A ROAD LIGHTING SURVEY METHOD FOR ACCIDENT SITES

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ABSTRACT

A rapid method has been developed to evaluate the night lighting conditions at a road site in terms of the performance values of the Road Lighting Code. The method involves the use of luminance, illuminance, length and angle measurements. The on-site measurements can be readily carried out in under half-an-hour with the results recorded on a check sheet for analysis later by a computer programme developed for the purpose.

Road accident sites can be readily identified by the use of the Ministry of Transport's database and sites with potential lighting problems can be identified by examining the night accident ratios at these sites. Twenty sites in the Wellington urban area were identified with unusual night accident ratios and the measurement method was tried at these sites. The lighting at most sites met only the Minor Road performance values even though many roads would be classified as Intermediate or Main Roads.

The sample size was too small to show any relationship between accidents and lighting performance values. However, the method can be readily adopted to investigate the suitability of lighting at accident sites and the need to upgrade the lighting to the Road Lighting Code of Practice.

1. INTRODUCTION

The relationship between road lighting and accidents has been widely researched overseas (CIE 1960, 1987). For developed countries the results show that adequate road lighting decreases road accidents by about 30%, with greater reductions in pedestrian accidents and severe injury accidents. A similar benefit should occur for New Zealand but very little information is available about road lighting and accidents. A variety of methods have been used to investigate this relationship and an examination of the results suggests that many of the methods would not be appropriate for New Zealand. However as these results indicate the practical means that can be used to improve road safety, they have been used in this study.

This study on road accidents and road lighting has two main aims:

- To provide a uniform and meaningful method of evaluating road lighting for investigations of accident rates.

- To provide a good indication to a road lighting authority, where to allocate resources to obtain benefits through accident reduction.

Both aims require, as a first step, a means to readily identify areas for a lighting investigation. The starting point is the database on reported road accidents maintained by the Ministry of Transport (MOT) as the data are readily available to interested users.

Selection of an accident site can be obtained from the database for any of the recorded categories of accidents (MOT 1985). The night ratios of several categories of accidents are examined nationally and regionally to determine their suitability in selecting sites for lighting investigations. Detailed studies were then made for the urban areas of the Wellington region.

Measurement methods for road lighting are examined in detail to allow a very simplified method to be developed. Application of the simplified method is made on the accident sites identified and an evaluation made of the findings.

2. NIGHT RATIOS

In this survey the concept of a night ratio for a category of accident is used. It can be defined as:

$$\textit{night ratio} = \frac{\textit{total number of accidents at night}}{\textit{total number of accidents of same type}}$$

The ratio will normally be given as a percentage. Note that the term "night" is how the accident was recorded in the Traffic Accident Report and the term "total" refers to the 24-hour day.

The choice of a night ratio as the basis for this investigation is made because:

- The night and day classification of accidents is the major lighting-related parameter reported in the statistics.

- The night ratios appear to be relatively insensitive to other traffic factors, e.g. number of accidents (see below).

Figure 1 shows the national trend (MOT 1979-1986) in the night ratios for all reported urban traffic accidents between 1979 and 1986 as well as that for fatal accidents. Over that period 40% of all accidents occurred at night as did 60% of all fatal accidents. As the traffic volume is lower at night than during the day then clearly night-time driving is dangerous. The danger comes with the poorer visibility at night which often results in insufficient warning of a dangerous condition.

For developed countries such as those in the European Community, the night ratio is 30% (CIE 1987), somewhat lower than the New Zealand value. This suggests that some feature of the night driving situation could be improved. The most obvious difference is the quality of the lighting which, in Europe, is higher than that installed in New Zealand. Clearly a method for evaluating road lighting in New Zealand would lead to improved road lighting and consequently would help towards lowering the night accident rate.

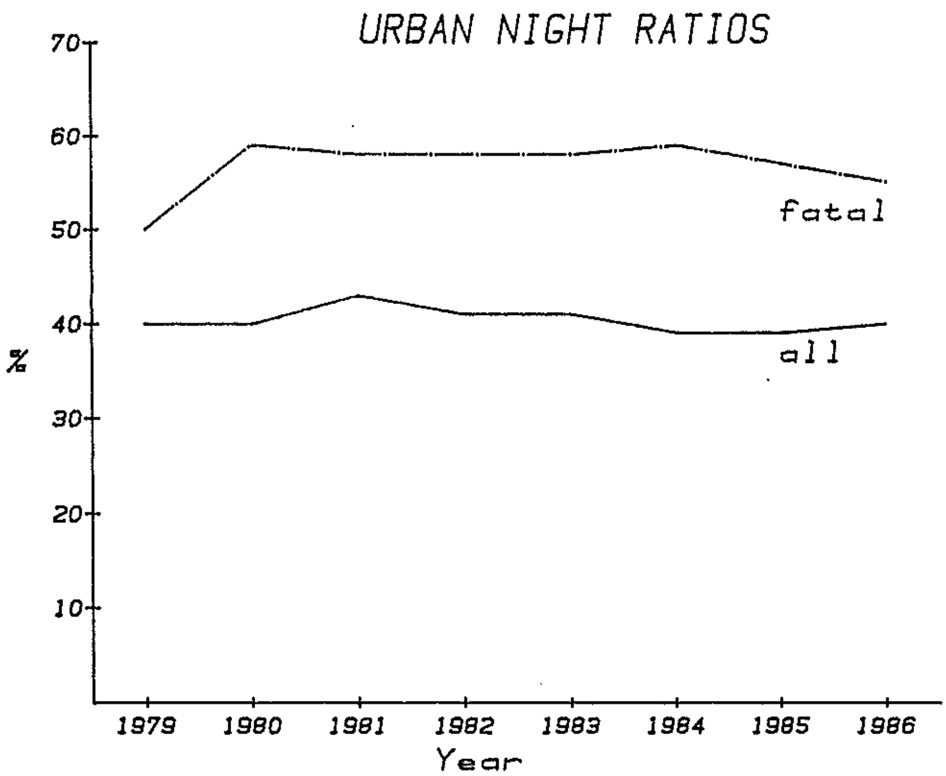

Figure 1. Night ratios for reported urban traffic accidents for fatal and all accidents.

3. STATISTICAL APPROACH

Accident statistics are notoriously difficult to draw definite conclusions from because of the large number of factors contributing to an accident. However the statistics are useful as indicators of problems and their probable causes.

The types of road accidents for which lighting problems are an important contributing factor need to be distinguished. At least two classes of accidents are known to be more sensitive to the effects of road lighting:

- Severe injury accidents.
- Pedestrian accidents.

One of the difficulties in locating problem sites is that the number of accidents at any site is low and it is not practical to use for investigation the accident types which have a low number of accidents. Thus severe injury and fatal accidents are not suitable types even though they are more prevalent at night. The total number of accidents can be split into four categories based on the movement classification of accidents (MOT 1980):

- Intersection accidents: accidents involving two or more vehicles at intersections; about 42% of accidents are of this type.

- Single vehicle accidents: accidents in which only one vehicle and no other road user is involved; 25% of accidents.

- Pedestrian accidents: accidents in which a pedestrian is involved; 13% of accidents.

- Other accidents: all other accidents, about 20%, are spread over five movement classifications and are not considered further here.

Intersection accidents will not be considered in detail because of their more complex nature. The lighting problems associated with intersections can arise both from vehicle lighting and road lighting. The night ratio for intersection accidents is 30%, which is the same as for pedestrian accidents.

Single vehicle accidents are considered here largely because of their high night ratio (60%). One reason for this could be the lower traffic density at night. As fewer factors contribute to them than to intersection accidents, it is of interest to determine the effect of lighting. In any event they provide a different accident category for comparison against pedestrian accidents which are known to be affected by road lighting.

Figure 1 gives the national urban area night ratios for all accidents and for fatal accidents over the period 1979 to 1986 (MOT 1976-1986). The ratios are remarkably constant compared to the changes in the annual number of total accidents (both urban and rural) shown in Figure 2. Figure 3 gives the corresponding night ratios for the three major accident categories, and Figure 4 gives the proportion that these accident categories are of the total number of all reported urban accidents. Here again the night ratios are fairly constant. The only noticeable trend is a decrease in the proportion of pedestrian accidents with a corresponding growth in intersection accidents. The trends of Figures 3 and 4 were confirmed with spot checks of the data going back to 1972.

Thus on a national basis, the urban accident night ratios are constant. For a 15-year period the social and engineering factors which could affect the night ratios also must have been constant.

An important factor in terms of this survey is the road lighting. Most of the lighting for the period was based on the 1963 road lighting code (SANZ 1963) which, by 1972, would have been largely implemented. Also, road lighting practice did not change until the 1983 road lighting code was introduced (SANZ 1983). As the change over to this latest code was slow, the last three years of the period would not greatly affect the accident data.

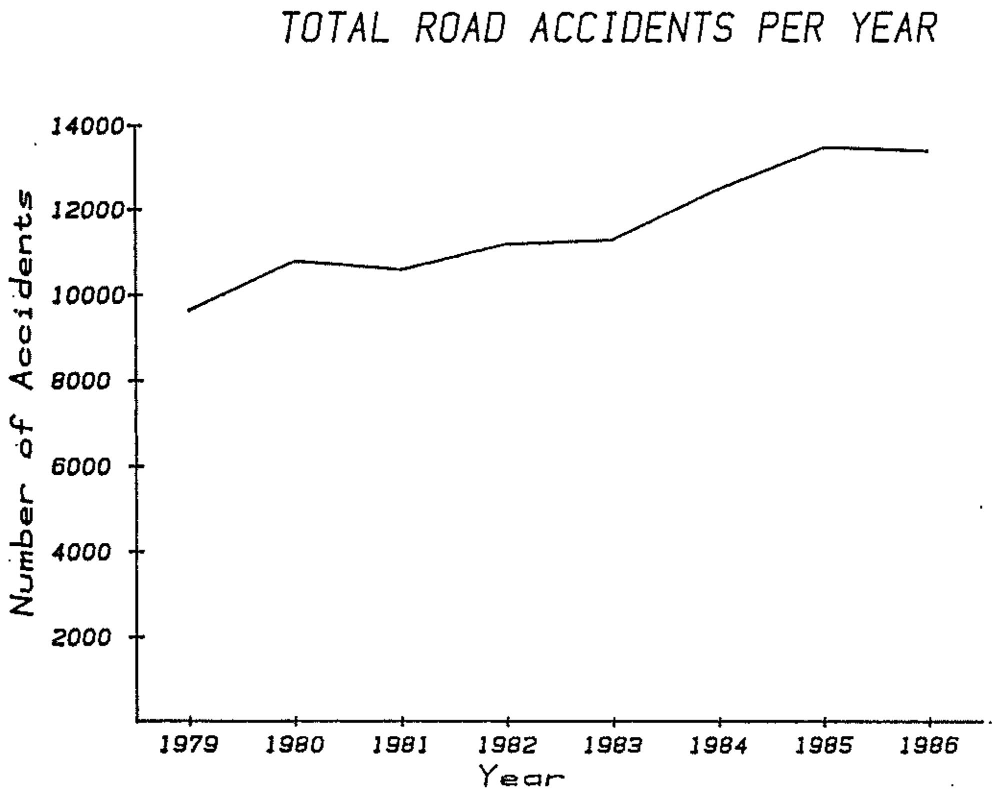

Figure 2. Total road accidents per year.

