How does the level of road lighting affect crashes in New Zealand-– A pilot study

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Executive Summary

Purpose

This project aims to improve our understanding of how the quantity and quality of road lighting influences the frequency of night time crashes.

While it is well-established that improving lighting increases safety, no well-established dose-response relationship to lighting parameters exists from which one can deduce benchmark levels of lighting for safety.

This study looked at a sample of street lighting installations spread over the urban areas of nine territorial local authorities. Standard street lighting parameters were measured in the field using a variety of instruments including illuminance meter, luminance meter and a calibrated digital camera. Field measurements were related to the ratio of night-time to day time crashes (from the CAS database) as a measure of night time safety vis-à-vis daytime safety. This index makes use of the fact that road lighting only influences night time crashes. Also as it measures relative rather than absolute crash frequencies it was possible to include non-injury as well as injury crashes to substantially increase sample size and sensitivity.

With the advent of LED technology in road lighting new opportunities have arisen to allow for an increase as well as a decrease in the level of lighting throughout the night. Benchmarking the level of lighting to specific road safety outcomes will be critical as this technology expands.

Light Technical Parameters

The CIE parameters measured for this project were:

Average luminance ($\overline{L}$)

Average luminance is the average brightness of the road surface as seen by a driver. Road safety lighting is divided into four sub categories of average luminance (V4, V3, V2 or V1) with V1 being the highest.

Overall uniformity (Uo)

Overall uniformity is a measure of how evenly lit the road surface is. In design the overall uniformity is established by dividing the minimum value of luminance (L_{min}) by the average luminance ($\overline{L}$).

$$Uo = L_{min} / \overline{L}$$

Longitudinal uniformity (Ul)

Longitudinal uniformity is a measure to reduce bright and dark bands of light appearing on road lit surfaces. The effect can be somewhat hypnotic and present confusing luminance patterns. In design it is expressed as the ratio of the minimum to maximum luminance within the lane of travel.

$$Ul = L_{min} / L_{max}$$

Threshold increment (TI)

Threshold increment is a measure of the loss of contrast a driver suffers because of light shining directly from the luminaire into the driver's eye. The effect is commonly referred to as disability glare.

These same variables are used in road lighting design and are referred to in the New Zealand/Australian road lighting standard as Light Technical Parameters.

Field Measurements

Field measurement of lighting parameters has rarely been attempted in New Zealand before. The study team explored a number of options and decided that photographic measurement was the best option. The camera employed was calibrated by establishing a relationship between pixel brightness and luminance.

Luminance measurements were made at midblock locations and no attempt was made to measure the increase in light at individual intersections. The luminance measurements would more closely represent midblock light levels than intersection light levels.

Road Lighting Database

Each of the nine Road Controlling Authorities in the study area (Upper Hutt, Lower Hutt, Wellington, Porirua, Palmerston North, Hastings, Napier, New Plymouth and Nelson) contributed data from their road lighting maintenance databases. From this data the survey routes were selected and a database measure of light intensity (lamp lumens per square metre of carriageway) was obtained. This index provided a check on the homogeneity of the lighting along the route and was tested as a potential predictor variable in regression modelling.

Study Method

The study followed what is known as a relation methodology. Values for the light technical parameters were measured under existing lighting in situ and the results matched with the crash history for the same section of road. The Poisson multiplicative regression model was then used to establish the most important predictor variables of the night to day crash ratio. The relation method was chosen as it allowed a much larger sample size than the traditional Before and After study.

Results

The results from the models were:

Average Luminance:

Average luminance was the only variable whose impact on the night/day crash ratio was unambiguous and statistically significant in all models. Perhaps this is appropriate as in New Zealand design average luminance is the only parameter which increases as the level of lighting is increased.

Further, the dose-response curve for average luminance suggests that road safety gains from road lighting continue as average luminance increases from 0.25cd/m^2 up to a value of 2 cd/m^2. The parameter values for average luminance suggest that a reduction in night crashes of around 19% can be expected for each increment of 0.5 cd/m^2 in average luminance.

Threshold Increment (TI)

Threshold increment (glare) was the second strongest predictive variable after average luminance. It was statistically significant in most models it appeared in.

The regression models estimate that a reduction in the threshold increment by some 10 percentage points (e.g. from 20% to 10%) would result in a night crash saving of between 5% and 9%.

Uniformity

Neither overall nor longitudinal uniformity were identified in the models as significant variables. Improvements to Longitudinal uniformity were weakly associated with lower night crash ratios but this could be just by chance.

