al, 1988)

(except for new or altered roads for the purposes of the Noise Insulation (Scotland) Regulations 1975). The noise index derived from this prediction method is very different from that proposed for the EU. The UK index is based on a statistical description of the time varying sound levels whereas the EU indicators are based on a summation of sound energies. In addition, the indices refer to different periods of the day. The UK index assesses noise over the period 06:00 to midnight whereas the proposed Directive assesses the noise over the full 24 hour period with different weightings applied depending on the time of day.

For the UK to comply with the proposed Directive in providing the relevant strategic noise maps an interim computation method needs to be developed. This report considers the various options available. In particular, it examines the possibility of adapting CRTN to produce outputs in the form of the EU indices. Two issues not considered in detail in this study are;

1. the effect of average annual meteorological conditions, compared with the situation where the winds are light and have a positive wind component in the direction from the road towards the receptor as assumed in CRTN and,
2. the differences in the screening effect of barriers on the L_{Aeq} as compared with the L_{A10} .

2 COMPARISON OF NOISE SCALES AND INDICES

As mentioned earlier, in the UK the noise index $L_{A10,18h}$ dB is currently used to assess the impact of traffic noise. This has been the preferred index since the early 70's when it was shown that it offered a reasonably good correlation with average community annoyance/bother (Morton-Williams et al, 1978). Its introduction in UK legislation also pre-dated the development of equipment that could simply measure acoustic energy-based noise measures such as L_{Aeq} . At that time this fact clearly helped to establish $L_{A10,18h}$ as both the most appropriate and the most practical measure to use to assess traffic noise impacts.

With the advent in the early 80's of instrumentation that could measure acoustic energy based measures most other nations now use indices based on L_{Aeq} to assess all forms of transport noise including that from road traffic. This is particularly the case in the European Union where the UK is now alone in its use of $L_{A10,18h}$ for road traffic noise assessment. While this situation is not a major concern when dealing with noise problems such as the assessment of sound insulation compensation, it is becoming increasingly difficult to continue with the current practice of using $L_{A10,18h}$ when dealing with the noise issues raised by the European community, such as the generation of strategic noise maps.

Since the commencement of noise mapping is imminent, there is clearly an urgent need to change UK practice for this application, by adopting the noise indices required by the Directive, which are based on L_{Aeq} . A step in this process is to establish whether there is a simple relationship between the two indices. If such a relationship could be established then simply converting $L_{A10,18h}$ values using an 'end correction' to CRTN calculations could satisfy the requirements of the EU.

This section gives a brief description of the fundamental differences between the various noise descriptors used in the literature including the noise indices used in the UK and those recommended by the EU. This section also contains an overview of published research where various indices have been compared.

2.1 DEFINITIONS OF LEVELS, SCALES AND INDICES

Initially it is important to establish the differences between noise levels, scales and indices or ratings since the relationships between them will vary depending on the formulation used.

Noise level is the fundamental measure used subsequently to construct scales and indices. The objective is to obtain a physical measure of sound level that correlates well with the subjectively assessed noisiness of the sound. Experience has shown that the measure should emulate the variation of sensitivity with frequency of the human hearing system. Clearly for most noise sources, the level will vary with time although in defining a noise level, time is not included in the description. The 'A' weighted level is the most commonly quoted noise level used in environmental acoustics. Noise levels measured using 'A' weighting are normally expressed as L dB(A) or more commonly these days as L_A dB.

Noise scales combine noise level with time in some way. This may be the level exceeded for a given proportion of time, as in L_{A10} dB, or it might be an integration of level with respect to time, as in L_{Aeq} dB. Other forms have also been quoted in the literature but are less commonly used in a transport context.

Noise indices or ratings are created to provide an evaluation of noise in particular circumstances. Most commonly, indices are formed from the noise scales by merely defining the time period over which the scale applies. For example the $L_{A10,18h}$ dB index refers to the specific time of day over which the noise scale should be averaged. A similar index in common use is the $L_{Aeq,24h}$ dB which integrates the values of L_{Aeq} over a complete day.

The day/night level, L_{dn} , provides a further refinement. In addition to defining separately a day and night time period, it also applies a 10 dB 'penalty' to the night time level. This is an attempt to reflect what is generally felt to be a more intrusive period even though generally the noise levels are lower. Recently the EU has proposed two further indices for use in noise assessments, L_{den} and L_{night} . The subscript 'den' refers to defined 'day', 'evening' and 'night' time periods and as with L_{dn} , additional weighting values are attached to the levels occurring during the evening and night periods. As with the day/night level, the 'night' term is included to take account of possible sleep disturbance. The 'evening' term is added primarily to take account of interference with recreational activities.

2.1.1 UK traffic noise index $L_{A10,18h}$

The traffic noise index $L_{A10,18h}$ is based on the L_{A10} scale which gives a measure of the level of noise exceeded for 10% of a given time period. It is determined by the average of the values of $L_{A10,1h}$ for each hour between 06:00 and 24:00 hours and may be expressed as:

$$\text{Traffic noise index, } L_{A10,18h} = \frac{1}{18} \sum_{t=6}^{t=23} L_{A10,t} \text{ dB(A)} \quad (2.1)$$

where t signifies the start time of the individual hourly $L_{A10,1h}$ values in the period 06:00 – 24:00 hours.

Although the index does not specifically include the night time period (24:00 to 06:00 hours) it does include periods when people are most sensitive to sleep disturbance, i.e. those periods when people are trying to get to sleep and just before waking.

The index is based on a statistical description of the fluctuating noise level and is therefore dependent to some extent on the distribution of the individual vehicle passby events within the period of interest. It should therefore be understood that for low traffic flow conditions, the hourly variation in $L_{A10,1h}$ will depend not only on variations in traffic parameters but on the random variation in vehicle passbys.

Methods for the prediction and measurement of $L_{A10,18h}$ are published (Department of Transport et al, 1988).

2.1.2 EU noise indices

The EU has proposed two noise indicators L_{den} and L_{night} . These are based on the recommendations of the Working Group 'Indicators' which were approved by the Steering Group (Commission of the European Communities, 1999). The primary noise indicator is the day-evening-night level L_{den} that is an indicator of annoyance from long-term exposure to noise, whereas, L_{night} is an overall night-time indicator related to 'self-reported sleep disturbance' again from long-term exposure.

Both indicators are based on the scale L_{Aeq} . This is the equivalent sound level that if maintained would cause the same sound energy to be received as the actual sound over the same period. The equivalent sound level, determined from the actual sound levels during a period T is mathematically expressed as follows:

$$L_{Aeq,T} = 10 \times \log_{10} \left(\frac{1}{T} \right) \int 10^{L(t)/10} dt \text{ dB(A)} \quad (2.2)$$

where $L(t)$ is the A-weighted sound level at time t and T is the duration of the exposed period (seconds).

From this basic definition the noise indicators L_{den} and L_{night} are defined as follows:

$$L_{den} = 10 \times \log_{10} \left(\frac{1}{24} \right) \left(12 \times 10^{L_{day}/10} + 4 \times 10^{(5+L_{evening})/10} + 8 \times 10^{(10+L_{night})/10} \right) \text{ dB(A)} \quad (2.3)$$

where

L_{day} is the A-weighted equivalent noise level over the 12-hour day time period from 07:00 to 19:00 hours

$L_{evening}$ is the A-weighted equivalent noise level over the 4-hour evening period from 19:00 to 23:00 hours

L_{night} is the A-weighted equivalent noise level over the 8-hour night time period from 23:00 to 07:00 hours

$L_{evening}$ and L_{night} have a 5 and 10 dB weighting applied to each respectively to take account of the difference in annoyance due to the time of day.

The A-weighted equivalent noise level L_{night} , as defined above, is also used as a separate noise indicator in the Directive as a metric for the assessment of sleep disturbance but does not include the 10 dB weighting that is applied when determining the noise indicator L_{den} .

2.2 RELATIONSHIPS BETWEEN DIFFERENT NOISE SCALES AND INDICES

It should be clear from the above definitions that establishing conversion factors between different indices is not straightforward. In particular, the different time periods and, in some cases, the weightings applied to these time periods add both uncertainty and complexity to the process.

For these reasons, the comparison of noise scales and noise indices are treated separately in the following sections.

2.2.1 Comparison of L_{A10} and L_{Aeq} noise scales

(i) Gaussian distribution

In general, road traffic noise at a given location is the combination of the individual noise from each vehicle that comprises the traffic stream. Many investigations of traffic noise have involved sampling the time-varying sound level and grouping the values into noise level categories to form a distribution. It has been found that the distribution of noise levels approximates closely to a Gaussian or 'normal' distribution for conditions where the traffic flow exceeds about 100 vehicles per hour and is freely flowing. This fact is particularly convenient since it means that the distribution curve can be defined by just two parameters only, for instance, the median level, L_{A50} , and the standard deviation, σ , of the levels. This logic can also be extended to other statistical measures such as L_{A10} and energy integrated measures such as L_{Aeq} . Lamure (1975) has published several relationships of this form derived from the assumption that traffic noise distributions obey a Gaussian formulation. Of particular interest is the relationship shown in equation (2.4) below

$$L_{A10} - L_{Aeq} = 1.28\sigma - 0.115\sigma^2 \text{ dB} \quad (2.4)$$

For freely flowing traffic, σ is often in the range 2-5 (Don and Rees, 1985). By substituting these values into (2.4) the familiar approximation is obtained:-

$$L_{A10} - L_{Aeq} \approx 3 \text{ dB} \quad (2.5)$$

(ii) Non-Gaussian distributions

In practice traffic may not be flowing freely and propagation can be affected by screening, reflection from facades etc, and varying ground effects. Under these conditions, variations from a true Gaussian distribution can be expected. In addition, traffic volume, speed and distance from the road can be important. For these situations, the simple conversion shown above in (2.5) may no longer be valid.

Driscoll et. al. (1974) presented one of the first investigations of the relationship between L_{A10} and L_{Aeq} . An analysis of several real and theoretical noise level distributions revealed that, on average,

$$L_{A10} = L_{Aeq} + 3.6 \text{ dB} \quad (2.6)$$

The Noise Advisory Council (1978), Reeves and Wixley (1986) and Huybregts and Samuels (1998) have also established simplified linear transformations deduced from measured traffic noise levels. These are reproduced below;

Noise Advisory Council:
$$L_{A10} = L_{Aeq} + 3 \text{ dB}^2 \quad (2.7)$$

Reeves:
$$L_{A10} = L_{Aeq} + 4.2 \text{ dB} \quad (2.8)$$

Huybregts and Samuels:
$$L_{A10} = L_{Aeq} + (2.5 \text{ to } 3.5) \text{ dB} \quad (2.9)$$

While a linear transformation offers considerable advantages in terms of simplicity, it is clear that on detailed examination and under certain traffic and site conditions a simplistic linear conversion is not valid. For example, under low flow conditions, L_{Aeq} may actually exceed L_{A10} (Brown, 1989; Burgess, 1978). Other studies have revealed that, particularly for low flows, the relationship is dependent on both traffic volume and composition (Carter et al, 1992) and on the separation of vehicles, distance from the road and ground cover (Barry and Reagan, 1978). A theoretical maximum value of 19 dB(A) for the difference between L_{A10} and L_{Aeq} has been suggested by Lau et al (1989).

The range of possible conversion factors is illustrated in Figure 2.1. This shows the difference between L_{A10} and L_{Aeq} derived from a theoretical study carried out for the Federal Highway Administration in the USA (Barry and Reagan, 1978).

The Figure shows that for open site propagation (i.e. free from screening or reflection effects) the difference between L_{A10} and L_{Aeq} is a function of the traffic flow (Q veh/h), distance from the road (d m) and the average vehicle speed (V km/h). To understand this complex relationship it is helpful to imagine that as the function Qd/V decreases the noise will tend to consist of relatively long periods of low noise levels separated by short periods of relatively high noise levels. Alternatively, as the function increases the fluctuation in noise level reduces. For low flow situations and for positions located close to a road, L_{A10} is less affected by the occasional high noise level than L_{Aeq} and may lead, as suggested above, to L_{Aeq} exceeding L_{A10} . These conditions might occur at night or where the noise level distribution is characterised by infrequent very noisy events such as might occur near to an access road to a quarry carrying heavy vehicles but with low traffic volume.