Nationally, night ratios appear to be stable but differences between areas in New Zealand could be expected because of local effects not related to lighting, e.g. the night and day usage of a city centre would be different from that of a dormitory suburb. This is one reason we look for differences from the local average rather than from the national average in the site surveys.

The national data therefore indicated that for site investigations, three accident categories are worthy of study by using their night ratios:

- All accidents.
- Single vehicle accidents.
- Pedestrian accidents.

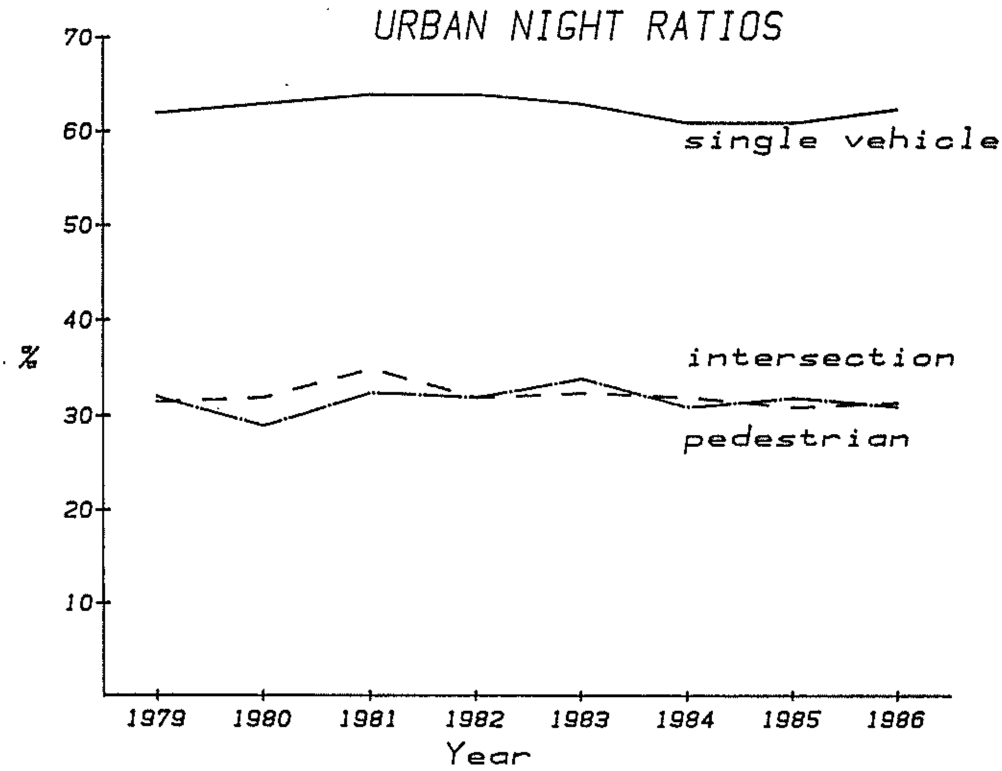

Figure 3. Night ratios for all reported urban traffic accidents for the three main categories.

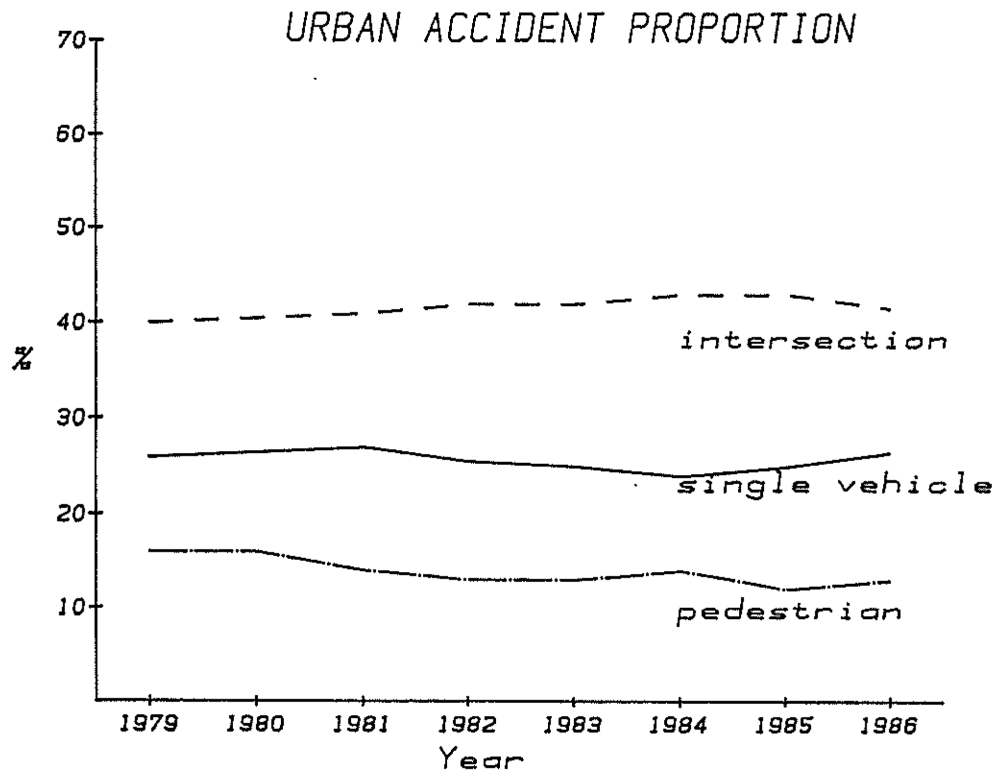

Figure 4. Proportion of all reported urban accidents occurring for the three main categories.

4. TRIALS IN WELLINGTON URBAN REGION

The resource available for this study is the MOT database of all reported traffic accidents for the years 1982 to 1986. (Note: the actual number of accidents is greater than that reported but in this report "accidents" refers to reported accidents.) A considerable amount of information is stored for each accident and the information can be sorted into a variety of categories using a personal computer. Of most use are the accident locations with map grid reference which can be found and readily plotted. The Wellington urban region is taken as an example to trial the method of investigating relationships of road accidents and lighting.

Note that in this study only **urban** roads are considered, i.e. roads with a speed limit of 50 km/h or less (MOT definition). Thus some important connecting roads for the Wellington region are omitted. In general, urban areas have road lighting installed everywhere whereas in other areas there may be neither lighting nor delineation provided. Therefore in urban areas a solution to an accident problem could involve improvements to the road lighting whereas in other areas the solution may involve other techniques, such as delineation. Such roads would need a separate study.

Eight different areas are controlled by local bodies in the Wellington urban region. Figure 5 shows their 1986 population (Department of Statistics 1988) and this can be compared with Figure 6 giving the number of reported accidents for the period 1982 to 1986. Eastbourne with a population of 4500 was not considered in this study because of its correspondingly low number of accidents, leaving seven areas for investigation.

The population figures in Figure 5 are taken from the local body data and hence the area designation is not always the same as the urban road network on which the accident data is based. The value given for Wainuiomata is actually that of the Hutt County population which is greater than that of the urban area of Wainuiomata. For Upper Hutt on the other hand, some areas of Hutt County are included in the accident data since they are part of the road network of Upper Hutt. More properly it is the traffic density which should be compared to accident rates. However the accident numbers can be seen to follow the population trend except in Petone through which passes nearly all the traffic between Wellington and the Hutt area.

The areas were treated separately regardless of their wide disparity in sizes because the policy on the road lighting for each local body will vary as also will the approach of the designers and installers.

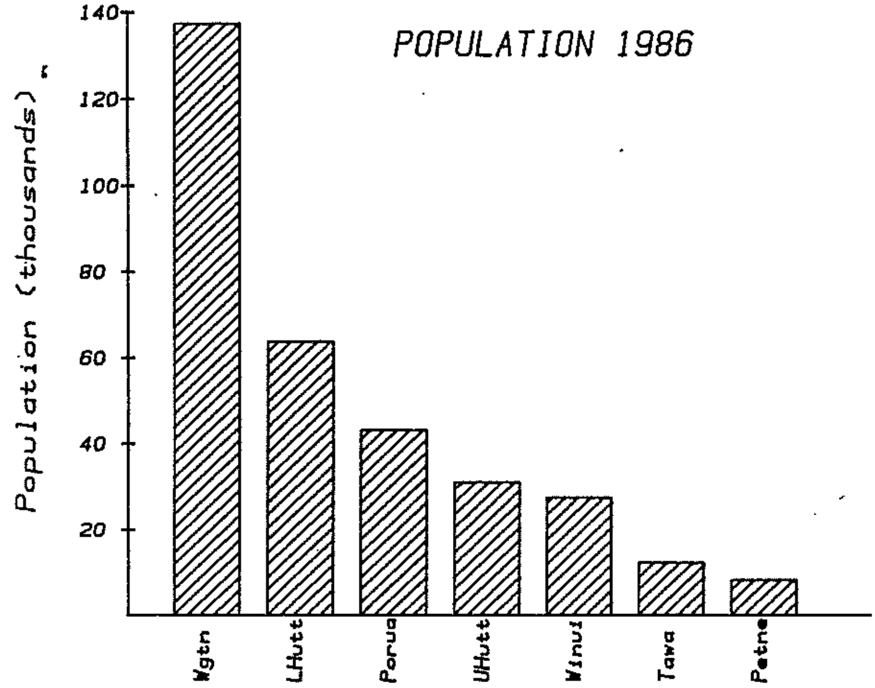

Figure 5. Urban area population from 1986 census.