From a designer's perspective this is a surprising result. The uniformity measures are often what distinguish a quality road lighting installation from a poor one. Further the whole concept of luminance design relies on providing motorists with a uniformly lit background luminance by which objects on the road can be easily and quickly be recognised by silhouette.

This result for uniformity is similar to that found in the Scott (1980) study.

Grouped Data Results

The regression models identified average luminance as the most important lighting variable with regard to road safety so the data was then grouped into narrow 0.25cd/m^2 bands of average luminance for more detailed analysis. Without necessarily testing each result for statistical significance the following general tendencies were found:

All Crashes (Intersection and midblock crashes combined)

- A strong dose-response relationship was found between the average luminance of the road lighting and the night to day crash ratio.
- The dose-response was similar in three groups of roads stratified by traffic volume (under 9,000 vpd, 9 – 12,000 vpd and 12 – 30,000 vpd). This result was important in establishing credibility for the relation method employed in the study.
- The dose response was positive for both dry and wet road surfaces suggesting that road lighting continues to be effective even when the surface is wet.

Midblock Crashes

- Midblock pedestrian crashes demonstrated a steep dose-response but on a small sample.
- The single vehicle collision with obstruction crashes exhibited a steep dose-response. This movement type involves a vehicle colliding with some stationary object located within the carriageway. As the object will rarely be internally lit it is intuitive that this type of crash should be influenced by lighting.
- Both rear end and manoeuvring type midblock crashes exhibited a dose-response relationship.
- Overtaking, head-on and cornering midblock crashes did not show any clear dose-response relationship to average luminance.

Intersection Crashes

- Both major (Traffic signal or Roundabout controlled) and minor (all other) intersections demonstrated a dose-response to average luminance but the effect was weaker than for midblock crashes. The reason for this is not clear but the average luminance measurements made in this study were at midblock and did not attempt to measure the lighting at specific intersections.

Recommendations

- Review the NZTA advice on crash savings from installing street lighting on the basis of results from this study.
- This study has developed a reliable field method to examine the effect of urban road lighting on crashes and can now be extended to include:
  - the safety benefits of lighting intersections.
  - the safety benefits of lighting rural roads and state highways.
- Develop “new technology” guidelines to guide decisions on when and where to raise or lower the level of lighting with new LED technology using the results and database developed for this study.
- Review the values for light technical parameters and road surface reflectivity in the New Zealand road lighting standard in the knowledge that additional crash savings are available when higher levels of road luminance are provided.

Glossary

CAS: Crash Analysis System developed by NZTA and MOT

Day crashes: Crashes identified as occurring in “Bright sun” or “Overcast”

Dose-response: The tendency for night time crashes to reduce as the level of road lighting increases

LED: Light Emitting Diode

MOT: Ministry of Transport

Night crashes: Crashes identified as occurring in “Twilight” or “Dark”

NZTA: New Zealand Transport Agency

R^2: The correlation co-efficient

Vpd: Vehicles per day

1 Introduction

This project aims to improve our understanding of how the quality of road lighting influences the ratio of night-time crashes to daytime crashes.

It also actions a recommendation of the NZTA research report no. 383 “Measurement of the reflection properties of road surfaces to improve the safety and sustainability of road lighting” by the authors of this report.

That project found that the reflectivity of our road surfaces is similar to international norms and that the continued use of special highly reflective parameters in NZ design surfaces could no longer be justified. However if the special NZ design surface was replaced with one which best fits our road surface characteristics, either more light will be needed to meet the standard or the design level should be lowered.

This decision would be assisted with better information on the current safety benefits of road lighting in New Zealand, and in particular on any dose-response relationship that may exist between road lighting parameters and the ratio of night-time crashes to daytime crashes.

It is known that road lighting has significant safety benefits. Before and after studies both here and overseas indicate reductions in crashes of around 30% where lighting has been improved. Section A6.6 of the NZTA Economic Evaluation Manual (EEM) quotes a 35% reduction in crashes as the effect of upgrading or improving lighting where lighting is poor. However, there is no accompanying definition of “poor” or what constitutes an acceptable improvement.

Also, there is no objective means to prioritise safety related lighting schemes against other uses of road safety funds. The estimated social cost of night time crashes under category V (safety related) lighting in urban areas is around $310M per year, about 8% of a nationwide total of around $3.8 billion per year.

The last review of the safety benefits of NZ lighting was conducted 15 years ago and did not examine relationships with lighting design parameters, rather concentrating on measuring the level of crash risk before and after lighting improvements without paying attention to the absolute levels of lighting involved.

This project is a pilot study in urban areas to assess any dose-response relationships between lighting parameters and safety within the scope of the study, and the worth of extending the scope of the study to ascertain if such a relationship exists for other lighting parameters and for other parts of the road network.