² It should be noted that the conversion value quoted by the Noise Advisory Council is an average value. The study established that for 95% of situations, a range of 1-5 dB(A) would actually apply for the conversion factor.

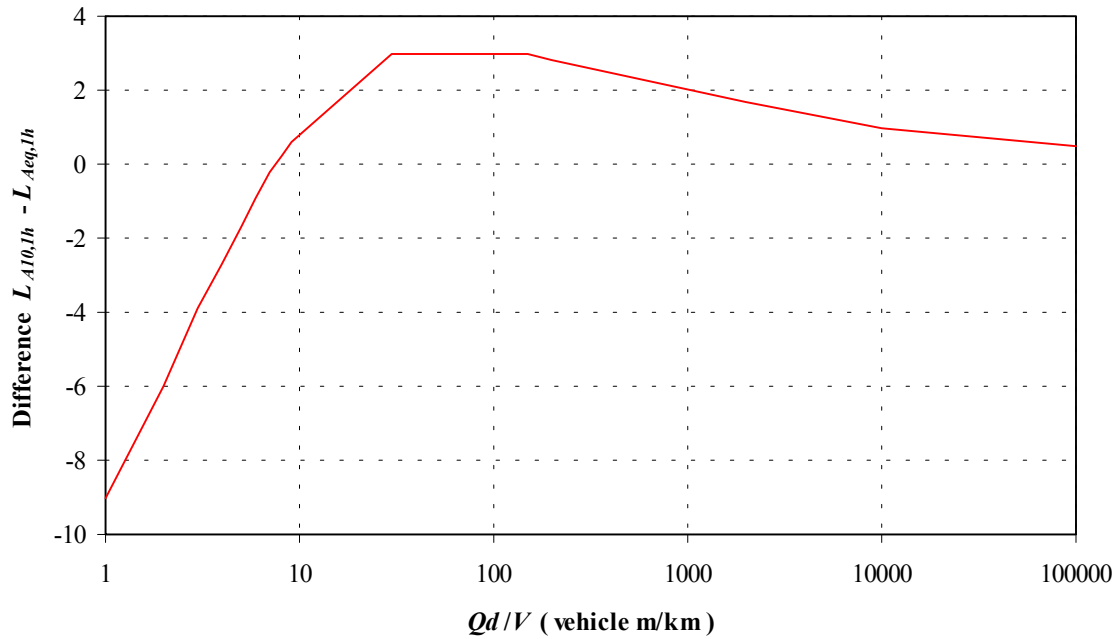


Figure 2.1: Theoretical difference between $L_{A10,1h}$ and $L_{Aeq,1h}$

As the function Qd/V increases, the difference between L_{A10} and L_{Aeq} increases rapidly and then becomes relatively stable with L_{A10} exceeding L_{Aeq} by about 3 dB, which, as noted earlier, is generally regarded as typical for most situations.

Further increases in the function Qd/V indicate that the difference between L_{A10} and L_{Aeq} reduces, with differences reaching about 1dB(A) at the highest values in the range. Generally, therefore, this indicates that, at some distance from the road, as flow increases the rate of change in L_{A10} will be less than for L_{Aeq} . However, this will be confounded because as flow rate increases the speed of vehicles tend to reduce as the road becomes congested. Alternatively, where traffic flows are high and road speeds are constant, noise levels described on the L_{A10} scale will attenuate at a greater rate with distance than described using L_{Aeq} . A further examination of (2.4) also lends support to this effect. As the receiver moves further away from the road the variation in noise level decreases, $\sigma \rightarrow 0$ and the difference between L_{A10} and L_{Aeq} is reduced.

Although it is beyond the scope of this report it is important to note that the influence of noise variation on the relationship between L_{A10} and L_{Aeq} is also important when considering screening. Results from studies examining the performance of roadside barriers have shown that barriers reduce noise variability. In general, therefore, barriers may have a larger effect on L_{A10} than on L_{Aeq} . Theoretical studies carried out by Fisk (1975) indicate that although this effect is relatively small (i.e. generally less than 1 dB) it is progressive as the screening potential of the barrier increases and is dependent on vehicle speed and traffic flow.

2.2.2 Comparison of indices

The comparison of noise scales detailed in the previous section provides useful insight into the fundamental problem of converting from a statistical scale measure such as L_{A10} to an integrated average scale measure such as L_{Aeq} . Such conversions become more complex when considering the conversion of indices where the time intervals also differ. In such cases, the traffic flow parameters are not identical and therefore allowance has to be made to take account of differences in flow

volume, speed and composition of the traffic for the different time periods concerned. In the particular case of interest here, the $L_{A10,18h}$ index covers the contiguous period from 06:00 to 24:00 hours whereas the L_{den} is a weighted average of three different periods covering the total day.

A further aspect to be considered when examining the complex relationship between L_{A10} and L_{Aeq} is in the derivation of the index, $L_{A10,18h}$, which is defined as the arithmetic average of the 18 hourly $L_{A10,1h}$ values from 06:00 to 24:00 hours. Over the same time period, the $L_{Aeq,18h}$ index may be derived from a logarithmic average of the 18 hourly $L_{Aeq,1h}$ values. The difference, therefore, between these two indices will not only depend on the distribution of noise levels within each hour, as discussed above, but also on the diurnal variation of the individual hourly values. For example, if we assume a 3 dB(A) difference between hourly values of $L_{A10,1h}$ and $L_{Aeq,1h}$ as shown in (2.5), the difference between the indices, $L_{A10,18h}$ and $L_{Aeq,18h}$, will also be 3 dB(A) but only if all the hourly values are the same. Generally, as the diurnal variation in hourly values increase the difference between the indices, $L_{A10,18h}$ and $L_{Aeq,18h}$ will be less than 3 dB(A). This is a consequence of the different averaging processes. Any low hourly noise level included in the period will reduce the magnitude of the arithmetically averaged $L_{A10,18h}$ value relatively more than the logarithmic averaged $L_{Aeq,18h}$ value. This clearly has important implications for determining conversion factors but also is important in determining equivalent criteria levels used in existing legislation and noise planning policy.

Unfortunately, the available literature comparing noise indices is less comprehensive than that relating to the comparison of noise scales. Brown (1989) has examined the relationship between $L_{Aeq,24h}$ and $L_{A10,18h}$ for Australian road conditions. In these cases, the difference in the time periods between the two indices relates to the night period from 24:00 to 06:00 hours where typically the flows are relatively light. Brown notes that for this comparison any low hourly noise level included in the period will reduce the magnitude of the arithmetically averaged L_{A10} relatively more than they will the energy based L_{Aeq} . In addition it is noted that the low traffic volumes that occur at night often generate short-term (hourly) L_{Aeq} values that are greater than short-term L_{A10} with consequent elevation of the long-term (24 hour) L_{Aeq} . Brown points out that these two effects are mutually compensating, a fact supported by the average conversion factor listed in his paper that was derived from empirical observations at 19 different sites in Australia,

$$L_{A10,18h} = L_{Aeq,24h} + 3.5 \text{ dB} \quad (\text{Brown, 1989}) \quad (2.10)$$

Brown also used his data set to examine the relationship between the L_{dn} index and $L_{A10,18h}$. He noted that, while a simple translation was not applicable, due to the fact that the differences in the scales were themselves dependent on the overall noise level, the data set did provide a regression relationship with a high degree of correlation ($r^2 = 0.94$). Predictive errors involved were of the order of 1.5 to 2dB (95% confidence limits).

$$L_{dn} = 1.21 \times L_{A10,18h} - 14.7 \text{ dB} \quad (\text{Brown, 1989}) \quad (2.11)$$

Huybregts and Samuels (1998) have also examined the relationships between different road traffic noise indices using measurements taken from relatively high traffic flow locations in Melbourne and the State of Victoria in Australia. The indices compared were $L_{A10,18h}$ and $L_{Aeq,24h}$ as well as indices based on a 16-hour day (06:00 to 22:00 hours) and an 8-hour night period (22:00 to 06:00 hours). A regression analysis revealed the following relationships:

$$L_{A10,18h} = L_{Aeq,24h} + 3.2 \text{ dB} \quad (2.12)$$

$$L_{A10,18h} = L_{Aeq,16h} + 2.2 \text{ dB} \quad (2.13)$$

$$L_{A10,18h} = L_{Aeq,8h} + 6.7 \text{ dB} \quad (2.14)$$

$$L_{A10,16h} = L_{Aeq,16h} + 2.5 \text{ dB} \quad (2.15)$$

$$L_{A10,8h} = L_{Aeq,8h} + 2.6 \text{ dB} \quad (2.16)$$

It should be noted that the relationship between $L_{A10,18h}$ and $L_{Aeq,24h}$ is in good agreement with the relationship found by Brown (1989) shown earlier. Huybregts and Samuels also noted the standard deviation of the relationships involving night noise indices was greater than those involving daytime indices. Again this was attributed to the broader range of traffic volumes typically occurring during the night period and to the fact that differences between the L_{A10} and L_{Aeq} scales is dependent on traffic parameters, particularly traffic volume. It was concluded that a larger data set was needed in order to reduce the uncertainty introduced through inter-site differences.

2.3 DISCUSSION OF THE COMPARISON OF NOISE SCALES AND INDICES

The comparison of noise scales and indices detailed in the previous section provides useful insight into the fundamental problem of converting one to the other. At the simplest level, subtracting 3 dB(A) from L_{A10} to obtain equivalent L_{Aeq} scale values appears to be remarkably robust, providing reasonably accurate estimates for a wide range of traffic conditions. However, such simple conversions become more difficult to justify when considering the conversion of indices. Primarily, the fundamental differences between the two forms of index are of importance. The UK index is based on a statistical description of the time varying sound levels whereas the EU indicators are based on a weighted summation of sound energies. This difference is most noticeable when there are large fluctuations in noise levels, typical at sites close to the road where traffic flows are low. Under these conditions, noise indices based on the L_{A10} scale are influenced by the time distribution of noise events whereas noise indices based on the L_{Aeq} scale sum the energies of all noise events independently of when they occur.

In addition, the indices refer to different periods of the day. In such cases, the traffic flow parameters are not identical and therefore allowance has to be made to take account of differences in flow volume, speed and composition of the traffic for the different time periods concerned. Furthermore, whereas the index $L_{A10,18h}$ is based on a simple un-weighted averaging of hourly values, the noise indicator L_{den} includes a logarithmic averaging of period L_{Aeq} values with different weighting dependent on the time of day.

Although it may seem that, on the basis of these fundamental differences in formulation, it would be unlikely that a practical relationship between the noise index $L_{A10,18h}$ with either L_{den} or L_{night} exists, the evidence in the literature does not necessarily confirm this. The evidence does suggest, both from empirical and theoretical studies, that a relationship between period L_{A10} and L_{Aeq} which is dependent on traffic flow, vehicle speeds and sound propagation can be found. The results from these studies and from further analysis of existing data may therefore provide the foundation for developing an interim prediction method for determining the noise indicators L_{den} or L_{night} from predicted L_{A10} values using CRTN. This prospect is explored further in the following sections.

3 METHODS FOR CALCULATING EU NOISE INDICES

The following sections describe the various methodologies that could be introduced to form the basis of an interim prediction method to determine the noise indicators L_{den} or L_{night} . It is convenient to separate these methodologies into two different approaches. The first approach, described in section 3.1, deals with methods that enable the noise indicators L_{den} or L_{night} to be determined directly assuming the relevant input parameters are known. These methods rely on the development of a L_{Aeq} traffic noise prediction method and include the French national computation method 'NMPB' (CETUR, 1996) and the model developed by the Noise Advisory Council (Noise Advisory Council, 1978). The second approach, described in section 3.2, deals with methods which enable the noise indicators L_{den} or L_{night} to be determined by adapting the procedures described in CRTN. The aim has been to examine the advantages and limitations of each approach to enable a valid, practical and transparent method to be adopted as the basis of an interim prediction method to be used in the UK.

3.1 L_{Aeq} TRAFFIC NOISE MODELS

A fundamental concept common to L_{Aeq} traffic noise models is to assume that road traffic consists of the movement of a collection of discrete vehicles and that traffic noise is the sum of their individual noise emission. Thus if the acoustic energy of an average single vehicle passby is known then the overall traffic noise level, L_{Aeq} , can be calculated by the summation of the energy from all the vehicle passbys in the traffic stream.