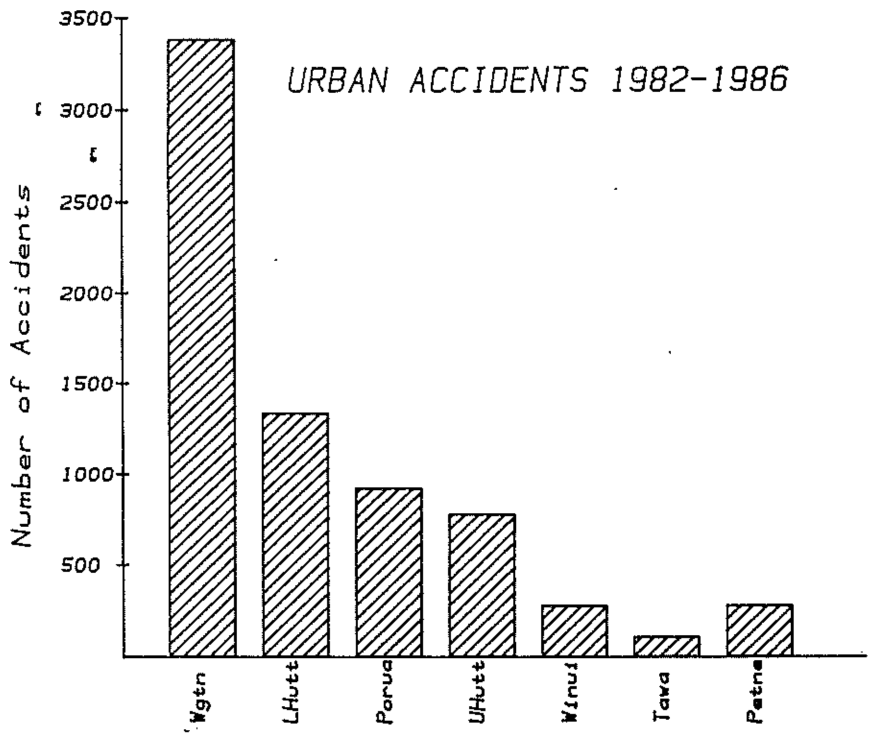

Figure 6. Number of recorded urban traffic accidents for the years 1982-1986.

Figures 7 to 9 summarise the night ratio data for the seven areas and the average values for New Zealand.

Figure 7 shows that the night ratios for all accidents are very similar throughout the region except for Wainuiomata. Overall the region has a slightly lower ration than the New Zealand average. The constancy shown is taken as an indicator that the night ration is generally insensitive to other traffic factors. The fact that a significant difference shows up warrants further investigation.

This constancy is again shown in the single vehicle accident data (Figure 8) with Wainuiomata again being the exception. While proportionally there are more single vehicle accidents in the district, the night ratios are lower than the national average.

Pedestrian accident data (Figure 9) however show no clear trends. For instance, Wellington with its high pedestrian night ratio has the highest proportion of pedestrian accidents, whereas Upper Hutt with the next higher night ratio has the second lowest proportion. The variations could be related to the road lighting which is known to have greater effect on pedestrian accidents.

The anomalous night ratios for Wainuiomata need further comment. The value comes not only from the high single vehicle ratio but also from a high night ratio, for all other accidents, of 42%. Note that the comparison made for the sites is with respect to the average for Wainuiomata. A comparison of the lighting throughout the area with another similar area would be of interest.

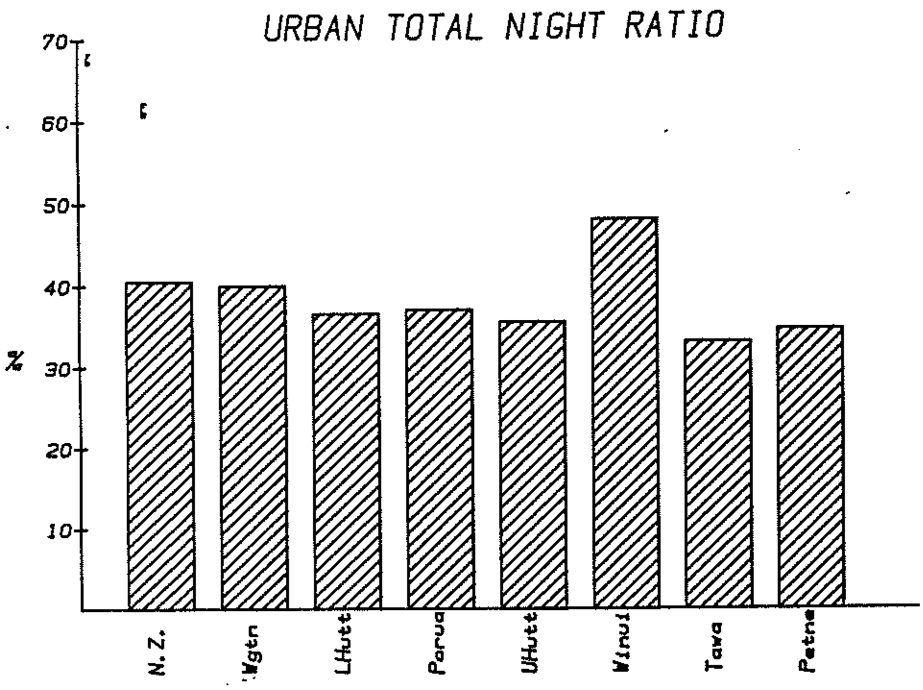

Figure 7. Calculated night ratios of all reported road accidents in various urban areas.

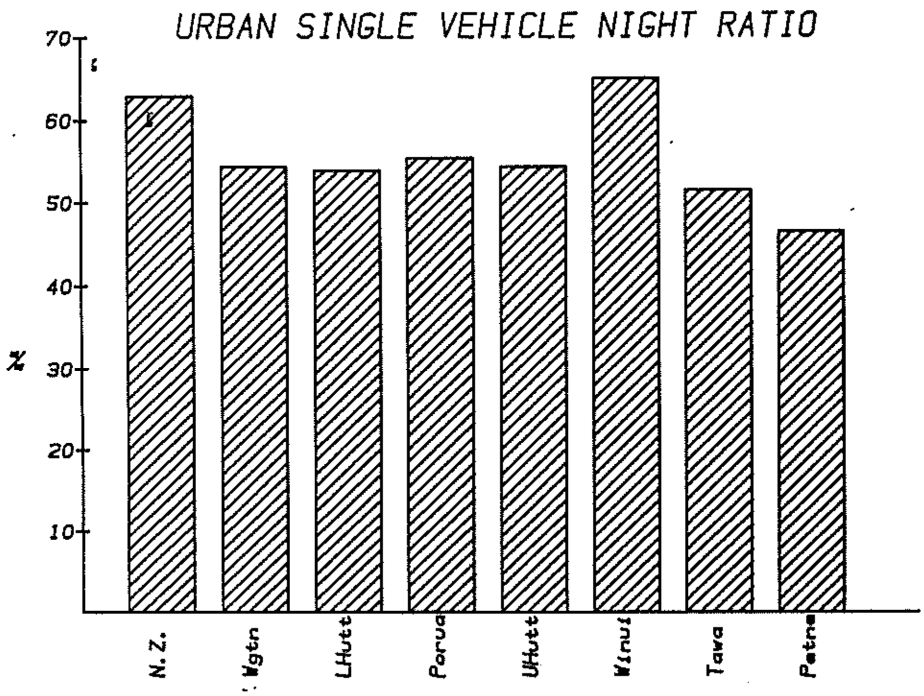

Figure 8. Calculated night ratios for reported single vehicle road accidents in various urban areas.

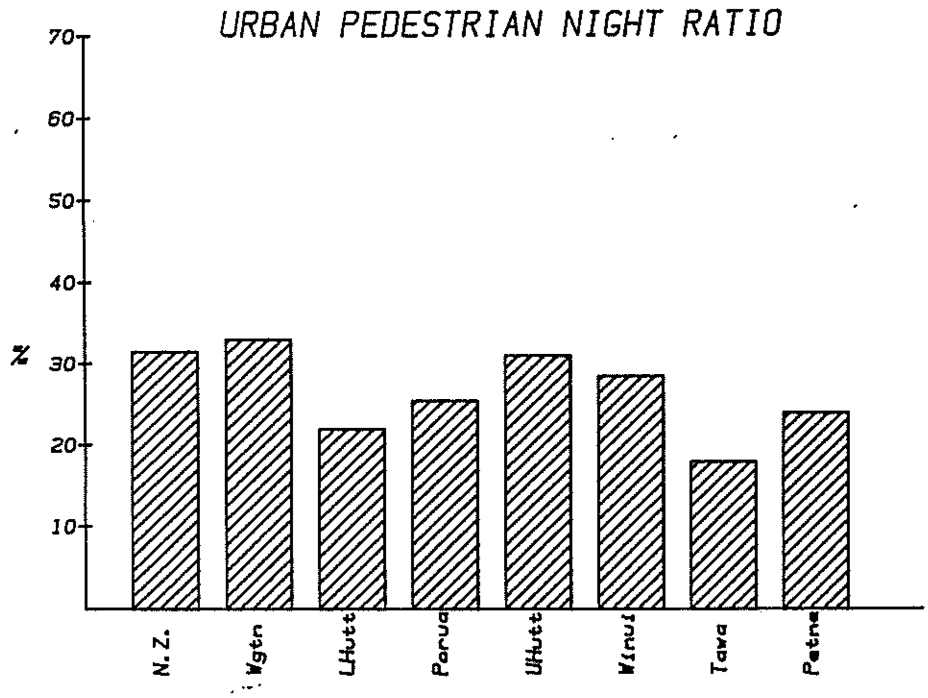

Figure 9. Calculated night ratios for reported pedestrian road accidents in various urban areas.

5. SITE IDENTIFICATION

For each of the seven areas a map of different accident types was plotted using the MOT computer and plotter. These plots helped identify sites (or more correctly, roads) for which more statistical data could be extracted from a full printout of all accident data. For each site the night ratios for all pedestrian and single vehicle accidents, as well as their relative proportions, were calculated. A statistical test was applied to determine the significance of the differences from the area average. Because low numbers were involved the level of significance will also be low in most cases. A single standard deviation was taken as significant.