2 Background

2.1 Road Lighting Standards

Road lighting has two primary functions:

- security for property and people walking on the street at night, and
- safety associated with the movement of motorised traffic.

In New Zealand lighting required to ensure a reasonable level of personal security is known as Category P lighting and by design is less intense than that required to ensure road safety (Category V lighting).

Category V lighting is lighting for road safety on traffic routes. This lighting must cater for relatively fast moving traffic where safety decisions are highly time critical. The amount of light needed for category V lighting is often an order of magnitude higher than that needed for adequate category P lighting.

This report is concerned with the performance of Category V lighting – lighting for road safety.

In New Zealand category V road lighting design follows the joint New Zealand – Australian standard AS/NZS1158. The methodology comes from the international CIE method of luminance design.

The New Zealand lighting standard is a performance standard that defines a set of lighting criteria that must be satisfied if an installation is to comply with the standard. The precise arrangement and output of individual luminaires are immaterial if the lighting criteria, defined by Light Technical Parameters (LTP), are met.

There are 5 LTP for mid-block sections, 2 for intersections and 1 which applies everywhere to control light pollution. The values of the light technical parameters are shown in Table 1 and the parameters themselves are described in section 2.1.1 to 2.1.5.

Table 1 Values of Light Technical Parameters from Table 2.2 of the New Zealand Road Lighting standard (AS/NZS1158.1.1:2005)

Lighting subcategory	Light technical parameters								
	For straight sections, curves and intersections						For intersections and other specified locations		For all applications
	Average carriageway luminance[c,d] $(\overline{L})$ cd/m²	Overall uniformity[a,d] (U_o)	Longitudinal uniformity[d] (U_L) In Australia	Longitudinal uniformity[d] (U_L) In New Zealand	Threshold increment[e] (TI) %	Surround verge illuminance[d] (E_s) %	Point horizontal illuminance[c,d] (E_{Ph}) lx	Illuminance (horizontal) uniformity[e] Cat V (U_{E1})	Upward waste light ratio[e] $(UWLR)$ %
V1	1.5	0.33	0.5	0.3	20	50	15	8	3
V2	1.0	0.33	0.5	0.3	20	50	10	8	3
V3	0.75	0.33	0.5	0.3	20	50	7.5	8	3
V4[b]	0.5	0.33	0.5	0.3	20	50	5	8	3
V5	0.35	0.33	0.5	0.3	20	50	3.5	8	3

a) The calculated value for U_o may be less than 0.33, provided the corresponding value for $\overline{L}$ is 10% or more above the specified minimum, but shall in no case be less than 0.31.

b) V4 is the minimum subcategory recommended for application in New Zealand.

c) These values are maintained.

d) Compliance is achieved by being greater than or equal to the applicable table value.

e) Compliance is achieved by being less than or equal to the applicable table value.

2.1.1 Average luminance $(\overline{L})$

Average luminance is the average brightness of the road surface as seen by a driver. In design the road surface is nominally gridded with some 60 – 100 points as shown in Figure 1. Computer software calculates the luminance at each grid point using information on light from the luminaires and the reflection properties of the road surface.

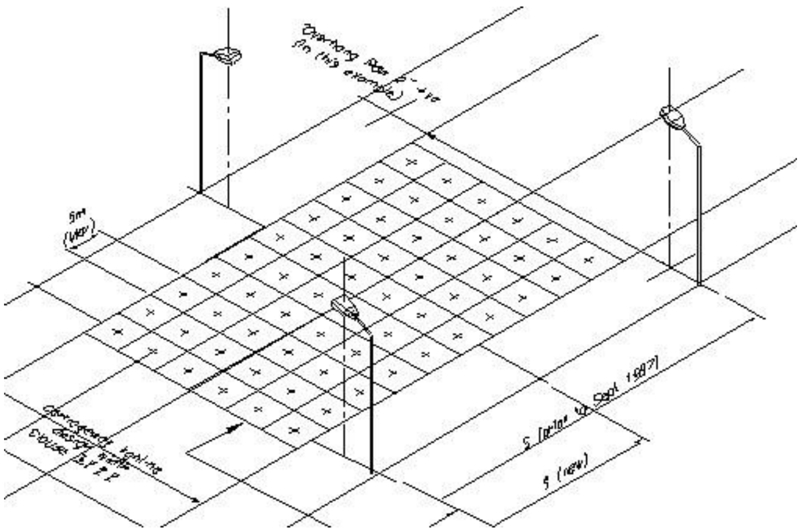


Figure 1 A typical road lighting design grid for calculating luminance

Average luminance is the key parameter which determines the category of lighting provided, be it V4, V3, V2 or V1(highest level of luminance)[1]. As can be seen from Table 1 all other light technical parameters are held constant as the lighting level changes. Knowledge of how changes to average luminance affect safety performance would be of considerable help in the decisions on lighting levels made by road controlling authorities.