There are a number of road traffic noise models for predicting L_{Aeq} available in Europe. The two methods described here have been included for the following reasons. The French 'NMPB' method is recommended in the proposed Directive as a permitted interim prediction method. This recommendation followed a review of European prediction models carried out by TRL for the European Commission (Morgan et al, 2000). The Noise Advisory Council method is an established form of L_{Aeq} model developed initially in the UK. It is therefore a good example of a form of model that could be simply adapted to produce outputs in terms of the EU recommended indices.

3.1.1 The French 'NMPB' method

This method is based on the decomposition of a line road source into a series of equivalent point sources. For each point source, sound power levels are determined and together with an appropriate propagation model that includes meteorological effects, the contribution from each point source is combined to give the overall level at the receiver position.

The source model includes two categories of vehicles: *light* which are all vehicles with a gross vehicle weight (gvw) less than 3,500 kg and *heavy* which are all vehicles with gvw exceeding 3,500 kg. The input sound power levels are expressed in terms of octave bands in the frequency range 125 – 4000 Hz. Values are derived from surveys carried out in France in the 1970's and are therefore typical of French traffic conditions of some thirty years ago (CETUR, 1980). The propagation model allows for two conditions of propagation: "favourable" to propagation e.g. adverse wind conditions; and "homogeneous" where meteorological effects have no influence on propagation. Included in the method are values of the long-term occurrences for meteorological conditions favourable to sound propagation at various locations across France together with contour maps to allow values to be approximated at other locations. The method assumes that when meteorological conditions are not favourable to sound propagation, conditions for homogeneous propagation should be assumed. It follows therefore that since the method does not allow for situations where the wind conditions help to reduce noise propagation, the method will tend to over estimate long-term average values.

Long-term estimates of noise levels are derived by adjusting the source noise levels for propagation assuming both favourable and homogeneous conditions separately to give two noise components, L_F

and L_H , respectively. At a given location, if p is the long-term occurrence of meteorological conditions favourable to sound propagation ($0 \leq p \leq 1$), then the long-term noise level L_{LT} is obtained by summing the energy levels L_F and L_H weighted with respective occurrences p and $(1-p)$ i.e.

$$L_{LT} = 10 \times \log_{10} \left\{ \left[p \cdot 10^{L_F/10} + (1-p) \cdot 10^{L_H/10} \right] \right\} \text{ dB(A)} \quad (3.1)$$

Although the method has been recommended by the EU as the interim computation method for predicting road traffic noise there are a number of limitations that would need to be overcome if the method was to be adopted by the UK:

1. The input source data is no longer typical of the vehicle fleet in either France or the UK, or representative of the types of road surfaces currently used in the UK.
2. Input source data typical to UK traffic conditions would need to be developed. The source noise data would need to be expressed in terms of octave-band sound power levels to provide the correct input to the propagation model. Although TRL does have a large data bank of vehicle noise emissions levels including some frequency information, the vehicle data at low speeds or for congested traffic conditions is not suitable for use in predicting absolute traffic noise levels.
3. Existing software programs used for predicting the UK noise indicator, $L_{A10,18h}$, could not be adapted to the French 'NMPB' method.
4. Information on meteorological effects which are favourable to noise propagation at all locations in the UK are not, at present, readily available to allow long-term noise indicators to be derived.
5. Results from the prediction method have not been statistically compared with measured values and therefore no standard error in prediction has been published.
6. The method has not been used previously in the UK for routine calculation and therefore there may be some reticence by users in adapting to the new method. Furthermore changing to a completely new method will undoubtedly lead to some inconsistencies and errors initially as users familiarise themselves with the new formulation.

3.1.2 The Noise Advisory Council (NAC) method

The NAC method uses a source noise model to predict traffic noise levels, L_{Aeq} , at a given reference distance. This provides input to a propagation model based on the UK prediction method CRTN.

The source model requires as input the relationship between noise level and speed for various vehicle categories. From this relationship, together with the mean traffic speed for each vehicle category, the sound exposure level, SEL , typical for each vehicle category is derived³. For a two vehicle category model consistent with that used in the CRTN model i.e. light vehicles with unladen weight up to 1525kg and heavy vehicles, the predicted traffic noise level, $L_{Aeq,T}$ can be determined from the following equation:

$$L_{Aeq,T} = 10 \times \log_{10} \left\{ \left[\frac{1}{T} \right] \left[\frac{N}{100} \right] \left[p \cdot 10^{SEL_{heavy}/10} + (100-p) \cdot 10^{SEL_{light}/10} \right] \right\} \text{ dB(A)} \quad (3.2)$$

where

³ The sound exposure level SEL is the level which if maintained constant for a period of 1 second has the same energy as that received during the entire vehicle passby event.

N is the total vehicle flow in the time period $T(s)$; p is the percentage of heavy vehicles; SEL_{light} and SEL_{heavy} are the sound exposure levels typical for light and heavy vehicles in the traffic stream respectively.

Using the appropriate corrections described in CRTN for gradients and road surfaces the noise level, L_{Aeq} , at a reference distance of 10 m from the road is determined. To predict the noise level, L_{Aeq} at a façade, additional corrections are applied to take account of propagation including distance, ground absorption, screening and reflection effects in accordance with the procedures described in CRTN.

This prediction method has certain advantages over the French 'NMPB' method:

1. The input vehicle noise data does not require octave band sound power levels and therefore is easier to model using existing data.
2. The propagation model follows similar procedures as those described in CRTN and therefore the existing software used for CRTN type calculations may be adapted relatively easily.
3. The method is relatively familiar to UK practitioners and therefore more readily accepted than the French model.

However, if the method were to be introduced as an interim computation method a number of limitations would need to be overcome:

1. Input source data typical to current UK traffic conditions would need to be developed. Although TRL does have a large data bank of vehicle noise emission levels, the data for low speed application or for congested traffic is not suitable for predicting absolute noise levels.
2. The corrections applied to the reference noise level for propagation effects have been derived for the prediction of L_{A10} and may not be applicable to L_{Aeq} for all possible conditions encountered in practice. These conditions include the attenuation due to varying ground cover and the screening provided by barriers. However, (Fisk, 1975), reviewed in section 2, has examined the effects on propagation of both types of noise scale and it is anticipated that appropriate corrections could be incorporated based on this reported research.
3. Altering the propagation model may no longer calibrate the method to adverse wind conditions and therefore may introduce complications when adapting the method to predict long-term noise indices.
4. The method would need to provide results which were equivalent with those derived from the French 'NMPB' method.

3.2 ADAPTING THE CRTN METHOD

The following sections deal with a range of possible options that will enable the noise indicators L_{den} or L_{night} to be determined by adapting the procedures described in CRTN. In the first three options, the approach involves calculating the value of L_{A10} using the CRTN method in the usual way and then adjusting these values to produce the corresponding values of the relevant EU indicators. It follows that to ensure that these methods are internally consistent, road schemes that require segmenting⁴ will require that the 'end correction' is applied to each segment contribution prior to the procedure for combining the noise levels from each segment. The final option, described in section 3.2.4, introduces the possibility of altering the input traffic parameters so that the output from CRTN would directly

⁴ Where the generated noise along a length of road varies due to changes in traffic variables, road design or progressive variations in screening, the CRTN procedure is to divide the road scheme into segments within which the noise level varies by less than 2 dB(A). Each segment is then treated as a separate road source.

derive the corresponding EU indicator. The advantages and disadvantages of each approach are described.

3.2.1 Modelling the relationship between $L_{A10,1h}$ and $L_{Aeq,1h}$ for different traffic conditions

As previously mentioned in Section 2, there is evidence in the literature both from empirical and theoretical studies of the possibility of establishing a relationship between period L_{A10} and L_{Aeq} ; for example, (Noise Advisory Council, 1978; Brown, 1989). This suggests that a simple 'end correction' to CRTN calculations of L_{A10} values would, in principle, be possible. The overall aim would be to provide a model to predict $L_{A10,1h}$ according to CRTN procedures which can then be converted to $L_{Aeq,1h}$ values. These values could then be used to calculate the required period L_{Aeq} 's which can then be used to determine the EU indices.

This approach would have the major advantage of retaining the method that is familiar to UK users and would be easily incorporated into existing software. However, the information contained in the literature needs to be supplemented by additional data and more comprehensive analysis covering a wider range of traffic flow and propagation conditions. In addition, any systematic and random errors introduced by this approach also need to be established before any firm recommendations can be made. The work described in Section 4.1 to 4.4 addresses these issues and the procedures for calculating EU noise indices are described in Section 4.6.

A possible disadvantage of this approach is that hourly traffic information may not be generally available to prospective users.

3.2.2 Deriving EU noise indices from the predicted $L_{A10,18h}$ index and the diurnal variation in traffic parameters

A similar approach to that described in Section 3.2.1 would predict the EU noise indices given the predicted noise index $L_{A10,18h}$, obtained by using CRTN, and information regarding the diurnal variation in traffic parameters. In this form of conversion, the relevant period values of L_{Aeq} would be derived from the predicted $L_{A10,18h}$ index by converting to $L_{Aeq,18h}$ and then corrected according to changes in traffic parameters registered for the relevant time periods. The main advantage of this approach is that users will be able to retain the CRTN model or existing software in their present forms to carry out the initial calculations. The work to support this approach is described in Section 4.5.1 and the procedures for calculating EU noise indices are described in Section 4.6.

Similarly, as with the previous method, this approach relies on the availability of traffic data for the relevant time periods.

3.2.3 Using road type to develop relationships between measured UK and EU noise indices

This form of model conversion would enable the user to predict EU noise indices using as input the UK noise index, $L_{A10,18h}$, derived using CRTN or appropriate software, and the type of road assuming typical traffic conditions. This approach would provide a potentially viable method where no traffic data is available other than that required by the prediction method CRTN. However, the method would need to be supported by a detailed analysis of existing data relating traffic noise to traffic flow parameters and road classification. The work described in Section 4.5.2 addresses these issues and the procedures for calculating EU noise indices are described in Section 4.6. The objective would be to produce reliable conversion factors, $L_{A10,18h}$ to L_{den} , for a range of road classification/descriptors that adequately cover the potential range in the network. As before, the main advantage of this approach is that CRTN is retained as the UK prediction method. However, in addition, detailed information about traffic flows that range outside the normal averaging period required by CRTN would not be required by the user. The main disadvantage is that relatively gross assumptions have to be made about the diurnal variation in traffic flow for different road types. Any significant deviations from the average

will introduce errors into the eventual conversion calculation. It is uncertain at the present time whether these errors could be confined to an acceptable range for noise mapping purposes.

3.2.4 Altering traffic-parameter inputs to derive EU noise indices

In the preceding 3 sections, various methods have been described which may enable the EU indicators to be predicted by applying a correction to the predicted noise level from CRTN, dependent on the range of traffic information available. A possible refinement to this approach would be to alter the input traffic parameters to CRTN such that the predicted noise levels would be equivalent to the EU noise indices. For example, if the correction to derive the EU noise indices L_{den} and L_{night} from the predicted UK index $L_{A10,18h}$ was calculated to be +3 dB(A) and -6 dB(A), respectively, then predicting the absolute L_{den} value from the CRTN output could be achieved by doubling the input traffic flow and, likewise, for the L_{night} index, by reducing the traffic flow by a factor of four. The main advantage of this approach is that the user would continue to use CRTN in the normal way and would not be required to make any further adjustments to the output level.

This refinement to the method, however, may lead to confusion. Manipulating the input traffic variables in order to effect a given change in output values could be achieved by any number of different combinations. This could potentially lead to further errors. There are a number of corrections in the procedures described in CRTN which are dependent on the actual traffic parameters e.g. the low flow correction is dependent on traffic flow, the surface correction is dependent on traffic speed. If the actual traffic parameters are not used as input then errors in calculating the noise index $L_{A10,18h}$ may be introduced if this refinement is included in the method. In addition, where a road scheme requires segmenting due to variations in screening, the value of the correction to convert to L_{Aeq} indices for each segment may also vary. To allow variations in the correction value would require the input traffic parameters to be altered at the segment boundaries, which may lead to unnecessary confusion.

3.3 DISCUSSION OF ALTERNATIVE METHODS OF CALCULATION

The previous sections have illustrated that adopting the French ‘NMPB’ method as an interim computation method would result in significant problems for users in the UK. Apart from the obvious difficulties for users of introducing a completely new method, and the difficulties imposed by having to write new software programs to accommodate the changes, the main area of concern is the lack of appropriate vehicle noise input data. Users may also be very reticent to adopt a new procedure at this time given that a completely new EU method is promised in a few years time. Changing the official method twice in what will be a relatively short time span is not a particularly attractive proposition for UK practitioners.