With the pedestrian proportion of accidents being only 13%, the actual number of pedestrian accidents at any site is low. However since pedestrian accidents are considered more sensitive to lighting, the sites involving only a few night pedestrian accidents have been included in spite of a low statistical significance.

The MOT programme groups accidents into 70-m square grids referenced to the New Zealand Map Grid. This enables, for instance, all the accidents at or near an intersection to be collated and tested to determine if the night ratio exceeded a specified value. However this test does not work so well for accidents spread out along a length of road (as expected for pedestrian and single vehicle accidents), and therefore the plotted accident data was collated by hand.

Ninety-two sites were identified overall. The level of significance varies between sites because sites were included even if there was some doubt about the significance. Both high and low night ratios are included. The sites tend to be along main routes where there are sufficient numbers of recorded accidents to obtain any significance. There appears no obvious correlation between different accident types, e.g. many sites with a high night ratio for single vehicle accidents have a low ratio for pedestrian accidents.

In Tables 1 to 4 the night ratio is given as a percentage, with the number of accidents involved given in parenthesis. Note that the grouping of accidents for a site is in part arbitrary and assumes that the road lighting conditions are homogeneous.

A visual inspection at night was made of most of the identified sites to select sites suitable for a survey of the lighting. Only those sites selected or used in developing the measurement survey method are given in Tables 1 to 4. The original site numbers are given in the Tables.

6. MEASUREMENT PROBLEMS

Before the lighting at the selected accident site could be evaluated, several measurement problems needed to be overcome. This section and the next two sections outline how a very simple method has been developed.

The New Zealand Code of Practice for Road Lighting (SANZ 1983) specifies the lighting required for roads in terms of a method developed through the CIE (1976). Hence for any check on code compliance, the CIE measurement method should be followed. Quite detailed measurement methods are given by the CIE to arrive at the relevant performance values of average luminance, uniformity of luminance and glare. For example, the area under investigation is to be gridded into 100 points, and luminance measurements are made with a high resolution photometer, mounted at precise angles, for viewing the road. All this takes several hours to carry out. Experience using this method (Nicholas and Stevens 1982b) suggested simpler methods were possible that could give a reasonable evaluation of the existing lighting, especially when strict compliance with the Code is not sought.

Four main factors need consideration:

- **Number of Measurement Points**
  While the 100 points used in the CIE method (1976) gives good statistical data it is too many for a quick evaluation. Eight well-chosen points are sufficient for most applications as this is the minimum number needed to calculate an average and uniformity for the road luminance.

Table 1. Wellington:
% Night Ratios and Accident Numbers

Site No.	Site Locality	All Accidents	Pedestrian Accidents	Single Vehicle Accidents
-	Whole area	40 (3382)	33 (723	54 (933)
2	Riddiford Street	46 (92)	45 (31)	44 (9)
8	Kent Terrace	54 (59)	70 (30)	50 (8)
10	Cambridge Terrace	49 (49)	48 (23)	67 (3)
18	Lambton Quay	35 (55)	10 (30)	100 (4)
23	Karori Road	39 (44)	44 (9)	50 (6)
24	Tinakori Road	33 (46)	43 (14)	50 (4)

Table 2. Lower Hutt:
% Night Ratios and Accident Numbers

Site No.	Site Locality	All Accidents	Pedestrian Accidents	Single Vehicle Accidents
-	Whole area	36 (1337)	22 (169)	54 (423)
11	Daysh St and Fairway Drive	51 (47)	0 (1)	75 (12)
15	Waiwhetu Road	62 (39)	67 (9)	80 (5)
27	Knights Road	18 (17)	25 (4)	33 (3)
29	Cornwell Street	4 (24)	- (0)	0 (2)
30	Kings Crescent	9 (33)	0 (3)	50 (4)

Table 3. Upper Hutt:
% Night Ratios and Accident Numbers

Site No.	Site Locality	All Accidents	Pedestrian Accidents	Single Vehicle Accidents
-	Whole area	35 (776)	31 (94)	54 (234)
1	Fergusson Drive St Patrick's to Camp Street	41 (78)	30 (10)	73 (22)
2	Fergusson Drive Camp Street to Whakatiki Street	33 (132)	17 (18)	64 (25)
3	Fergusson Drive Whakatiki to Main	46 (57)	27 (15)	79 (14)
4	Fergusson Drive Main to Totara Park	41 (110)	40 (25)	77 (17)
5	Ararino Street / Miro Street	44 (34)	50 (6)	42 (12)

Table 4. Wainuiomata:
% Night Ratios and Accident Numbers

Site No.	Site Locality	All Accidents	Pedestrian Accidents	Single Vehicle Accidents
-	Whole area	48 (278)	29 (49)	65 (105)
1	Wellington Road	58 (33)	43 (7)	77 (13)
2	Fitzherbert Road	65 (20)	100 (4)	60 (5)
3	Hine Road	67 (9)	100 (2)	100 (2)
4	Wainuiomata Road	40 (40)	11 (9)	60 (10)
5	Wise Street	35 (20)	13 (8)	67 (3)

- **Field of View**
  The recommended field of view of 2′ x 20′ is only practical with a large (200 mm) objective on a photometer of the type used for research. A more practical hand-held one would have a field of view of 1/3° or 1°.

- **Observer Position**
  The small angle for the vertical field of view is needed because the observations are made at an angle of 1° to the road surface. The length along the road of the area under observation has to be short enough to determine the maximum or minimum luminances correctly. Some increase in the field of view angle is possible without degrading the measurement, e.g. if the luminance varies slowly with distance then the use of a larger area for the measurement would not greatly affect either the maximum, or minimum, values.

  A practical field-of-view angle would be 1/3° as suitable luminance meters with this field of view are now available. However, this angle means that the area viewed requires too long a length along the road and thus a good estimate of the peak luminance is not possible. To decrease the length required for the viewing area, a larger observation angle is required and this also implies a shorter viewing distance because the observation height is fixed by the eye height of the observer.

  As the reflection properties of the road surface will also change with observation angle their behaviour at these low angles needs to be known.

- **Glare**
  The calculation or measurement of glare is relatively complex. One solution is to use a qualitative evaluation of the glare. Several methods were investigated but they were discontinued and a quantitative measure, even if very approximate, was attempted. The method that was developed needs both illuminance and luminance meters. This requirement unfortunately adds to the cost and complexity of a field evaluation. However, as glare is one of the main differences expected between the old and new road lighting codes, an evaluation of glare in measurable terms, was important to obtain.

7. OBSERVER POSITION

The choice of the observer position will also influence the number of measurement points possible and the size of the field of view, as all three are interrelated by geometrical considerations. Therefore for a practical site they need to be considered together. Given below are the considerations for a test site, with the aim to help determine the suitability of available choices.

The CIE-recommended observer position is 60 m from the first lantern of interest, a 1° observation angle, and field of view of 2′x 20′. Therefore the maximum strip of road under observation is 3 m long by 0.6 m wide at the far lantern and about 1.5 m at the near lantern. The use of a simple photometer with a field of view of 1/3° means that the strip of road, 25 m long by 0.6 m wide, is unacceptably long. If an observation position is chosen of, say, 33 m (i.e. one lantern pole spacing away), then the observed strip would be 14 m long at the far lantern, and 3.5 m long at the near lantern, i.e. a range of observation angles from 1.72° to 2.5°. As the measurement need only be taken under the first lantern, and half way between two lanterns to obtain an average, then the strip under observation may be from 7 m to 3.5 m long. This is quite acceptable.

Measurements made on European road surfaces (Keitz 1955, Van Brommel and de Boer 1980) indicate that the reflection properties of the road surface do not change significantly for observation angles from 0.5° to 2.5°. Thus, providing New Zealand road surfaces behave similarly, a 2° observation angle should be possible. New Zealand road surfaces, while very similar to European ones (Nicholas and Stevens 1982a), do show some differences and therefore a practical test was made on one road lighting installation. The area chosen was a section of Gracefield Road, Lower Hutt, in front of the Physics and Engineering Laboratory (Figures 10 and 11). Besides being conveniently located, the area had a chip seal surface in good condition and a recently installed lighting scheme. The reference photometer (Pritchard model 1970) could be mounted and used with mains electricity without any interference from traffic.

Table 5 summarises the main features of the site chosen. This and subsequent tables will repay careful study by the reader to obtain an understanding of the measurement method finally adopted. Table 6 gives the measurements made with the reference photometer for a 20-point grid. The change from Position 1 to Position 2, corresponding to a change in the observation angle from 1° to 2°, produced no effective change in the measured luminance properties. The small differences most likely arise from the difficulty of aligning the very small aperture on to the same part of the road surface when repeating readings. The luminance of the road surface can vary because of occurrence of road polish, debris on the road, oil spills etc. Table 7 gives the measured results for the field photometer, a Minolta model LS110 (Appendix 1 lists factors in its selection). Because of its larger field-of-view, measurements from Position 1 were not possible. Even at Position 2, a 20-point grid could not be covered and, to obtain an average, the middle row in Table 7 was doubled to allow a comparison with the other results. At Position 3, 20 points could be measured but the observation angle varied from 2° to 6° in order to cover the measurement area. Even so, a very good agreement with the other results was found. There is no significant difference between the average luminance values, i.e. the 3% could be accounted for entirely from the instrument calibration and from the scale reading errors. The differences in the overall uniformity however are significant and in the direction expected. A systematic error is unavoidable when larger apertures are used since they cause the luminance reading to be averaged over a greater road area. Thus the "highs" will not be so high and conversely the "lows" not so low, with the result that the measured overall uniformity will be greater than it really is.

Table 5. Gracefield Road Site Description.

Observation Date	7 December 1988
Site Description	• Road in front of DSIR Physical Sciences, Lower Hutt. The road includes a parking bay as shown in Fig. 10 and measurements were taken over the half of the road which included the parking area. • The road surface had a recent chip seal and was in good order. A new lighting installation was mounted to the power poles. High pressure sodium lamps in a reflector fitting were used for the lighting.
Site Geometry	• The arrangement was single sided. • The calculated lantern mounting height = 6.7 m • The measured lantern column spacing = 33 m. • The effective road width = 10 m.
Measurement Positions	• Observer height was 1.5 m or eye level. • Position 1 was 60 m from the first lantern. • Position 2 was 33 m from the first lantern. • Position 3 was 15 m from the first lantern and was used for glare observations.