2.1.2 Overall uniformity (Uo)

Overall uniformity is a measure of how uniformly lit the road surface is. In design the overall uniformity is established by dividing the minimum value of luminance (L_{min}) by the average luminance ($\overline{L}$).

$$Uo = L_{min} / \overline{L}$$

The NZ road lighting standard specifies a minimum Uo of 0.33 for all subcategories of V lighting installations. The minimum value for Uo in New Zealand (0.33) compares with the CIE recommended level of 0.35 for V4 subcategory and 0.40 for subcategories V3 to V1).

2.1.3 Longitudinal uniformity (Ul)

Longitudinal uniformity is a measure to reduce bright and dark bands of light appearing on road lit surfaces. The effect can be somewhat hypnotic and present confusing luminance patterns. In design it is expressed as the ratio of the minimum to maximum luminance within the lane of travel.

[1] There is a lower level called V5 but that level is not recommended for use in New Zealand.

$$UI = L_{min} / L_{max}$$

The NZ road lighting standard specifies a minimum UI of 0.30 for all subcategories of V lighting. The minimum value for UI for New Zealand design (0.30) compares with the CIE recommended level of 0.50 for V4 level and 0.60 for V3 to V2 and 0.70 for V1. Of all the light technical parameters this is the one for which NZ is most at variance with CIE recommendations.

2.1.4 Threshold increment (TI

Threshold increment is a measure of the loss of contrast a driver suffers because of light shining directly from the luminaire to the driver's eye. The effect is commonly referred to as disability glare. In absolute terms TI measures by how much the average luminance of the road surface would need to be increased to restore visual contrast lost by direct light from the luminaires. In design the calculations are quite complex, summing the contribution from each luminaire in the driver's visual field. Three relevant formulas are given below:

The visual contrast when a glare source present is by definition:

$$C' = C\,(1 - TI)$$

Where: C' = the contrast with glare

C = the contrast without glare

TI = Threshold Increment

The Threshold Increment and Veiling luminance are given by;

$$TI = 65 \times L_{veil} \;/\; \bar{L}^{0.8} \quad \text{and}$$

$$L_{veil} = 10 \sum (E / \theta^2) \qquad \text{[Stiles-Holladay formula]}$$

Where E = illuminance at the driver's eye in a plane normal to the line of sight in lux

Lveil = Veiling luminance is the luminance caused by a glare source which, when superimposed on the driver's retinal image, reduces its contrast. cd/m2

θ = angle in degrees between the line of sight and the line to the glare source

$\bar{L}$ = Average luminance of the road surface in cd/m2.

Note: The value 10 in the Stiles-Holladay formula is a constant used to typify the driving population as a whole but for individuals the value has been shown to increase with age from around 9 for 25 year olds to around 19 for 75 year olds.

New Zealand accepts relatively high levels of glare compared to the CIE recommendations. The NZ road lighting standard specifies a maximum TI of 20% for all subcategories of V lighting. This compares with the CIE recommended maximum level of 15% for category V4 to V2 roads and 10% for category V1 roads.

The glare in a road lighting installation is a function of luminaire design and road surface reflectivity. A luminaire with well controlled light output and a road with a good reflectivity will provide the least amount of glare. Recent research (Jackett & Frith (2009)) has shown that NZ roads surfaces have less reflectivity (darker) than current design tables indicate and therefore computer calculations will tend to underestimate the true extent of the glare.

The physiological effects of glare increase with driver age and consequently glare is a concern in any country with an aging driving population.

2.1.5 Surround Illuminance (Es)

Surround Illuminance is a parameter which ensures the illuminance in the first three metres from the edge of the design area does not fall to unacceptably low levels. It prevents a canyon-like driving experience where the light on the road surface abruptly transitions to near darkness on each side of the road.

The NZ road lighting standard specifies a minimum Es of 50% for all category V lighting which is also the level recommended by the CIE. When traditional semi-cut off luminaires are used this surround illuminance (Es) value is easily achieved, however the parameter will become more important in future as LED luminaires with cut off distributions become more common.

This parameter was not measured in the field study.

2.1.6 Lamp lumens per square metre of carriageway (Lms/m2)

This is an additional measure, not part of the standard set of LTPs. It is a calculated measure of the light provided per unit area of carriageway and can be derived from information available in road lighting and road maintenance databases without field measurement. It is similar to the LTP, average luminance.