The source data contained in the French method was obtained over 30 years ago and clearly relates to the traffic and road surface conditions found to be typical in France at that time. It should also be noted that the French method has never been validated against independently measured traffic noise values and so its accuracy for predicting current UK traffic noise is, at best, questionable. Consequently, if the French method were to be employed in the UK there is a strong case for providing up-to-date vehicle noise emission data to replace the existing French vehicle noise source data. While this is theoretically possible, TRL is not aware of a data-base that is sufficiently comprehensive to allow the necessary source terms to be derived for the whole of the speed range encountered in practice. This is the case for roads where vehicle speeds fall below 80 km/h. As mapping in urban areas (i.e. with traffic moving at low speeds) will form an important part of the exercise, application of this method will be restrictive if the appropriate input data is not available.

The review has also examined the potential advantages and disadvantages of adopting a L_{Aeq} model such as that described by the Noise Advisory Council. The main difficulty here is that this type of model is neither the officially recommended EU interim procedure nor the standard UK prediction

method. It therefore satisfies neither of the fundamental requirements stipulated by the EU. It also suffers from the same disadvantages for UK users as the French method in that it requires inputted vehicle noise source terms covering a broad range of vehicle operation. It has already been pointed out that this information is scarce particularly at low operating speeds and for congested traffic.

Consequently, the only acceptable and practical alternative to adopting the French model is to adapt in some way the existing CRTN method to enable the noise indicators L_{den} or L_{night} to be determined. As has been pointed out the most sensible approach is to attempt to convert period noise indices on the scale L_{A10} to L_{Aeq} and then to formulate the EU indices from the converted values. Amending input traffic factors to affect this conversion is a possible approach but is likely to produce confusion by the user and further errors. It is recommended therefore that the best approach is to apply an 'end correction' to the CRTN method using an appropriate conversion model.

The main advantages of this approach are:

1. Programs that follow the procedures described in CRTN will be able to be easily adapted to enable the noise indicators L_{den} or L_{night} to be determined.
2. The CRTN philosophy of approach is retained and therefore more acceptable to the UK user than introducing a different method.
3. The method will retain its empirical bias, based on typical UK traffic conditions.

The main disadvantage is that although a range of possible corrections have been produced and published in the scientific literature, a suitably comprehensive and user friendly 'end correction' has not yet been determined for UK conditions. The following section explores this issue further.

4 DERIVING AN 'END CORRECTION' FOR CRTN

CRTN allows the user to calculate values of $L_{A10, 1h}$ or $L_{A10, 18h}$ depending on whether the inputted traffic parameters relate to a single hour or to the specified 18-hour period. The indices L_{den} or L_{night} required by the EU refer to values of L_{Aeq} averaged over a 12 hour day, 4 hour evening and 8 hour night period - Section 2.1.2 of this report provides details of these relevant time periods.

It is clear, therefore, that in order to convert one form of index into another consideration has to be given to both the basic relationship between the two scales and the different averaging periods involved. Perhaps the simplest way to affect this conversion is to attempt initially to establish a relationship, for a broad range of traffic and site conditions, between predicted values of L_{A10} using CRTN and corresponding measured values of L_{Aeq} and then to configure the appropriate EU indices as appropriate from the converted values. Initially it is important to examine the possibility of a relationship between L_{A10} and L_{Aeq} for both freely flowing traffic and interrupted or non-freely flowing traffic since the two types of flow may yield different results.

4.1 FREELY FLOWING TRAFFIC

To examine the relationship between L_{A10} and L_{Aeq} , for freely flowing traffic, use was made of a data-base compiled by Sargent and Aspinall (1977). This data-base contains details of 460 measurements taken at 27 different road sites in the UK. This information is documented in terms of a range of traffic noise measures including $L_{Aeq, 1h}$ together with relevant traffic data and site details. It was noted that the traffic was freely flowing at all sites investigated and propagation was not influenced by reflection or screening by barriers or buildings.

The traffic parameters included in the data set covered the following ranges:

| | |
|-------------------------|--------------------------|
| Flow: | 408 - 4740 vehicles/hour |
| Composition (%heavies): | 2.3 - 57% |
| Mean traffic speeds: | 60 - 102 km/hour |
| Distance from the kerb: | 5 - 260 metres |

The traffic parameters and site details described in the report were used as input to a customised spreadsheet containing the CRTN formulation. The spreadsheet produced calculated/predicted values of $L_{A10, 1h}$. These values were then plotted against the reported measured values of $L_{Aeq, 1h}$ for each of the 460 measurements in the data-base and a regression analysis carried out. These results together with the corresponding regression statistics are shown in Figure 4.1.

It can be seen that although there is some scatter on the data the overall fit provided by the regression line is good over the whole of the range of noise levels encountered. Overall it can be seen that approximately 89% of the measured variance in the $L_{Aeq, 1h}$ levels are explained by the predicted values of $L_{A10, 1h}$ and the standard error of the estimate is relatively low at just over 2 dB(A). It was noted that the low noise level end of the range was achieved mainly from measurements taken at relatively long distances from the road. For these ranges, variations in meteorological conditions can significantly affect the propagation of noise and this could account for the excess scatter seen in the data set at the lower end of the noise level range.

An attempt was made to reduce some of the scatter in the data by regressing the residual variance $L_{A10, 1h} - L_{Aeq, 1h}$ against the traffic and site variables. However, perhaps not surprisingly, in view of the high degree of correspondence existing between the basic data from this form of analysis, it did not provide any significant improvement in the degree of correlation obtained.

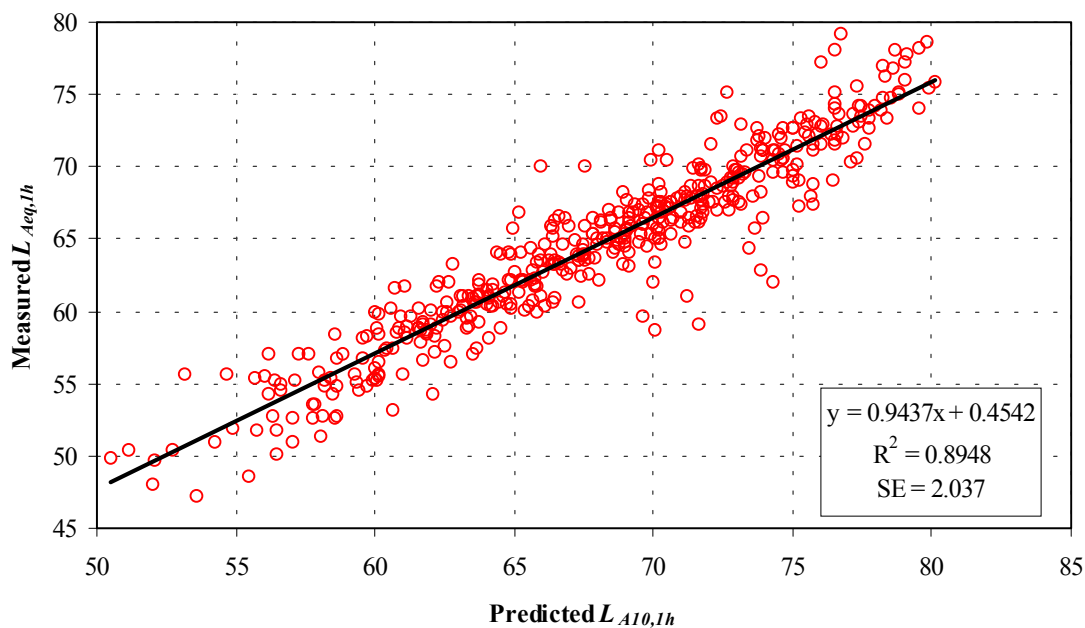


Figure 4.1: Measured $L_{Aeq,1h}$ and predicted $L_{A10,1h}$ for free-flow conditions

4.2 NON FREELY FLOWING TRAFFIC

Relevant data dealing with non-freely flowing traffic is relatively scarce in the literature. However, in the late seventies, TRL sponsored a study carried out by staff from Imperial College, London to examine both L_{A10} and L_{Aeq} in urban streets where the traffic flow was predominantly interrupted (Gilbert, 1977). As part of this study hourly measurements were taken at 17 different sites in the London area. A total of 33 different measurements were identified from this data set that contained sufficient traffic and site layout information for CRTN predictions to be carried out.

The range of traffic parameters included in the data set covered the following ranges:

| | |
|---------------------------------|----------------------------|
| Total flow: | 632 - 1816 vehicles /hour |
| Percentage commercial vehicles: | 3.3 - 27.3 % |
| Mean traffic speed: | 45 km/h ⁵ |
| Distance from kerb | 4 - 38 metres ⁶ |

It should be noted that the distance range quoted is narrower than that used for freely flowing traffic. This is consistent with the fact that all measurements were carried out in urban streets.

⁵ Crompton and Gilbert found that speed in urban areas was not significantly related to overall noise levels. For the purpose of calculating noise using CRTN a default value of 45 km/h has been assumed.

⁶ Although the distance from the kerb is an important input value for CRTN predictions, the proximity of buildings on both sides of the road is also important to allow for both single and multiple reflections of traffic noise. However, these reflections would be expected to affect both L_{Aeq} and L_{A10} by similar amounts. Consequently comparisons would not be affected. A default value for the effects of reflections has been assumed at all sites.

The traffic parameters and site details described in the report were used as input to CRTN to obtain calculated/predicted values of $L_{A10,1h}$. These values were then plotted against the reported measured values of $L_{Aeq,1h}$ for each of the 33 measurements in the data-base and a regression analysis carried out. These results together with the corresponding regression statistics are shown in Figure 4.2.

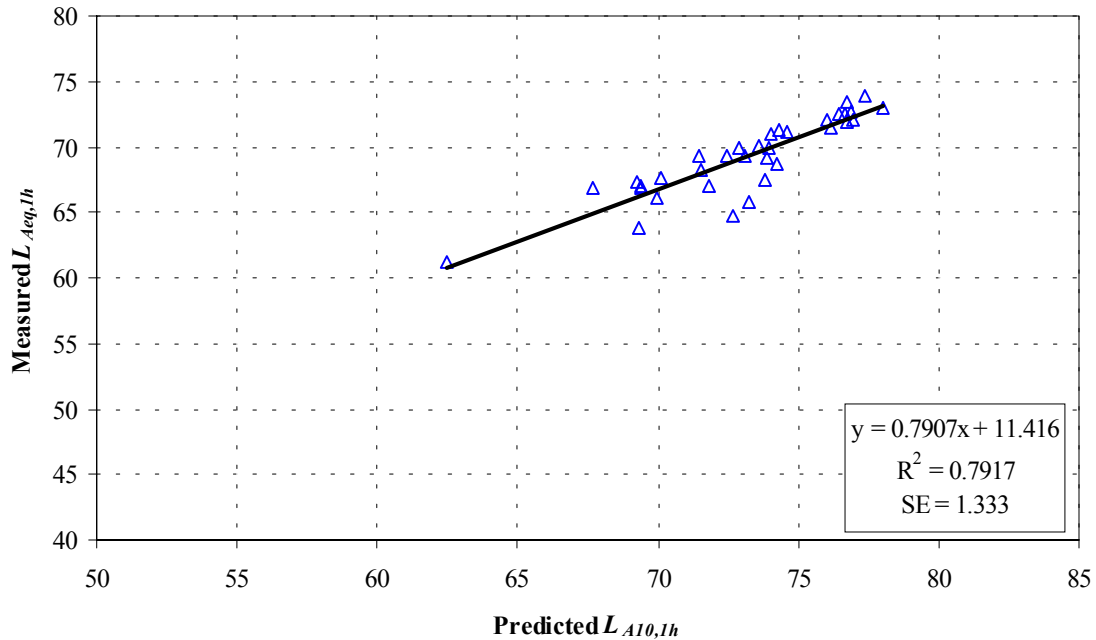


Figure 4.2: Measured $L_{Aeq,1h}$ and predicted $L_{A10,1h}$ for interrupted flow conditions

As in the case for freely flowing traffic, shown in Figure 4.1, it can be seen that there is a good fit over the whole of the range of noise levels encountered. Overall it can be seen that approximately 79% of the measured variance in the $L_{Aeq,1h}$ levels are explained by the predicted values of $L_{A10,1h}$ and the standard error of the estimate is also low at 1.3 dB(A).