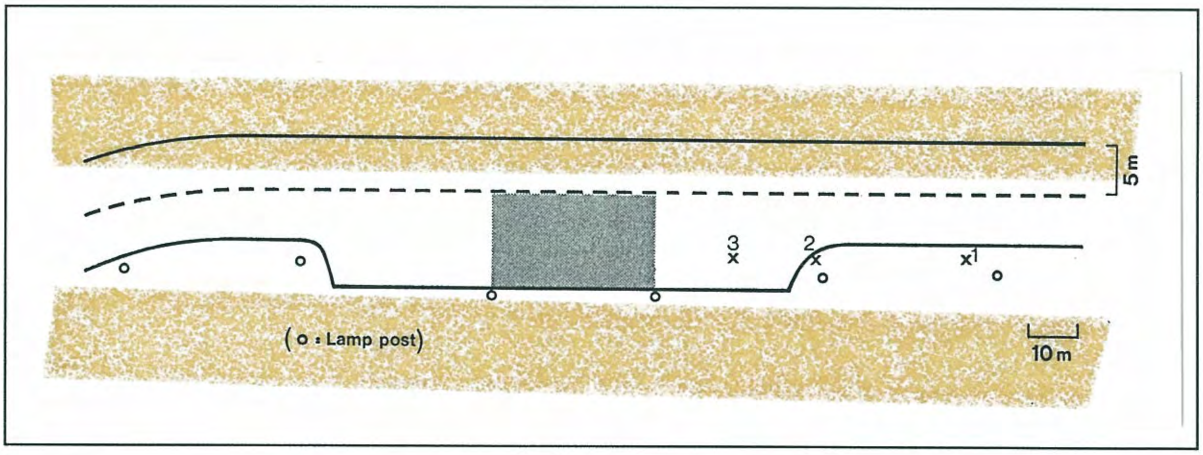

Figure 10. Plan of Test Site Area (see Table 5 for description).

Figure 11. Test Site — Gracefield Road, Lower Hutt
$\bar{L}$ = 0.34 cd/m^2, U_0 = 0.59, TI = 12%

Table 6. Reference Photometer Readings, Gracefield Road Site.

Position 1			(Road luminance values in cd/m²)		
	Kerb				Middle
Far	0.44	0.47	0.47	0.36	0.29
	0.32	0.32	0.32	0.23	0.20
	0.32	0.35	0.29	0.23	0.20
Near	0.50	0.47	0.41	0.36	0.32
Average 0.34 cd/m²			Overall uniformity 0.59		
Position 2					
	Kerb				Middle
Far	0.44	0.47	0.41	0.35	0.31
	0.29	0.31	0.29	0.25	0.20
	0.29	0.32	0.29	0.22	0.20
Near	0.53	0.50	0.48	0.42	0.32
Average 0.34 cd/m²			Overall uniformity 0.59		

Table 7. Field Photometer Readings, Gracefield Road Site.

Position 2			(Road luminance values in cd/m²)		
	Kerb				Middle
Far	0.38	0.41	0.37	0.30	0.28
	0.26	0.29	0.30	0.27	0.22
Near	0.44	0.49	0.47	0.41	0.30
Average 0.33 cd/m²			Overall uniformity 0.67		
Position 3					
	Kerb				Middle
Far	0.45	0.45	0.37	0.29	0.29
	0.25	0.28	0.29	0.26	0.20
	0.25	0.31	0.29	0.26	0.21
Near	0.45	0.50	0.45	0.40	0.30
Average 0.33 cd/m²			Overall uniformity 0.61		

The results clearly indicate that for a rapid site evaluation, measurements can be made at 33 m observation distance, i.e. at approximately 2° observation angle and with a 1/3° field of view. A choice of a grid of eight points can be used rather than 20, providing four are taken along the brightest, and four along the darkest strips across the road (e.g. normally under the first lantern and halfway between lanterns respectively). These are readily identified either by eye or by taking a rapid scan with the photometer over the area.

8. GLARE

The evaluation of the average luminance and uniformity requires no other facility than the portable photometer. Any distances involved are not critical and can be paced out by the observer if needed. However, for a quantitative measure of glare, more accurate dimensional measurements are needed. Basically the distance and height of each light source contributing to the glare need to be known as well as the intensity of the light source. Appendix 2 gives a more detailed analysis of the method. Note that glare observed by a driver is not constant as the vehicle moves along the road and the CIE method evaluates glare for one observer position where maximum glare is expected.

The largest glare contribution is from the first lantern in front of the observer (Table 8) and therefore the distance to it and its height need to be measured. The distance can be measured with a 50 m tape measure. The distances to subsequent lanterns further down the road are not so important and can be estimated by a trained observer.

An assessment of the height of the lantern above the road surface will generally involve an angle measurement for which Appendix 3 outlines two simple methods. The observer position for glare measurement is determined by an angle, and the observer position is not the same as the observer position for the luminance measurements. An angle of 19° above the horizontal is required for the line of sight from eye level to the lantern.

Ideally the luminance meter could be readily adapted to measure the lantern intensities (or more properly the illuminance produced by each lantern on the vertical plane at eye level). To do this, the lantern when viewed must have a smaller angular size than the field of view of the luminance meter. Unfortunately since a 1/3° photometer is required for luminance measurements, the field of view is not large enough to cover the first lantern but is adequate for the subsequent lanterns. A variable aperture photometer would have been desirable but this feature was not found on any small photometer.

In practice, the vertical illuminance of the first lantern can be measured directly in lux using an illuminance meter. Illuminance meters are more generally available and cheaper than luminance meters. The lighting levels in lux are the traditional way of specifying the lighting and the values are still of interest to a designer. In particular, a check on the maintenance levels of the lanterns can be easily made with an illuminance meter.

Therefore four measuring devices are required for glare but with practice the measurements can be carried out quickly. The results can be processed using a computer program outlined in Appendix 4. The results of the various stages of the calculation of glare are listed in Table 8 from which the relative importance of the various lanterns can be assessed.

9. SITE MEASUREMENT PROCEDURE

All the basic requirements for a site measurement are given in the Site and Road Lighting Check Sheet of Appendix 5. Observers should check that the information they require for their particular site measurement is included. If it is not, add appropriate statements. The various stages that have to be considered are outlined below.

Before going on site, collect the following equipment: a luminance meter (Minolta LS110 preferred), an illuminance meter, a tape measure and an instrument to measure angles (Appendix 3).

On site, the lantern of interest is selected. If accident data are for one place then the choice is obvious. However, if accidents have been recorded along a length of road, then one typical lantern is chosen, usually based on its convenience for measurement. In either case the illuminance from the lantern should be compared with its neighbours to check that it is typical.

- **Site Identity**
  Record sufficient information to identify the site, the time and date of the measurements. Any reference to relevant accident information should also be included.

- **Site Description**
  The type of lighting used and its age is of interest but not essential. General layout is of more importance. Other roading factors could contribute to the accident rate at the site and the observer's experience should be used in recording these factors:

  - Is the road straight?
  - What surrounds the road site; how close are houses, trees, walls, shops, etc?
  - Are there humps or dips in the road which would block out or increase the glare from car headlamps?
  - What form of traffic control is used, lights, markings, etc?
  - Is the delineation of the road provided by the lanterns misleading or absent?
  - Any other relevant factor, e.g. near hotel, hospital, theatre, etc?

Table 8. Glare Calculations, Gracefield Road Site.

Lantern Number	Intensity cd/m^2	Illumination lux vertical	Veiling luminance	Angle
1	—	2.78	0.070	20.0°
2	1600	0.043	0.008	7.5°
3	144	0.004	0.002	4.9°
4	78	0.002	0.001	3.8°
5	21	0.001	0.000	3.1°
• Total veiling glare is 0.81 cd/m^2 • Threshold increment is 12% • Observations made with a lux meter and 1/3° luminance meter				

- **Site Geometry**
  Road layout is used in glare calculations and therefore should be given as accurately as permitted by the road geometry itself. Because existing poles are used for mounting lanterns it is often difficult to determine if the overall geometry is staggered or opposite. Even a single-sided arrangement can appear as a double-sided arrangement, for example where extra lighting is provided at intersections. Good estimates of the road width and spacings are sufficient unless accurate detail is required for other purposes.

- **Spot Luminance**
  If the peak luminance under a lantern is below 0.5 cd/m^2 then the lighting does not qualify as road lighting but rather as pedestrian lighting. Therefore it need not be measured.

- **Luminance Readings**
  If possible take luminance measurements from the parking lane using a parked car for protection from traffic. The readings should be made at a distance of 33 m or one pole spacing back from the lantern of interest. To help avoid flare go forward, i.e. with your back to the lantern, if the observation position is close to a lantern. Locate the brightest strip across the road, usually starting from underneath the selected lantern, and measure four points evenly spaced across the road. Repeat for the darkest strip past the selected lantern, which will usually be midway between selected lanterns. Note that for a very wide road it may be better to measure only one side at a time especially if there is a median strip containing bushes or barriers.

- **Glare Measurement**
  Use the angle measuring instrument to determine the glare observation position and then measure the distance of the observation position from the first lantern. Note if the angle was determined at ground level or at eye level. Hold the illuminance meter vertically at eye level, facing the lantern, and then take a measurement. Now shade the meter from direct rays from the lantern (e.g. by holding a card, no greater than A4 size, at arm's length) and take the background reading. The luminance meter is then used to sight on to the next four lanterns (or more if the lighting arrangement is double sided). The lantern should lie totally inside the field of view of the meter, and either a steady hand is needed or a tripod.

  Readings are taken in cd/m^2 to be entered later into a computer program with the illuminance results to calculate the glare. (In Table 8 typical values measured are given as are their conversions to lux in the vertical plane.)

- **Illuminance Measurement**
  Check the maximum illuminance under the selected lantern as well as at the position of minimum illuminance. As a rule of thumb the maximum should be at least 20 lux and the minimum 3 lux if the Code of Practice is to be met.

10. SITE SURVEYS

To develop the survey method all the sites identified in Wainuiomata were visited as well as several sites in Lower Hutt and Petone. Because these were preliminary investigations in the development of a Site and Road Survey Check Sheet (Appendix 5), the information gathered was not as detailed as those of sites that were more fully investigated in Upper Hutt and Wellington. In all, over 25 sites were visited and some site data collected. A photographic record was made of 20 of the sites (exposure 4 sec at f4 for 200 ASA colour negative film). The photographs (Figure 12) show the overall sites and do not detail the part of the road measured, though that part is included. Also, within the limits of the photographic process, they show the relative lighting levels.

The sites chosen show a wide variety of characteristics and with the very limited number investigated no statistical inference can be made at all. Therefore in the summary of results, the emphasis is put on the lighting characteristics and not on the accidents. Any comments made should be treated as just that – "comments".

However, they should help accident-site investigators to look for features that may contribute to accidents. Other relevant traffic data have not been collected, such as traffic densities, even though assessment of the adequacy of the lighting is relative to the amount of night use of the area.

In Figure 12 the captions summarise the lighting results in terms of the three CIE parameters required by the New Zealand Road Lighting Code (SANZ 1983), namely average luminance, overall uniformity and threshold increment. (Table 9 lists the expected requirements.) Other details are omitted as not being relevant or, as noted in Appendix 2, only approximate values need to be known and used in the calculation of the lighting parameters, e.g. the spacing between lanterns. Some general information can be obtained from the photographs (Figure 12). (The reader can obtain a better idea of how the road appears at night by viewing the photographs through a tube approximately 15 mm diameter, such as obtained by rolling up a piece of paper.)

Wainuiomata
Wainuiomata Road
$\bar{L}$=0.43 cd/m², U_o=0.44, TI=23%
Site No. 4

Wainuiomata
Fitzherbert Road
$\bar{L}$=0.27 cm/m², U_o=0.26, TI=40%
Site No. 2

Wainuiomata
Main Road
$\bar{L}$=0.19 cm/m², U^o=0.36, TI=37%

Wainuiomata
intersection Main Road
L^{max}=0.2 cd/m²
Site No.3

Figure 12a. Site Survey Summary.

Wainuiomata
Wellington Road
$L_{max} = 0.53$ cd/m²
Site No. 1

Wainuiomata
Wise Street
L_{max} <0.5 cm/m²
Site No.5

Upper Hutt, Fergusson Drive
Bridge to St Patrick's
$\bar{L} = 0.54$ cm/m², $U_o = 0.48$, TI=40%

Upper Hutt, Fergusson Drive
St Patrick's to Camp Street
$\bar{L} = 0.57$ cd/m², $U_o = 0.39$, TI=16%
Site No. 1

Figure 12b. Site Survey Summary.

Upper Hutt, Fergusson Drive
Camp St to Whakatiki St
$L=0.23$ cd/m², $U_o=0.34$, TI=34%
Site No. 2

Upper Hutt, Fergusson Drive
Whakatiki St to Main St
$L=0.55$ cm/m², $U_o=0.36$, TI=21%
Site No.3

Upper Hutt, Fergusson Drive
Main St to Totara Park
$L_{max}=0.36$ cm/m²

Upper Hutt
Ararino Street
$L_{max}=0.13$ cd/m²
Site No.5

Figure 12c. Site Survey Summary.

Wellington
Lambton Quay
$\bar{L}=1.27$ cd/m^2, $U_o=0.66$, TI=15%
Site No. 18

Wellington
Tinakori Road
$\bar{L}=0.41$ cm/m^2, $U_o=0.51$, TI=26%
Site No. 24

Wellington
Karori Road
$\bar{L}=0.41$ cm/m^2, $U_o=0.28$, TI=11%
Site No. 23

Wellington
Riddiford Street
$\bar{L}=1.30$ cd/m^2, $U_o=0.27$, TI=6%
Site No. 2

Figure 12d. Site Survey Summary.

Wellington
Cambridge Terrace
$L_{max}=0.32$ cd/m^2
Site No.10

Lower Hutt
Knights Road
$L_{max}=0.26$ cm/m^2
Site No. 27

Lower Hutt
Cornwall Street
$\bar{L}=0.60$ cm/m^2, $U_o=0.59$
Site No. 29

Lower Hutt
Kings Crescent
$L_{max}=0.23$ cd/m^2
Site No. 30

Figure 12e. Site Survey Summary.

Table 9. Performance Value Limits.

Lighting Parameter	Main Road	Intermediate Road
minimum $\bar{L}$	0.75 cd/m^2	0.50 cd/m^2
minimum U_o	0.35	0.25
maximum TI	20%	20%

L — average luminance
U_o — overall uniformity
TI — threshold increment caused by glare

NB: Minor roads have no specified values for the lighting parameters

Many of the sites had old lighting installations and hence the lighting values obtained will be representative of the end life of the installation and the performance therefore depends on the maintenance the lamps and lanterns had received, e.g. many lanterns were very dirty, with some lanterns giving only half the light output of their neighbours. The repeatability of the measurements has not been tested but all readings were made in dry conditions. Wet or damp roads would give different values.

A wide range of sites was evaluated in the time available for this project. Even so the sites do not adequately cover all types of road lighting as most sites did not meet the road lighting code values for Main or Intermediate Roads (Table 9).

10.1 Wainuiomata

All the identified sites (Table 4) were surveyed as well as Main Street because it records an accident pattern that is the average for Wainuiomata. Because Wainuiomata has a significantly higher night accident ratio than other areas in Wellington urban region, the sites were chosen to cover all the major road lighting installations in Wainuiomata (Figures 12a and 12b). Wainuiomata is (an almost) self-contained with access to and from it by Wainuiomata Road only.

Wainuiomata Road is separated into two parts by median strips and islands. Lighting measurements were made on one half only of this two-way road. The road surface was very worn and showed polish. The lighting is typical of a road that was installed to the 1963 road lighting code (SANZ 1963). The lower luminance values are most probably because old lamps are still in use. The glare values are also typical (i.e. threshold increments of around 25%) of installations of that pre-1983 period. The pedestrian night accident ratio is very low on this road.

Fitzherbert Road adjoins Wainuiomata Road and has a high overall night accident ratio and also a high number of pedestrian night accidents. The lighting level is almost half that of Wainuiomata Road and the glare has doubled. The luminance uniformity is somewhat lower than Wainuiomata Road, but is within the criteria required for an Intermediate Road. The far end of Fitzherbert Road ends in a major T-junction which is not well delineated by the lanterns at night.

Main Street has an even lower lighting level and there was considerable variation from lantern to lantern caused by age and dirt. The uniformity was good but the glare was high. A bend and a major intersection in this road were not well delineated by the lanterns.

For the above three roads the lighting values should have been those for Intermediate or Main Roads. However, the lighting did not meet the current code values for such roads. Wellington Road, Hine Road and Wise Street were obviously treated as Minor Roads but because they serve as main feeder roads to the area around them, they could be considered for reclassification as Intermediate Roads.

Both Wellington Road and Hine Road showed higher than average night accident ratios in all investigated accident categories. The lighting level was very low and though both are winding roads the lanterns did not delineate the run of the road. The photograph for Hine Road (Figure 12a), however, shows the intersection which has a high night accident ratio. Dips in Wellington Road cause car lights to disappear making it difficult to determine what other traffic was on the road, even in its straighter stretches. Wise Street, in contrast, had lower than average overall and pedestrian night accident ratios, possibly caused by the lanterns on this straight road delineating the run of the road. Even the location of the hump in the road could be seen.

None of the above lighting comes up to the performance requirements for an Intermediate Road, even if based on luminance values alone. The sites are therefore classified as Minor Road lighting, i.e. it is installed for the benefit of pedestrians and not motorists. This could be a main factor contributing to Wainuiomata having a significantly higher night accident ratio than other areas in the region.

10.2 Upper Hutt

All the Upper Hutt sites were surveyed (Table 3). The site designations were somewhat arbitrary in that Fergusson Drive was split into several parts at points where this long road changes direction (Figures 12b and 12c). Fergusson Drive has a high single vehicle night accident ratio, and its pedestrian night accident ratio ranges from high to low along its length. To a casual observer the lighting scheme appears to be the same along its length in that it is all low pressure sodium lighting. However, a significant variation in the lighting parameters occurs for different parts of the road. For instance the stretch from St Patrick's College to Camp Street and that from Whakatiki Street to Main Street both have a low glare rating and would comply with Intermediate Road standard, whereas the others have high glare ratings. The stretch from Camp Street to Whakatiki Street has low luminance as does that from Main Street to Totara Park which had such a low luminance that it did not warrant a measurement survey. Both meet only the Minor Road lighting standard.

The other site was Miro Street and Ararino Street combined, as they are feeder roads with a bend separating them. They had a high pedestrian night accident ratio. The lighting was low and clearly that of Minor Road standard. The lanterns delineated the run of the road and as well retro-reflectors were used to indicate the rather sharp bend.

10.3 Wellington

Unlike the sites in Upper Hutt and Wainuiomata, the Wellington sites do not have a close relationship (Figures 12d and 12e). Also the lighting in many areas has been recently upgraded to the current code so it is not possible to relate this lighting to the accident data which go back five years.

Lambton Quay is a good example of Main Road lighting with a high luminance and uniformity to overcome all the extraneous lighting associated with a main shopping centre. The accident data indicate a low pedestrian night accident ratio but a high single vehicle ratio.

Tinakori Road, which is a feeder road to the Wellington motorway, has a slightly lower overall night accident ratio but a higher pedestrian one. The lighting is typical of the earlier road lighting code. Some of the low pressure sodium lighting had been replaced by high pressure sodium lighting.

Karori Road showed a slightly higher pedestrian night accident ratio. The lighting met the Intermediate Road performance standard. The shopping centre in Karori Road has a higher lighting level.

Riddiford Street has had a new lighting scheme installed and therefore the accident data (Table 1) are not relevant, though a comparison of the night accident ratios before and after will be of interest. The lighting performance values met that for an Intermediate Road and had high luminance values. Some of the other identified sites in Wellington City also had recently installed lighting.

Cambridge Terrace and Kent Terrace are considered together as they are two one-way roads separated by wide medians and islands and both are main traffic routes. The night accident ratios were high in most of the investigated accident categories. The lighting level was not high enough to warrant a survey, being that for Minor Roads. It is not known if the low lighting level is caused by old mercury vapour lamps or inherent in the design. Some mercury lamps had been replaced by high pressure sodium lamps. In many locations the lighting from adjacent commercial premises gave a high contribution to the road luminance.

10.4 Lower Hutt

The sites in Lower Hutt were visited to develop the survey method but were not revisited after the survey method had been developed. As a result complete lighting data have not been collected for any Lower Hutt site (Figure 12e). However, some comments can be made.

Three interconnecting roads with a very low night accident ratio are Knights Road, Cornwall Street and Kings Crescent. They are all Minor Roads according to the lighting code except that lighting of a part of Cornwall Street has been recently upgraded to Intermediate Road standard. The low night accident ratio is most probably because the commercial area they serve is not busy at night.