4.3 COMBINING FREE FLOW AND NON FREE FLOW DATA

It is clearly important to compare the relationship found for freely flowing traffic with that found for non-freely flowing traffic. Figure 4.3 shows both data sets combined on the same scales. It is important to note that both data sets produce remarkably similar functional relationships over their respective ranges.

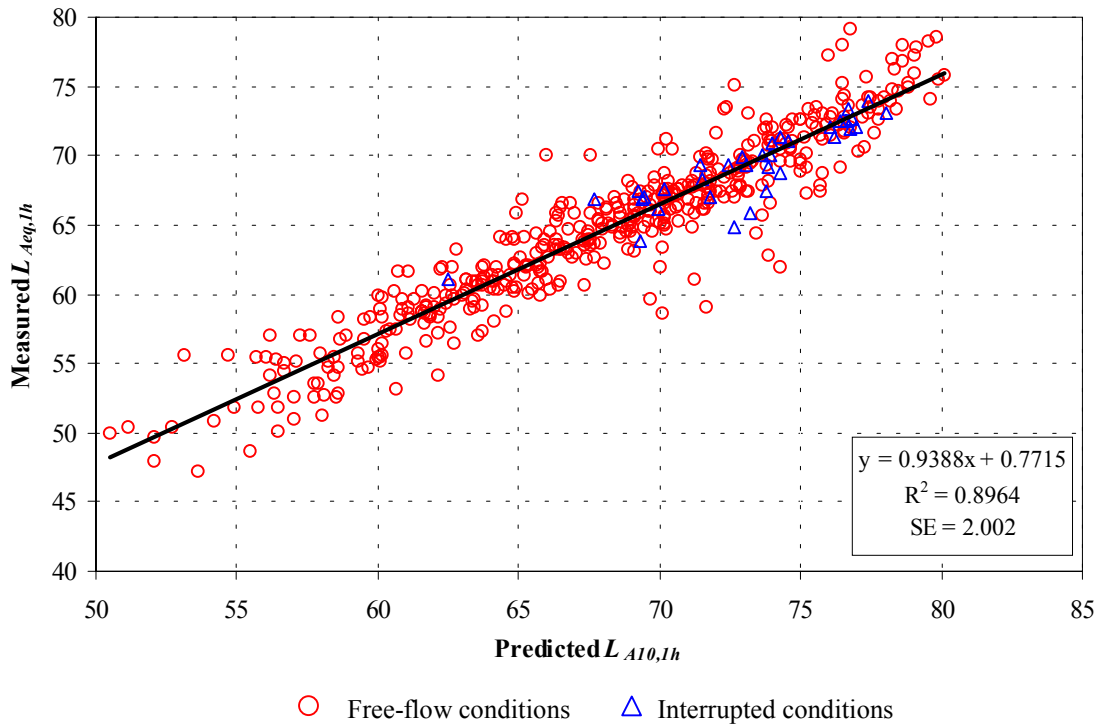


Figure 4.3: Comparing measured $L_{Aeq,1h}$ and predicted $L_{A10,1h}$ for interrupted and free-flow conditions

4.4 RELATIONSHIPS BETWEEN MEASURED HOURLY VALUES OF L_{Aeq} AND L_{A10}

The previous sections have provided evidence for a functional relationship between predicted values of $L_{A10,1h}$ obtained using CRTN and corresponding measured values of $L_{Aeq,1h}$. Although the form of the relationship appears to be robust in that it appears to be applicable for a broad range of traffic and site layout conditions, a possible criticism is that the measurements used to carry out the analysis were taken in the 70's and are therefore not applicable to current generation traffic. Additionally the measurements were confined to the day time period and so did not cover the night period where often the traffic flows are low. In order to examine these issues relevant data collected by TRL over the period 1991 - 2001 has been collated to form a new data-base. The data has been organised into two separate data files covering the periods 06:00 - 24:00 hours and 24:00 - 06:00 hours.

4.4.1 18-hour period 06:00 - 24:00 hours

The measurements were taken at 76 different sites which provided 1024 measured values of both $L_{A10,1h}$ and $L_{Aeq,1h}$. All measurements were taken in urban areas over the period 06:00 - 24:00 hours and covered a broad range of traffic conditions where traffic was both free flowing and interrupted. All measurements were taken at a height of 4 metres above ground thereby effectively eliminating the effects of varying ground cover at the different sites. However, it should be noted that the ground cover was predominantly acoustically 'hard'.

Figure 4.4 compares the measured values of $L_{A10,1h}$ and $L_{Aeq,1h}$ obtained by TRL with the corresponding measured values reported in the 1970's by The Building Research Station and Imperial College. It can be seen that all the data sets compared produce consistent results and there is no

evidence of any significant differences in the regression relationships determined for the different data sets.

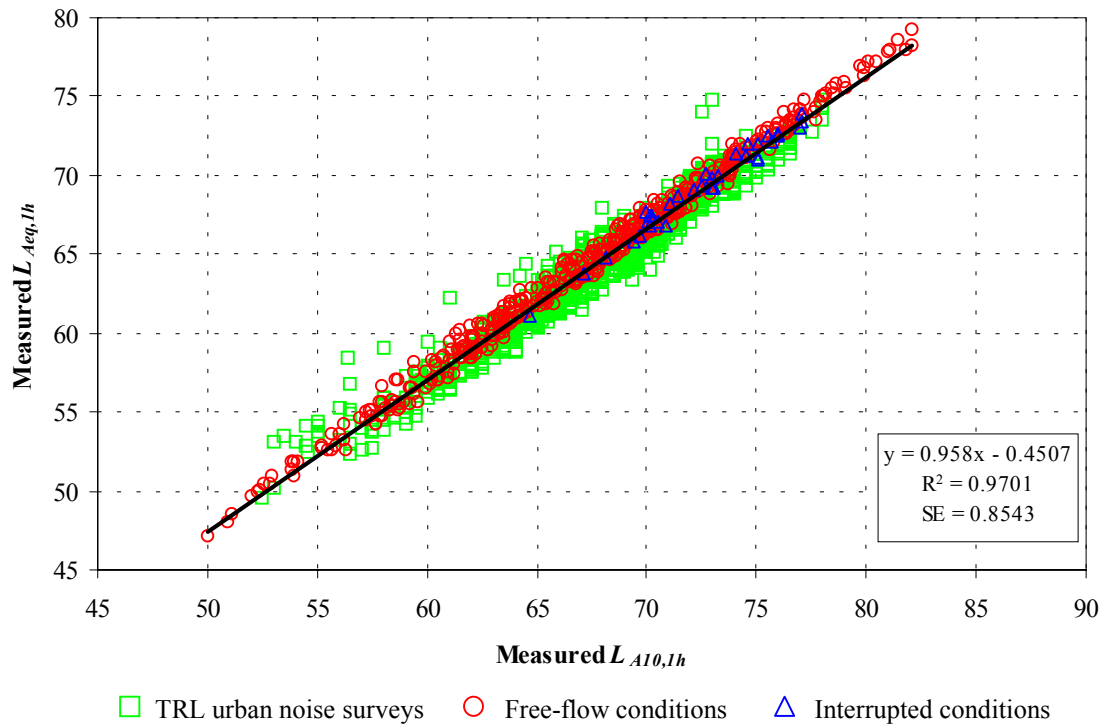


Figure 4.4: Comparing $L_{Aeq,1h}$ and $L_{A10,1h}$ for the 18 hour period 06:00 – 24:00

The regression statistics for the combined data set are included on the figure. It can be seen that overall, the measured values of $L_{A10,1h}$ and $L_{Aeq,1h}$ are highly correlated with 97% of the observed variance in the values of $L_{Aeq,1h}$ explained by the measured values of $L_{A10,1h}$. Overall the standard error of the estimate is low at 0.85 dB(A).

As a result of this analysis, it is reasonably safe to conclude that the relationship between $L_{A10,1h}$ and $L_{Aeq,1h}$ has not changed significantly since the 1970's. It follows, therefore, that the earlier data sets do provide a fair reflection of current relationships between the hourly indices and, at least, for the 18 hour daytime period a close correlation exists between predicted values of $L_{A10,1h}$ and measured values of $L_{Aeq,1h}$. A further point to note is that the regression lines shown on Figure 4.3 and Figure 4.4 are virtually identical indicating that it is reasonable to use measured values of $L_{A10,18h}$ as a surrogate for predicted values obtained using CRTN.

4.4.2 6-hour period 24:00 - 06:00 hours

During the night period 24:00 - 06:00 hours traffic flows tend to be much lower than during the day. Indeed very low flows are often the norm in residential streets during the early hours. Under these conditions a much higher degree of divergence between measured $L_{A10,1h}$ and $L_{Aeq,1h}$ values is to be expected due mainly to the sensitivity of L_{Aeq} to extraneous noise.

In order to examine the functional relationship between the two indices for the night-time period the data set compiled by TRL was used extracting only data taken during the period 24:00 - 06:00 hours. As in the previous analysis, described in Section 4.4.1, measurements taken at 76 different sites in urban areas were used. This provided 456 different hourly measurements.

The data comparing measured values of $L_{A10,1h}$ and $L_{Aeq,1h}$ for the night period are shown in Figure 4.5. The regression line and the correlation statistics are provided on the Figure. Also included is the regression line found for the combined data for the 18-hour daytime period, shown earlier in Figure 4.4. It can be seen that, as expected, a much higher degree of scatter is obtained for the night period.

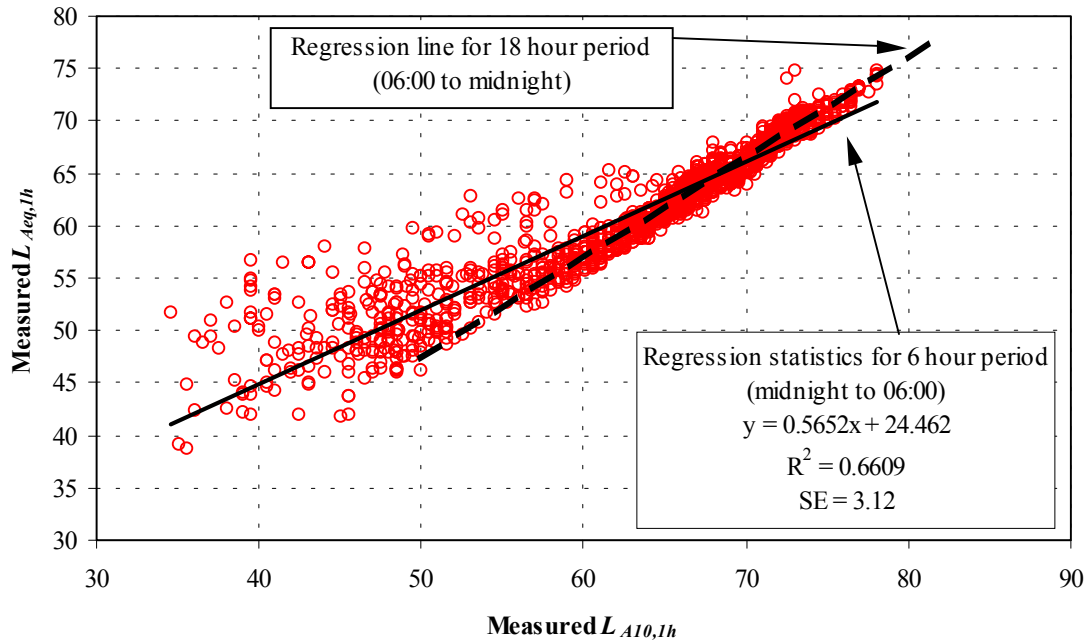


Figure 4.5: Comparing measured $L_{Aeq,1h}$ and $L_{A10,1h}$ for the 6 hour period 24:00 – 06:00

This has affected both the observed variance and the standard error values. The variance is lower and the standard error is greater than reported for the daytime period. A further point to note is that the slope of the regression line for the night period is less than for the daytime period. This is primarily caused by the fact that the values of $L_{Aeq,1h}$ become increasingly unstable as the overall flow reduces. For these conditions L_{Aeq} values are much more likely to be influenced by extraneous and non-traffic noise sources than are the values of L_{A10} . Further evidence of this can be seen from the increasing degree of scatter noticeable on the Figure as the overall noise level is reduced.