The following two sites have had only a few spot luminance readings made and no glare evaluations or photographic records have been made.

Waiwhetu Road has a high night accident ratio with a high number of accidents and is one of the worst accident sites identified. While the road had extra lighting provided by a double lighting scheme it still has only Minor Road lighting. The delineation of the road by the lanterns was confusing in that on one side the lanterns followed the parking lane while on the other side the lanterns followed the footpath and trees hid some lanterns. At one end the lanterns did not help to indicate a narrowing of the road. Some of the mercury vapour lamps had been replaced by high pressure sodium lamps.

Daysh Street and Fairway Drive are part of a major route across the Hutt Valley to connect to State Highway 2. The overall night accident ratio is high but there are virtually no night pedestrian accidents. The lighting level and uniformity would easily meet the standards for a Main Road although the glare has not been measured. Route guidance from the lanterns is confused where these roads change direction.

11. DISCUSSION

The method outlined here for conducting a lighting survey is convenient and will give a good evaluation of the average luminance and overall uniformity in terms of the CIE method (1976). A measurement indicator of the glare is also given but its accuracy in terms of the CIE method needs evaluation. Some further simplification of the glare measurement method may be possible. For most of the roads considered, the first illuminance reading for the glare would have given an adequate description of the glare. However, the more detailed method is more appropriate to assess Main Road lighting and, as only one example of Main Road lighting was measured, it was not possible to determine if the glare measurements could be significantly shortened.

The amount of equipment required is greater than that originally anticipated, mainly because of the method of glare evaluation. However, a site evaluation can be made in under half an hour if the traffic density is not great. Because traffic headlights upset the lighting pattern, obtaining a photographic record often took the longest time.

A main feature of the sites visited was that the lighting would not meet the new code values at sites which should have been classed either as Main Road or Intermediate Road. A feature of the new code was the Intermediate Road category which was based on the minimum lighting that would be useful to a driver. Any lighting level lower than this category can be considered as footpath lighting only in that it helps only pedestrians to see where they are going but may not allow drivers to see the pedestrians.

The maintenance of the lighting installations could be a major factor contributing to the lower lighting levels recorded. This is typical of a maintenance programme where lamps were only replaced on failure. Unfortunately discharge lamps can continue operating for a long time producing only a small fraction of their original light output and still consume a similar wattage. Dirty lanterns would lower the value even more.

High values of glare were found for many of the low pressure sodium lighting installations. This was found in a previous investigation (CIE 1976) that the cause arises from two factors. The first is simply that most of the lanterns were not designed to have a tight glare control (i.e. only moderate cut-off was required) and the threshold increment was typically 25%. The other factor is that installed lanterns do not meet the glare control of their design specification with the consequence that the threshold increment was over 40%, i.e. no glare control at all.

No relationship to accidents could be established because of the very small sample size. The sample size was made even smaller because many of the sites no longer had their original lighting. It may well be that the lighting had been upgraded because the lighting authority had become aware of the higher accident rate. Also the road usage for some sites will have changed, e.g. Upper Hutt now has a bypass road which has reduced traffic density on Fergusson Drive. However, by using the methods to identify accident sites combined with light measurement methods, the road authority can easily identify where lighting upgrades will give the best cost benefit. The relationship of lighting and accidents is difficult to establish and the experience of this study is that a sufficient number of sites cannot be found that are not affected by other factors. The best way is for the road authority to keep records of lighting, road changes, traffic densities, in some convenient form for analysis, e.g. a computer database.

12. CONCLUSION

The two main aims of this study have been achieved as follows:

- A meaningful method of evaluating lighting for accident investigations that is capable of uniform application has been developed.

- A lighting authority can combine the accident investigation method with the lighting evaluation to obtain an indication of the cost benefit of upgrading the lighting.

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APPENDIX 1
Field Photometer Selection

The availability of a suitable hand-held photometer is essential. Therefore the important factors in the selection of a field photometer are outlined below and how they are met by the Minolta model LS110.

- **Portability**
  A hand-held instrument operated from its own internal battery is desirable. Also the model should be relatively rugged. The LS110 meets these requirements and is a second generation portable instrument.

- **Aperture**
  This must be at most 1/3°. The most common aperture for a small photometer has traditionally been 1° but recently the 1/3° aperture has become more available. The LS110 has a 1/3° aperture.

- **Sensitivity**
  As the peak luminance for a road surface is around 1 cd/m^2 the photometer should be capable of measuring this with, say, a 2-digit resolution. The LS110 was the only smaller photometer found with this sensitivity which allows the luminance to be read to a 0.01 cd/m^2 resolution.

- **Flare**
  At night the luminance values of the road surface are low and have to be measured in the presence of many bright light sources. Measurement errors can easily arise from light scattered within the optics of the instrument.

  The worse effects of flare can be avoided by ensuring that the lens has an adequate lens hood to prevent light from unwanted light sources directly reaching the lens, and that the optical design is made for minimum flare. In both respects the LS110 was adequate. The built-on lens hood was grooved to decrease reflections and the manufacturer claimed that a low flare design was used. In practice the photometer had to be pointed within 1° of a light source before any flare was noticeable.

APPENDIX 2
Glare Evaluation

The disability glare depends on the equivalent veiling luminance, given by

$$L_v = \Sigma\ 10\ E_v/\theta^2$$

where the sum is over all light sources,
E_v is the vertical illumination in lux at eye level, and
θ is the angle in degrees between the line of sight to the area under observation and the line of sight to the light source.

For the CIE method (1976) the line of sight to the road surface is 1°, and the observer position is when $\theta = 20°$ for the first lantern, i.e. the line of sight to the lantern is 19° above the horizontal, at eye level. Note that this observer position is not the same for the luminance measurements.

To use the equation, both E_v and θ of each lantern are needed and this would involve considerable effort to achieve accuracy. However, here a simplified approach to the problem is made using Table 8 to assess where errors could make significant differences. The first simplification is to use a computer program to make the calculations. A program is given in Appendix 4 and the other simplifications are in the procedures for measuring the angles and the illuminances.

90% of the glare often comes from the first lantern, and while this high percentage does arise from the particular lighting installation investigated, it is true in general that the first lantern contributes the most, probably over 80%, glare. The most important exception will be in an opposite arrangement of lanterns where the lantern on the other side of the road gives a contribution of similar magnitude. Thus the accuracy requirements for glare measurements of all lanterns beyond the first are not great. For example the observer need only estimate the distance between lanterns to enable the angles to be calculated sufficiently accurately. As a consequence the computer program gives two default values for the spacing, 33 m and 66 m, which are sufficient for most installations. Of course, if more detailed plans of the installation are readily available to the observer, then the actual spacings can be entered.

Measurement of the illuminances from lanterns beyond the first can be simplified. Because the illuminances are small they cannot be measured directly with a lux meter, and instead a measure is made of the effective luminance, L_c, of the lantern by sighting the lantern with the luminance meter and ensuring the image of the entire lantern is inside the field of view. This, in effect, measures an average luminance over 1/3° field of view. The illuminance, E, at the meter due to the lantern is then:

$$E = L_e w,$$

where w is the solid angle corresponding to the field of view.

The manufacturer's data can be used for the solid angle and so for 1/3°, $w = 2.66 \times 10^{-5}$ steradians. Also since the angles are small, ut $E_v = E$. All these calculations are made by the computer program.

For the first lantern more care is needed and also for the opposite lantern in an opposite arrangement. The glare observation angle needs to be determined to within 1° for a 10% accuracy and, while it should be 20°, a value between 17° and 23° would be acceptable for most installations. (This assumes the lanterns do not have an extremely sharp cut-off at these angles.) This distance to the lantern from the observer position should be measured more accurately than ± 0.5 m as this distance is used to obtain the mounting height of the lantern (see Appendix 3).

The illuminance should be measured by holding the lux meter vertically at eye level and facing directly along the road towards the lantern of interest. Care should be taken to ensure the observer does not block the meter and a meter with a "hold" facility or detachable scale is useful here. The reading obtained is the total light, including that scattered from the road and from other lights. A second reading is then taken in which the direct light from the lantern of interest is blocked from reaching the meter. This can be achieved by holding a card at arm's length so that shadow covers the detector area of the meter. The difference in the two readings will give the direct vertical illuminance from the lantern. Note that ideally the card should be of a neutral colour, e.g. the same grey as the road surface. Avoid white or black materials.

In principle the glare for the opposite lantern can be measured in a similar way but in practice the effective luminance method can be used. Opposite lighting arrangements are used on wide roads and therefore the contribution to the veiling glare will be less than 10% because of the large angle involved. The computer program assumes this.

The method outlined here makes some very rough approximations. The calculation of the veiling luminance can be inaccurate by more than 10%.

The glare is finally expressed as a threshold increment, TI, given by

$$TI = \frac{65 \times L_v}{(\bar{L})^{0.8}} \%$$

where $\bar{L}$ is the average road luminance.

APPENDIX 3

Angle Measurements

Angle measurements are made to determine both the glare observation position and the lantern mounting height. The mounting height is best obtained from the plan of the lighting scheme and used to calculate the distance for a 19° line of sight at eye level from the horizontal as follows:

$$OD = (MH-1.5)/TAN(19°)$$

where OD is the observation distance in metres
MH is the lantern mounting height in metres
and an assumed eye level of 1.5 m.

In practice an angle measurement is quicker than obtaining plans. Two simple methods are described below using measuring instruments which can be readily assembled by an observer. One is a simple inclinometer which can be used night or day and the other is a shadow board for night use only.

1. **Inclinometer**
   A protractor, a board, two eyelet screws, a piece of string, and a weight are required. Attach the protractor to the side of the board so that its edge is parallel to an edge of the board and mount the string with the weight to the centre of the protractor. Mount the two eyelets along the edge of the board as far apart of practical. Additional sighting aids may be needed. The two eyelets are adjusted by sighting along the horizontal so that the string falls along the 90° line (Figure 13). To use, the observer takes up a position for a sighting angle of 19° at eye level and measures the distance to the lantern with a tape measure.