4.5 RELATIONSHIPS BETWEEN MEASURED $L_{A10, 18h}$ AND EU NOISE INDICES

The previous analysis has focussed on comparing both measured and predicted values of $L_{A10,1h}$ and $L_{Aeq,1h}$. This provides the basis of converting CRTN predicted values to EU indices but relies on the user having access to hourly traffic flow data. Clearly where this form of data is not available then it is important to also provide conversion relationships between $L_{A10,18h}$ and the EU indices directly. There are two possible approaches that could be adopted. Firstly, provided the traffic data is known or can be estimated for the relevant time periods specified by the EU it should be possible to derive values of the EU indices by converting $L_{A10,18h}$ to $L_{Aeq,18h}$ and then deriving the appropriate period L_{Aeq} 's from the traffic data over the relevant time periods. The second approach could be used where only limited traffic data is available and involves converting $L_{A10,18h}$ directly to the EU indices assuming typical variations in traffic flow etc over the relevant time periods.

4.5.1 Converting to EU noise indices using traffic data

To establish the relationship between $L_{A10,18h}$ to $L_{Aeq,18h}$ a comprehensive data-base was compiled from the TRL data set described earlier in Section 4.4 and from data from other surveys taken in mainly residential areas. In addition data obtained from three motorway sites has been added to the database. The motorway data included measurements taken alongside the M4 near Reading, the M25 between junctions 15 and 16, and the M6 near junction 9. The measurements alongside the M4 were taken at one location at a distance of 10 metres from the nearside lane. The measurements at the M25 were taken at two positions located at 10 metres and 210 metres from the edge of the nearside carriageway and measurements on the M6 were taken at a distance of 20 metres. For the measurements taken at the 210m position alongside the M25 the intervening ground cover was pasture. At each location, the measurements were taken continuously over the full 24-hour period generally covering the weekday period (Monday - Thursday). In total the combined data-base contained 203 measurements of both noise indices.

Figure 4.6 shows the results of comparing the measured values of $L_{A10,18h}$ to $L_{Aeq,18h}$. The data differentiates between motorway and non-motorway sites. It can be seen that a very high degree of correlation exists over the whole of the range covered by the data. The correlation statistics indicate that over 99% of the variance is explained and the standard error is small.

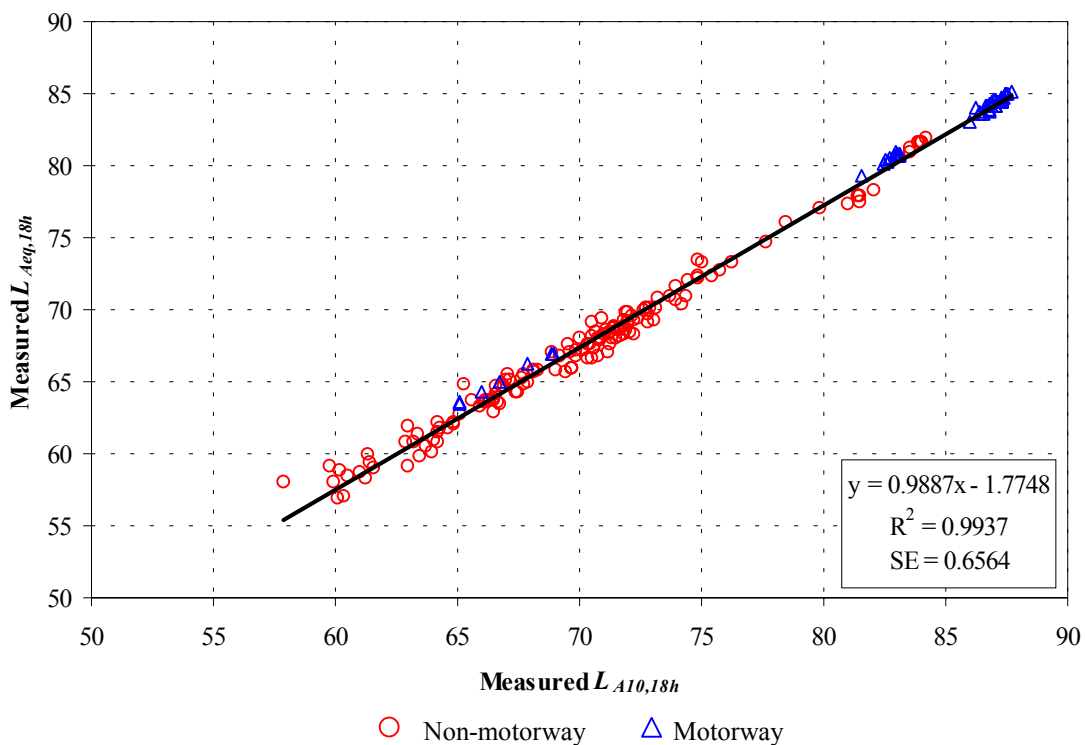


Figure 4.6: Comparison of measured $L_{A10,18h}$ and $L_{Aeq,18h}$ noise indices

Having established the functional relationship between $L_{A10,18h}$ and $L_{Aeq,18h}$ the following equations were used to determine the period L_{Aeq} 's specified by the EU in terms of $L_{A10,18h}$ and the relevant traffic parameters. The functional forms of these equations were determined from the model described by the Noise Advisory Council (Noise Advisory Council, 1978).

$$L_{day} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_{12} N_{12} V_{12}^2}{p_{18} N_{18} V_{18}^2} \right) \text{ dB} \quad (4.1)$$

$$L_{evening} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_4 N_4 V_4^2}{p_{18} N_{18} V_{18}^2} \right) + 4.76 \text{ dB} \quad (4.2)$$

$$L_{night} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_8 N_8 V_8^2}{p_{18} N_{18} V_{18}^2} \right) + 1.75 \text{ dB} \quad (4.3)$$

where

$L_{A10,18h}$ dB is the averaged hourly L_{A10} level measured over the period 06:00 to midnight;

p_t is the percentage of heavy vehicles in the time period t hours;

N_t is the total traffic flow in the time period t , and

V_t is the mean traffic speed in the time period t .

Figure 4.7 compares the predicted values of the L_{day} , $L_{evening}$ and L_{night} obtained using the equations given above with the corresponding measured values taken from the data set. Also included in the figure are values of L_{den} determined from the calculated and measured period L_{Aeq} 's. The line drawn on the figure shows the exact agreement function (i.e. where measured and predicted values are identical).

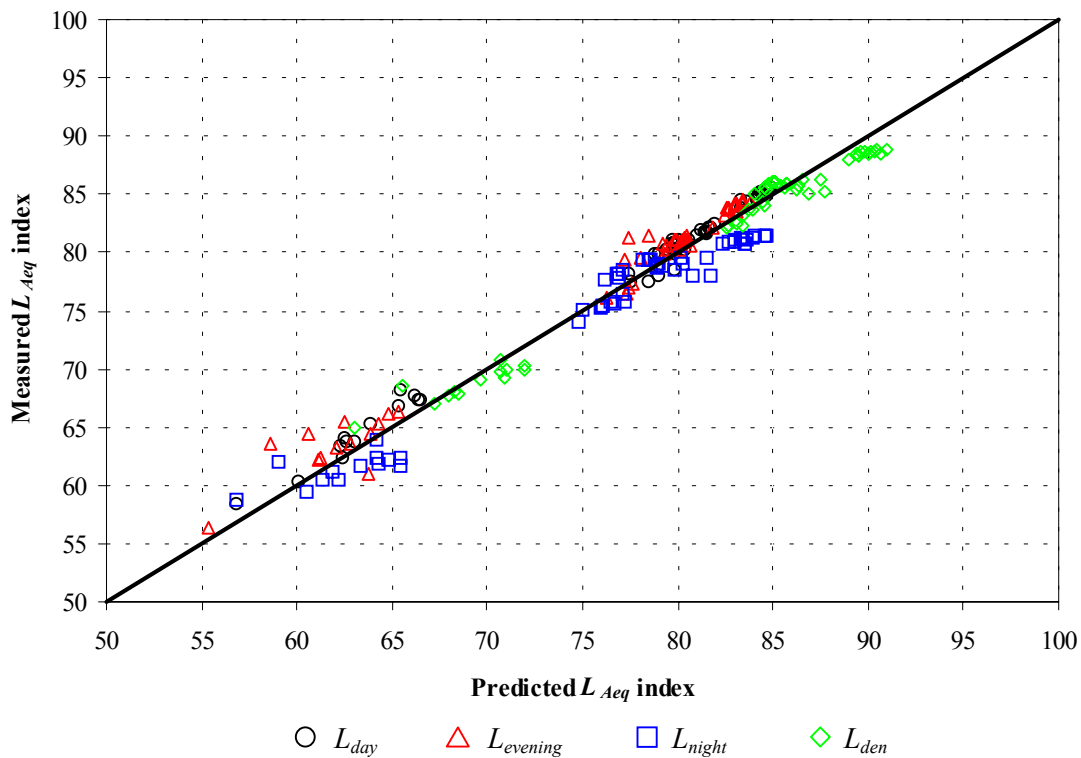


Figure 4.7: Comparison of measured and predicted EU noise indices

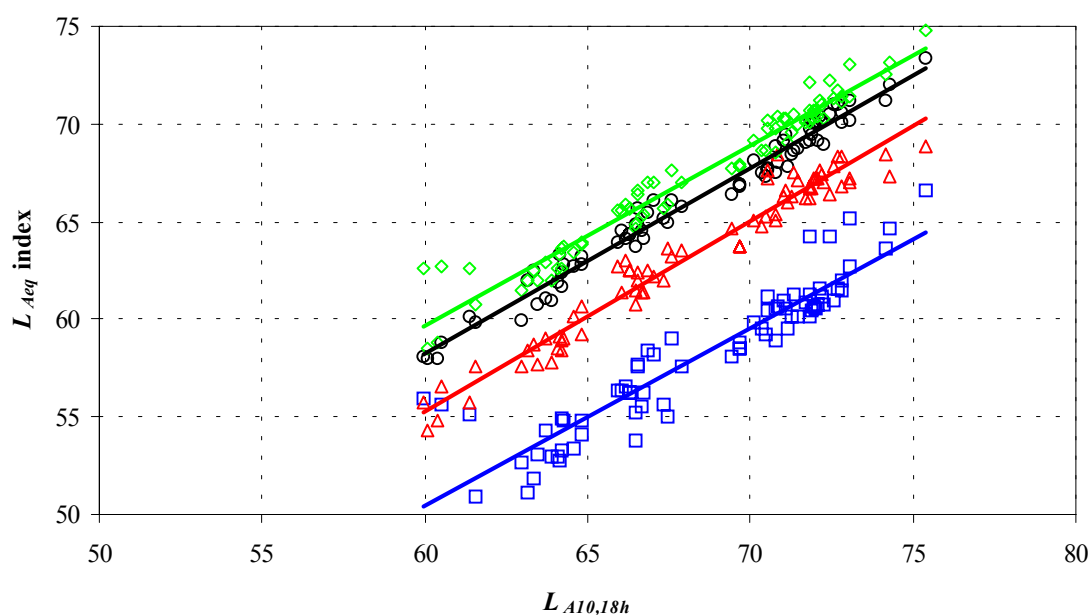
The figure clearly shows that using this approach a high degree of prediction accuracy is achieved over a wide range of noise levels for each of the EU indices and for the composite index L_{den} . Overall the standard error of the differences between predicted and observed values of L_{den} was 1.10dB. The corresponding standard errors for the 'day', 'evening' and 'night' indices were 0.67dB, 1.2dB, and 1.56dB respectively.

4.5.2 Converting to EU noise indices assuming typical traffic conditions

For situations where traffic data over the relevant time periods is not available then it is potentially possible to determine values of the EU indices from values of $L_{A10,18h}$ by assuming typical traffic conditions for the type of road being assessed. For this approach it is important to examine these relationships separately for motorways and non-motorway roads. This is because the relationships between day, evening and night time traffic flows are different for these different road types.

(i) Non-motorway roads

In order to examine relationships for non-motorway roads, the TRL data set described in Section 4.4 was used. Figure 4.8 shows the data and regression relationships obtained when comparing measured values of $L_{A10,18h}$ with the different L_{Aeq} indices; L_{day} , $L_{evening}$, L_{night} and L_{den} . In all cases a high degree of correlation was obtained although, as expected the correlation with the 8-hour night index was poorer and the standard error larger than for the other indices. Particularly noteworthy is the high degree of correlation between L_{den} and $L_{A10,18h}$.