2. **Shadow Board**
   As the lantern of interest is generally the main contributor to the lighting, a definite shadow is cast. The height of an object and the length of its shadow are required to calculate the mounting height and hence the glare observation position. Alternatively a board can be used with fixed dimensions so that the shadow of an object falls at a predetermined place when the board is located at the correct observation position (Figure 14). The board should have a linear dimension of over 0.5 m with the cross line mounted on one edge so that its shadow lines up with the opposite edge with the chosen sighting angle. In use, place the board on a flat part of the road, e.g. the kerb. As the angle is at road level, adjustment is needed for eye level. A sight angle of 23° is suitable for lantern mounting heights between 7 m and 10 m, and result in a glare observation angle between 20° and 21°. The computer program will request which method was used (i.e. eye level or road level angle) and will then calculate both the actual glare observation angle and the mounting height. In practice, the use of the board occasionally leads to anomalous mounting heights when compared to inclinometer measurements. Therefore it is important to ensure that the ground is level and that the correct shadow is identified. At some sites,

other lighting makes the identification of the shadow from the lantern of interest difficult.

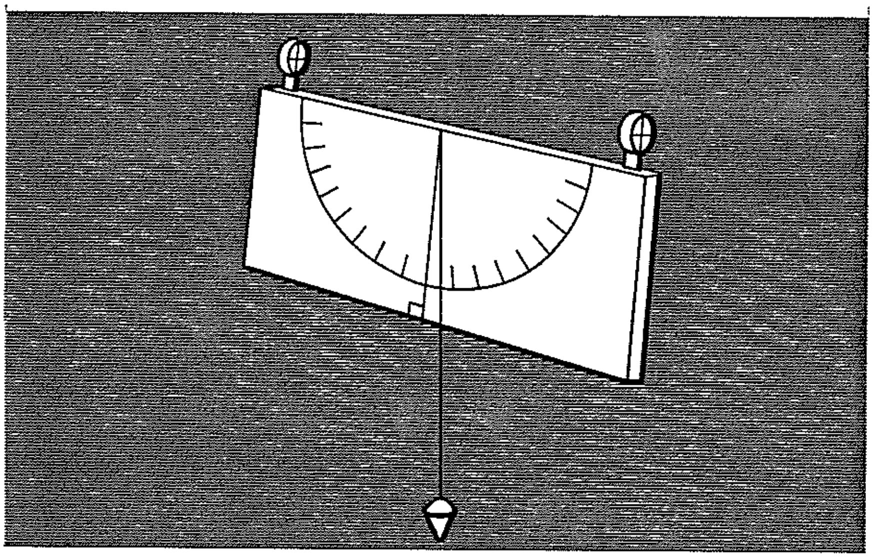

Figure 13. A simple inclinometer.

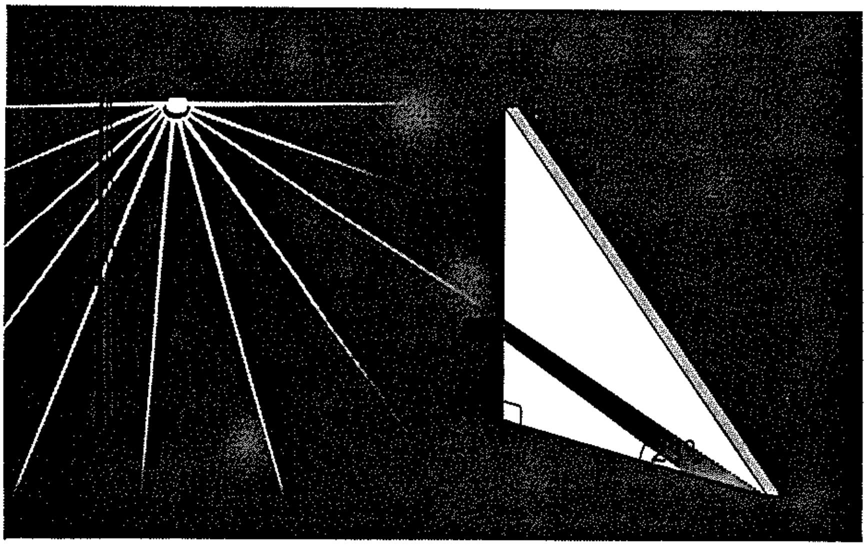

Figure 14. A shadow board.

APPENDIX 4
Computer Program

A computer program which will process the measured lighting data is described. The program is written in Turbo Pascal and a compiled version for an IBM compatible computer is available.

The program will request the data gathered on the Site and Road Lighting Check Sheet of Appendix 5. Where some parameters are not known the computer will suggest standard options.

Title Screen. Press <Return> to start.

Site Description. Up to 80 characters. Include date of observation if required.

Distance for Glare Observation. Give the actual distance measured after the angle has been determined.

Method to Determine Glare Angle. If the inclinometer was used at eye level than press "E". If the shadow board was used on the road level then press "R". It is important that the correct level is entered as it will determine how the program will interpret the sight angle.

Sight Angle for Glare. This is the angle to the horizontal not the actual glare observation angle, used to determine the glare observation position. For the inclinometer it should be 19°; for the shadow board it should be 23°. It is important that the actual angle used is entered as the program calculates the glare observation angle based on an eye height of 1.5 m. The resulting glare observation angle should be within 3° of 20° and also the mounting height will be displayed. There will be a small discrepancy between the two methods of determining mounting heights.

Average Spacing. This is the spacing along the same row of lanterns, i.e. on the same side of the road. If lanterns are on the other side of the road their spacing is assumed to be the same. Two options are given which suffice for most installations.

Single or Double Sided. This is not always simple to decide if the road has many intersections, about which extra lanterns have been installed. Press "S" or "D".

Opposite or Staggered. This will be requested for a double sided arrangement and, as for the previous input, is not always easy to decide. Use staggered unless a lantern is directly opposite to the one under observation. Press "O" or "S".

Road Width. This is also requested for a double sided arrangement. An estimate will suffice.

Glare Illuminance. At the observation distance used the vertical lux readings are requested in two parts: the total value, and the background value obtained with the meter shielded from the first lantern.

Glare Intensities. Enter the values measured with the luminance meter. The values must be measured with a 1/3° field of view. Values for up to four lanterns can be entered and, if double-sided, up to four on the other side. If no readings are taken enter zero.

Luminance Readings. Eight values need to be entered that are representative of the area under observation. If fewer values are measured choose those values that can be entered twice without upsetting the representative nature of the readings.

Printer. After the results are given on the screen a choice will be given to print a summary out on to a printer. Press "Y" to print. The print routine should work with a printer that is normally attached to the computer. Table 10 is a typical output.

Repeat or End. <RETURN> will allow another data set to be entered. <ESC> will return to DOS. Note that while the program does have extensive error trapping for input it can crash and return to DOS. Run the program again and avoid the problem if possible.

Program Variations. The author should be consulted if there are any extensive problems in the operation of the program.

For copies of the program, please send formatted $5\frac{1}{4}$ inch double density floppies to:

J V Nicholas, DSIR Physical Sciences, P O Box 31-313, Lower Hutt
telephone 04-5666919 or fax 04-5690117

Table 10. Sample of summary printout from computer program.

```
ROAD LUMINANCE DATA FOR
TEST SITE. GRACEFIELD RD. LOWER HUTT 7/12/89

ASSUMED GEOMETRY OF INSTALLATION
--------------------------------
THE ARRANGEMENT IS SINGLE SIDED.
LANTERN MOUNTING HEIGHT =  6.7M
LANTERN COLUMN SPACING  = 33.0M
EFFECTIVE ROAD WIDTH    = 10.0M

SUMMARY OF GLARE MEASUREMENTS
-----------------------------
GLARE ANGLE AT 1ST LANTERN = 20.0 DEGREES
VERTICAL LUX DUE TO 1ST LANTERN = 2.78 LUX
INTENSITIES, LEFT SIDE,  1600,   144,    78,     21.

SUMMARY OF LUMINANCE MEASUREMENTS
---------------------------------
VALUES IN CD PER SQ.M
 0.45 0.47 0.36 0.29
 0.32 0.29 0.23 0.20

PERFORMANCE CRITERIA AS PER CIE
-------------------------------
AVERAGE LUMINANCE   0.33CD PER SQ.M
OVERALL UNIFORMITY  0.61
THRESHOLD INCREMENT 13 %

LMIN=0.20CD/SQ.M,  LMAX=0.47CD/SQ.M,  LV=0.082CD/SQ.M
```

APPENDIX 5
Site and Road Lighting Check Sheet

Date:

1. **Place & Site**
   (a) Wgtn (b) LHutt
   (c) Porua (d) UHutt
   (e) Winui (f) Tawa
   (g) Petne (h) Other

2. **Location**
   (a) straight between
   (b) intersection with
   (c) other

3. **Direction of View**
   N S E W

4. **Lamp Type**
   (a) tungsten filament (b) fluorescent
   (c) mercury vapour (d) low pressure sodium
   (e) high pressure sodium (f) other (specify)

5. **Lantern Type**
   (a) bare lamp (b) reflector
   (c) refractor (d) other

6. **Age of Installation**
   (a) old (b) new
   (c) being upgraded (d) other
   Obtain dates if possible.

7. **Road Surface**
   (a) good condition (b) poor condition
   (c) chip seal (d) asphaltic concrete

8. **Lantern Delineation**

(a) footpath (b) parking lane
(c) driving lane (d) centre
(e) Do the lanterns give an indication of any changes in the road, e.g. rises, width changes, bends etc?
(f) Any confusion at end of road?

9. **Delineation**

(a) road studs (b) white line
(c) signs (d) other

Give further description if relevant, e.g. retro-reflective or ordinary materials.

10. **Lantern Arranging**

(a) single sided (b) staggered
(c) opposite (d) other

11. **Lantern Spacing**

(a) every post (b) every second post
(c) other

Give estimate of distance.

12. **Lantern Height**

sight angle?
eye or road level?
mounting height?

13. **Road Width**

(a) 2 lane (b) 2 lane + park
(c) 4 lane (d) median

Give measured width if known.

14. **Road Luminance Check**

Measure one post spacing back.
Is peak intensity under lantern greater than 0.5 cd/m^2?
If "Yes" then proceed with luminance (15), glare (16), illumination (17).

Otherwise Lighting is not to Code, and measure "darkest spot":

(a) max luminance
(b) min luminance

15. Average Luminance

		Left		Right
lane	parking	driving	driving	parking
Bright Strip				
Dark Strip				

16. Glare

Distance from lantern for observation:

(a) Vertical lux total

vertical lux shaded

(b)

Lantern No.	1	2	3	4	5
reading in cd/m^2					

17. Illumination

peak
minimum