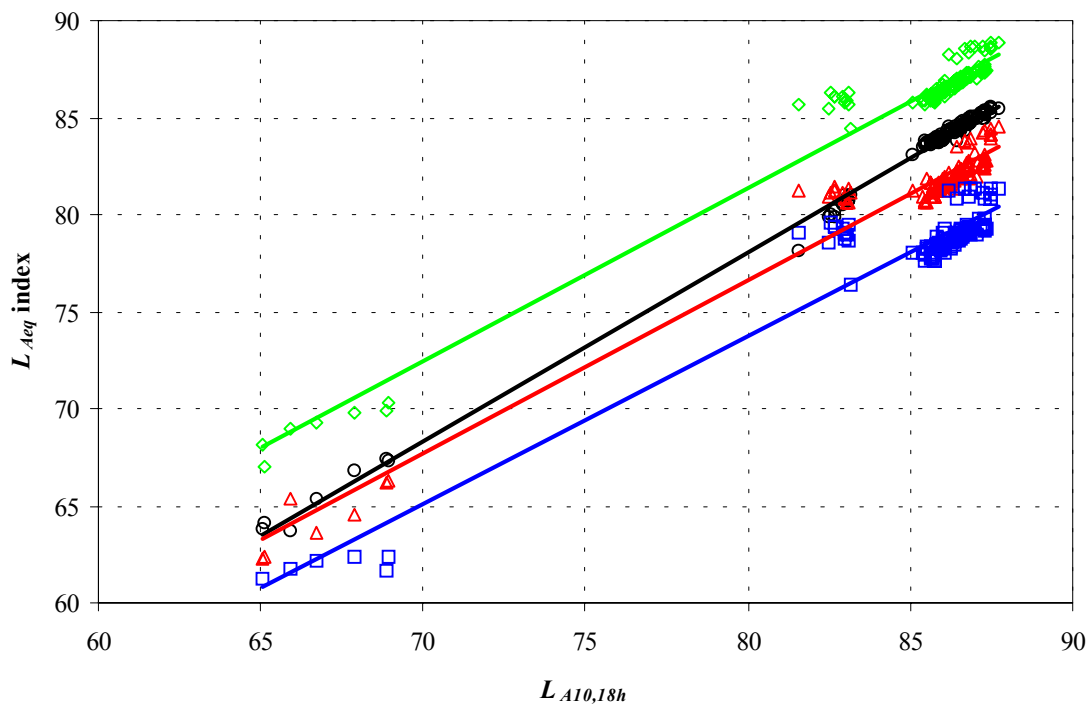
| \circ L_{day} | \triangle $L_{evening}$ | \square L_{night} | \diamond L_{den} |
|------------------------|---------------------------|------------------------|------------------------|
| $y = 0.9471x + 1.4385$ | $y = 0.9697x - 2.8702$ | $y = 0.9044x - 3.7683$ | $y = 0.9241x + 4.1982$ |
| $R^2 = 0.9767$ | $R^2 = 0.9530$ | $R^2 = 0.8582$ | $R^2 = 0.9529$ |
| $SE = 0.58$ | $SE = 0.86$ | $SE = 1.47$ | $SE = 0.82$ |

Figure 4.8: Comparing L_{Aeq} indices and $L_{A10,18h}$ for non motorway roads

(ii) Motorways

An analysis for motorway traffic has been accomplished using the data collected by TRL alongside the 3 different motorway sites described earlier in section 4.5.1. In total the number of 24-hour measurements included in the data set was 108.

Figure 4.9 shows the values of $L_{A10,18h}$ obtained plotted against the various L_{Aeq} indices of interest. It can be seen that the degree of correlation obtained for each of the indices examined was very good and the standard errors were low in each case. However, it must be noted that the available data is not evenly distributed over the full range of noise levels and this may have flattered the degree of fit indicated by the statistics. The higher levels were recorded at the sites located close to the motorways and the lower levels refer to the site on the M25 located at 210 metres from the motorway. It is important to note that the correlation obtained for the night period was higher than for non-motorway roads with over 92% of the variance explained. This is a reflection of the fact that for motorways the night flows and hence noise levels were generally higher, which provides for a greater degree of stability in the relationship between the two indices.



| ○ L_{day} | △ $L_{evening}$ | □ L_{night} | ◇ L_{den} |
|----------------------|----------------------|---------------------|----------------------|
| $Y=0.9751x + 0.0949$ | $y=0.8942x + 5.0805$ | $y=0.8691x + 4.239$ | $y=0.8963x + 9.6917$ |
| $R^2 = 0.9967$ | $R^2 = 0.9589$ | $R^2 = 0.9230$ | $R^2 = 0.9634$ |
| $SE = 0.28$ | $SE = 0.91$ | $SE = 1.23$ | $SE = 0.86$ |

Figure 4.9: The $L_{A10,18h}$ index and various L_{Aeq} noise indices for motorways

Despite the gap in the data in the central part of the range of noise levels, the high degree of correlation between $L_{A10,18h}$ and L_{den} provides a useful basis for conversion.

(iii) Comparison of motorway and non-motorway data

It is useful to compare the data presented earlier in Figure 4.8 and Figure 4.9 for non-motorway roads and motorways respectively. Figure 4.10 (a)-(c) show the values of $L_{A10,18h}$ plotted for both road types on the same scales for the day, evening and night-time periods. The corresponding Figure for the combined index L_{den} is also shown (d). Interestingly it can be seen that for the daytime period the relations for non-motorway roads and for motorways are essentially identical over their respective ranges. This is to be expected since daytime flow patterns for both road types are generally very similar. Differences between the different relationships are indicated for the evening period and, more noticeably, for the night period. This is evidence of the different flow patterns for the two road types for these periods, particularly during the night. It can also be seen that overall, despite the close agreement for the daytime data, the influence of the evening and night period has also given rise to a different functional relationship for L_{den} levels for non-motorway roads and motorways.

4.6 PROCEDURE FOR CALCULATING EU NOISE INDICES FROM CRTN DERIVED NOISE LEVELS

The previous sections have described the development of models derived from both measured and predicted data that enable period L_{A10} noise indices to be converted to period L_{Aeq} indices. Where possible the procedure for calculating EU noise indices have been based on predicted period L_{A10} values. However, this has not always been possible due to lack of traffic data, particularly, during the night period on non-motorway roads. In such cases, models derived from measured data have been used. Comparing the regression equations to estimate measured $L_{Aeq,1h}$ values derived from predicted and measured $L_{A10,1h}$ values, Figures 4.3 and 4.4 respectively, show that differences in estimated $L_{Aeq,1h}$ values over the range 50 to 80 dB(A) was no greater than 0.3 dB(A). This indicates that procedures for calculating EU noise indices based on either measured or predicted L_{A10} values would provide similar results. Generally, the regression analysis has shown that the relationship between L_{A10} and L_{Aeq} appear to be remarkably robust for the traffic and site conditions covered by the data. Apart from situations where the flow is anticipated to be low⁷ (e.g. non-motorway roads at night) a high degree of correlation was obtained in all cases examined with acceptable errors. The question remains, therefore, as to how to deal with the night period on non-motorway roads where flows can be much lower than during the day.

A possible approach is to use the regression relation derived from the TRL data set for the night period as shown on Figure 4.5. Although the correlation statistics indicate a poorer degree of correlation than for the daytime period, the overall variance explained is still quite good at approximately 66%. Additionally, it is expected that the data will inherently contain a higher degree of scatter at the lower noise levels indicated on the Figure purely as a result of the sensitivity of L_{Aeq} levels to noise from other sources and from short duration noisy events. The measurements taken were not monitored for extraneous noise.

It is reasonable to assume, therefore, that if it had been possible to remove extraneous noise from the data set, the actual variance explained by the regression analysis would have been higher than that indicated although it is clearly not possible to state by how much. It is clear, however, that the regression line for the night time period, shown in Figure 4.5, will tend to over-estimate values of L_{Aeq} since removing data points containing extraneous noise will tend to remove those data points that are significantly above the regression line shown on the Figure.

A further point to note is that all measurements included in the analysis were taken at sites that were relatively free from obstructions that could affect propagation. Additionally, the wind conditions at the different sites were either unimportant, due to the close proximity of the measurement points to the road, or, where longer distances were involved, only included data where the wind was blowing with a direction component from the road to the receptor.

⁷ Low flows are defined in CRTN as flows less than 200 vehicles per hour.

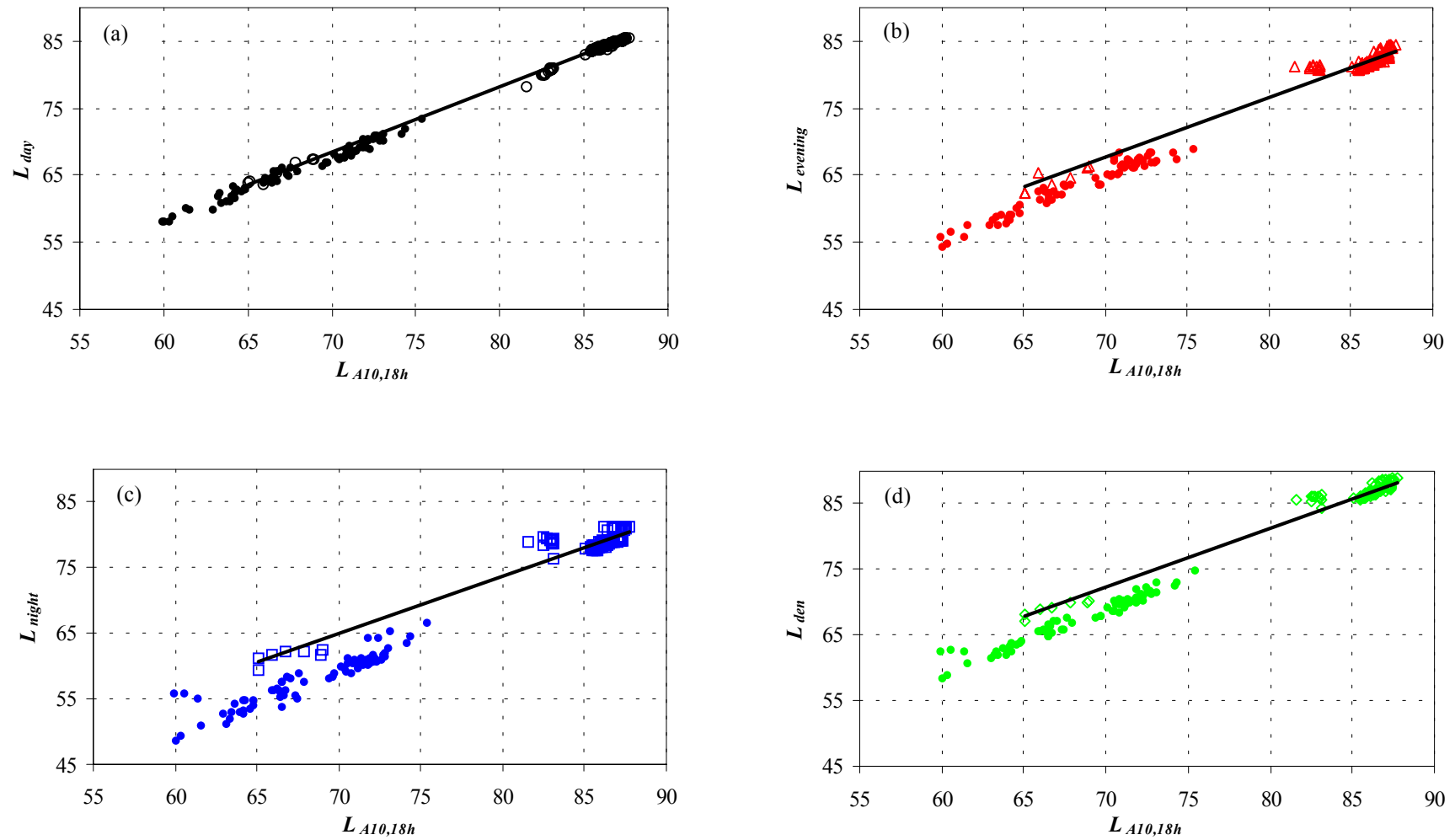


Figure 4.10: The $L_{A10,18h}$ index and various L_{Aeq} noise indices for motorways and non-motorway roads

○ △ □ ◇ Motorways • • • • Non-motorway roads

As has been pointed out earlier, the relative effect of screening on the different noise indices is likely to be small in practice. Consequently it appears reasonable, at this interim stage, to accept that the relationships derived for open site conditions can also be applied to sites where screening is involved with acceptable additional errors. The issue regarding wind effects has importance when considering the EU requirement to predict long-term average noise levels. This implies that the EU method has to consider average wind conditions rather than the moderately adverse conditions implicit in the CRTN formulation and in the data used in the analysis described above. This issue may be important when assessing locations with predominantly negative wind vector conditions. For such cases, the application of the conversion relations derived from the analysis described above will then tend to produce values of the EU indices that overestimate the values for average wind conditions.

In view of the above considerations, it is recommended that the following procedure is adopted in the UK as an interim measure to calculate the recommended EU noise indices.

Method 1. When the user has available hourly traffic data then CRTN⁸ can be used to produce values of $L_{A10,1h}$ which can then be converted to $L_{Aeq,1h}$ values using the relationship from Figure 4.3:-

$$L_{Aeq,1h} = 0.94 \times L_{A10,1h} + 0.77 \text{ dB} \quad (4.4)$$

However, for non-motorway roads when hourly traffic flows are below 200 vehicles per hour during the period 24:00 to 06:00 hours, the relationship from Figure 4.5 should be used:-

$$L_{Aeq,1h} = 0.57 \times L_{A10,1h} + 24.46 \text{ dB} \quad (4.5)$$

The converted values obtained for the full 24 hours can then be used to derive the values of L_{den} and L_{night} as required by the EU.

Method 2 Where detailed hourly traffic data is not available but traffic data is known or can be estimated for the relevant time periods specified by the EU then CRTN⁸ should be used to obtain values of $L_{A10,18h}$ which should then be converted to L_{day} , $L_{evening}$ and L_{night} using the following relationships:

$$L_{day} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_{12} N_{12} V_{12}^2}{p_{18} N_{18} V_{18}^2} \right) \text{ dB} \quad (4.6)$$

$$L_{evening} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_4 N_4 V_4^2}{p_{18} N_{18} V_{18}^2} \right) + 4.76 \text{ dB} \quad (4.7)$$

$$L_{night} = 0.99 \times L_{A10,18h} + 10 \times \log_{10} \left(\frac{p_8 N_8 V_8^2}{p_{18} N_{18} V_{18}^2} \right) + 1.75 \text{ dB} \quad (4.8)$$

⁸ For the purposes of noise mapping, the EU Directive assumes the assessment point is at 2 m in front of the most exposed façade and 4 m above the ground and that reflection effects from the façade are ignored.

where $L_{A10,18h}$ dB is the averaged hourly L_{A10} level measured over the period 06:00 to midnight; p_t is the percentage of heavy vehicles in the time period t hours⁹; N_t is the total traffic flow in the time period t , and V_t is the mean traffic speed in the time period t .

The converted values can then be used to derive the values of L_{den} using (2.3).

Method 3. Where detailed hourly traffic data is not available then CRTN¹⁰ should be used to obtain values of $L_{A10,18h}$ which should then be converted to L_{day} , $L_{evening}$ and L_{night} or, for single segment roads, directly to L_{den} using the following relationships shown in Figure 4.8 and Figure 4.9.

For non-motorway roads:-

$$L_{day} = 0.95 \times L_{A10,18h} + 1.44 \text{ dB} \quad (4.9)$$

$$L_{evening} = 0.97 \times L_{10,18h} - 2.87 \text{ dB} \quad (4.10)$$

$$L_{night} = 0.90 \times L_{A10,18h} - 3.77 \text{ dB} \quad (4.11)$$

$$L_{den} = 0.92 \times L_{A10,18h} + 4.20 \text{ dB} \quad (4.12)$$

For motorways:-

$$L_{day} = 0.98 \times L_{A10,18h} + 0.09 \text{ dB} \quad (4.13)$$

$$L_{evening} = 0.89 \times L_{10,18h} + 5.08 \text{ dB} \quad (4.14)$$

$$L_{night} = 0.87 \times L_{A10,18h} + 4.24 \text{ dB} \quad (4.15)$$

$$L_{den} = 0.90 \times L_{A10,18h} + 9.69 \text{ dB} \quad (4.16)$$

It should be noted that the preferred method is Method 1. The evidence from both the literature survey and subsequent analysis of data collected for UK traffic conditions indicates that this form of conversion will produce acceptable errors and is robust over a wide range of conditions. Method 2 also provides a good solution where hourly traffic information is not available but where traffic data for the relevant time periods specified by the EU is available. Method 3 is potentially the least reliable of the three methods since it relies on the assumption that different road types will, on average, produce a reasonably consistent diurnal flow pattern. Clearly for roads where significant deviations from the norm occur then further errors in conversion may result.

For each of the methods specified above, where a road scheme consists of several segments it is important initially to determine the components L_{day} , $L_{evening}$, L_{night} for each segment separately. These values should then be combined to obtain the corresponding values of L_{day} , $L_{evening}$, L_{night} for the whole road scheme. Once this has been achieved, the value of L_{den} can be calculated from the combined component values.

Figure 4.11 illustrates the procedure in the form of a flow chart.

⁹ When the value of p_t is zero then put $p_t = 1$

¹⁰ For the purposes of noise mapping, the EU Directive assumes the assessment point is at 2 m in front of the most exposed façade and 4 m above the ground and that reflection effects from the façade are ignored.

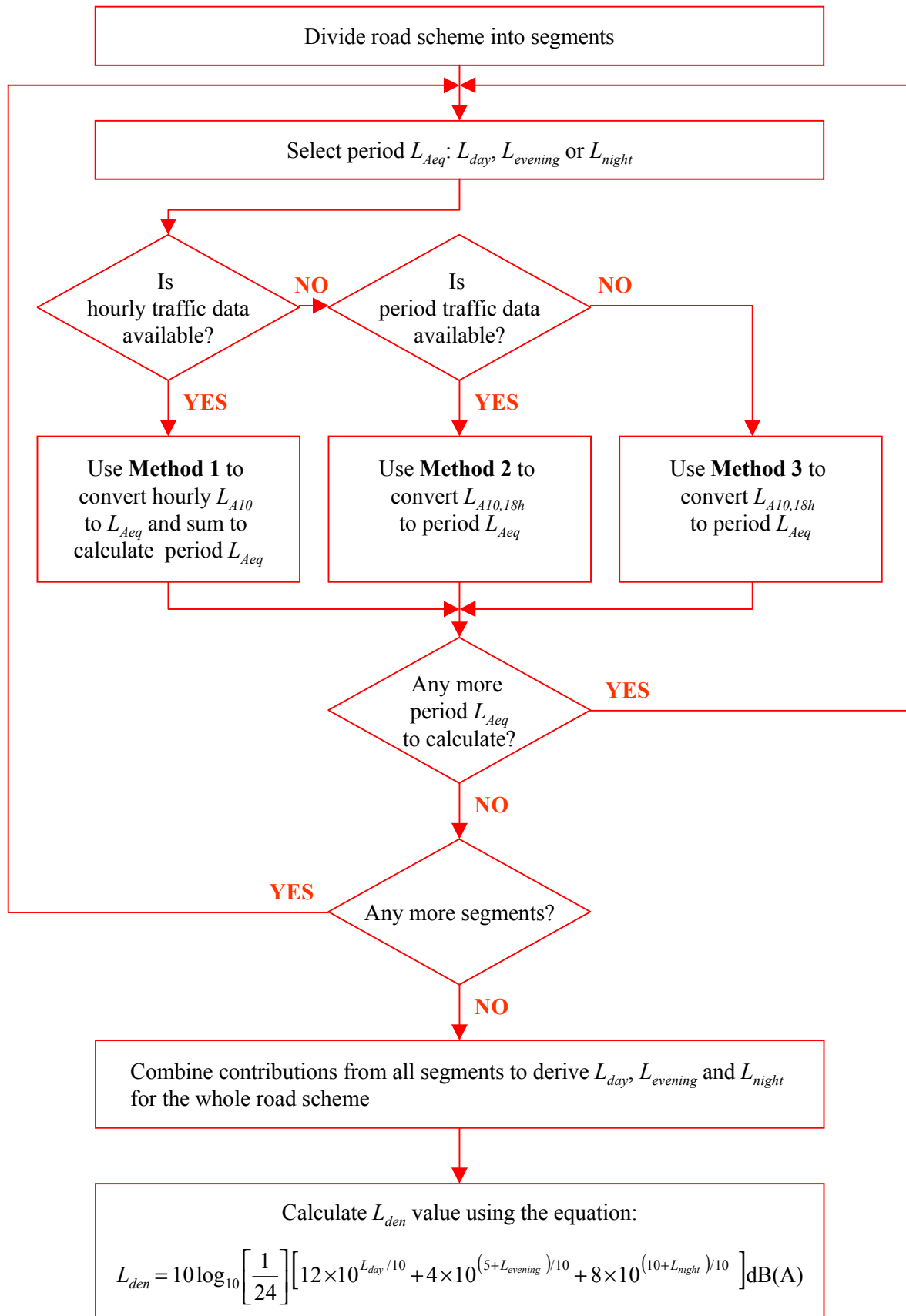


Figure 4.11: Flow chart of prediction method

5 CONCLUSIONS AND RECOMMENDATIONS

This Report provides an examination of the issues and methods that could be employed to develop an interim computation method for use in the UK to carry out noise calculations according to the requirements of the EU Directive. The objective has been to include as wide a range of options as possible for consideration. Two different approaches were considered. The first approach dealt with methods that enable the noise indicators L_{den} or L_{night} to be determined directly assuming the relevant input parameters are known. These methods rely on adapting an existing L_{Aeq} traffic noise prediction method and include the French national computation method ‘NMPB’ (CETUR, 1996) and the model developed by the Noise Advisory Council (Noise Advisory Council, 1978). The second approach dealt with methods that enable the noise indicators L_{den} or L_{night} to be determined by adapting the procedures described in CRTN. The aim has been to examine the advantages and limitations of each approach to enable a valid, practical and transparent method to be adopted as the basis of an interim prediction method in the UK.

The main conclusions are as follows:

1. Adopting either the French ‘NMPB’ method or the NAC method as an interim computation method poses significant problems. The main limitation is the lack of appropriate vehicle noise input data particularly for roads where vehicle speeds fall below 80 km/h. As mapping in urban areas (i.e. with traffic moving at low speeds) will form an important part of the exercise, application of either method will be restrictive if the appropriate input data is not available.
2. It has been argued that in the interim, the best approach is to adapt CRTN by applying an end correction to obtain the relevant EU indices from calculated values of L_{A10} .
3. As a result of further analysis carried out on measurement data taken at a wide range of road sites relationships have been established for UK traffic conditions that provide a means of converting CRTN calculated values ($L_{A10,1h}$ or $L_{A10,18h}$) to the relevant EU indices.
4. The preferred approach (Method 1) relies on determining hourly values of L_{A10} using CRTN and then converting these values to equivalent values of L_{Aeq} . Values of the EU indices L_{den} and L_{night} are then deduced from the 24 hourly L_{Aeq} values. However, for situations where hourly values cannot be determined, due to the absence of detailed hourly traffic information but where traffic data for the required period indices is known or can be determined, an alternative method is provided (Method 2). This allows CRTN to be used to produce values of $L_{A10,18h}$ which are then converted to $L_{Aeq,18h}$ and then subsequently to the component EU noise indices using the relevant period traffic data. L_{den} is then determined from these component values.
5. Method 3 is the simplest but least reliable of the three methods. It provides a means of determining the EU indices where additional traffic information is not available. The method allows CRTN to be used to produce values of $L_{A10,18h}$ which are then converted to the EU indices using the conversion formulae provided. However, it relies on the assumption that different road types will, on average, produce a reasonably consistent diurnal flow pattern. For roads where significant deviations in the average conditions occur then errors in conversion may result.
6. The procedures described in this Report provide the basis for an interim computation method that complies with the proposed EU Directive relating to the assessment and management of environmental noise.

6 ACKNOWLEDGEMENTS

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