3 Potential Data Sources

The following data sources/methods were reviewed as they had potential to contribute to this pilot study or any studies that may follow from it.

3.1 NZTA Financial Systems

Should a road controlling authority (RCA) wish to receive a subsidy for a new lighting scheme then provision must be made in the Regional Land Transport Programme. These programmes are combined to form 3-year National Land Transport Programmes (NLTP). The possibility that the NLTP could help provide a single, national source of information on the location of new street lighting schemes was investigated.

Discussions with NZTA officers indicated that this database is not a particularly helpful source. The projects specified in it are not necessarily implemented, some projects are fully funded locally so escape the net completely, and many of those that are specified for various reasons are not suitable for Before and After evaluation.

The most fruitful avenue for future projects may be in tapping the local knowledge of NZTA officers who help to put the programme together at a regional or national level.

For the reasons given above the NZTA financial systems were not used as a source of information for this study.

3.2 Design Calculations

Most existing lighting installations will have had a set of design calculations carried out prior to installation. If these calculations were still available then it would be possible to estimate the design level without field studies.

It is from these design calculations that a road is certified as meeting the lighting subcategories V4, V3, V2 and V1. It is not normal practice to subsequently carry out field tests to check that these levels are achieved.

Design calculations were not used in this project to determine lighting subcategory although the data collected from the maintenance database was almost sufficient to do so. Lacking were the design width, luminaire mounting height, luminaire overhang and luminaire tilt. The inclusion of this data in RCA’s maintenance databases would allow better follow-up action in future to determine whether lighting standards are being met.

3.3 Maintenance Database

Most road controlling authorities in New Zealand have a road lighting database of some description for maintaining the road lighting asset. The most common system is known as SLIM (Street Lighting Inventory Management) and integrates with roadway data in RAMM (Road Assessment and Maintenance Management). While primarily maintenance databases they can still provide information on timing, location and type of lighting that is helpful in research.

Limitations in the use of this data include:

- Unpopulated fields: While there are some 200 fields available many remain unpopulated depending on the needs of the RCA.

- Outdated information: There can be a time lag between lights being installed and the database being updated. Similarly some old light fittings may remain in the database despite being physically removed from the street.
- Detail: As mentioned in the previous section the information in the database is rarely sufficient to allow design software to derive the full set of light technical parameters for an installation.

However the State Highway SLIM data records kindly provided by NZTA did show populated fields for “date light installed” and “date pole installed”. A search for groups of more than 20 adjacent new poles indicated a number of new State Highway projects that could be evaluated at some time in the future.

As the earliest date for these projects was 2006 this approach offers more of a possibility for the future than the present.

3.4 Field Measurements

Field measurement is the most rigorous option to obtain the key parameters, however accurate measurement of road luminance can also be a demanding task. A summary of the options is given below.

3.4.1 Grid point measurements

Field measurements of luminance on a grid point by grid point basis are defined in the British Standard BS EN 1320-4:2003 “Methods of measuring lighting performance”. This standard identifies that a luminance meter capable of the task would need to measure as little as 2 minutes of arc vertically and 20 minutes of arc horizontally. This is a demanding capability and it is unlikely that such a luminance meter is still available in New Zealand. The time taken to complete a single site evaluation by this method is prohibitive – it is measured in hours not minutes.

3.4.2 Mobile photo-luminance devices

Mobile photo-luminance devices that measure luminance from a moving car have been developed overseas. Ease and speed of measurement is optimised with these devices but the sheer volume of data to be assimilated may increase the complexity of the analysis. This option has not been explored further.

3.4.3 Hand held luminance meter

A simplified method to measure luminance using a hand held luminance meter is outlined in Transit NZ Research Report No. 4 “A Road Lighting Survey Method for Accident Sites, 1991”. This method requires a hand held luminance meter capable of measurement at 1/3 of a degree. The measurements can all be made from a single standing position on the road shoulder located at a distance of 30m from the first luminaire.

Four equally-spaced measurements across the road are made in the closest bright patch followed by four equally-spaced measurements in the dark patch immediately beyond. An average of these 8 readings provides an estimate of the average luminance of the installation and the lowest reading divided by the average provides a measure of overall uniformity, Uo.

The estimate of uniformity obtained from this method suffers a little from the fact that the measurement area (circular, 1/3 degree) represents a highly elongated ellipse on the road surface (15m x 0.4m) which spans more than a single design grid point.

To reduce the impact of the above the method compromises the standard CIE observation angle just slightly by observing at around 2 degrees whereas CIE geometry has the observer at around 1 degree.

Within the context of a simplified measurement technique neither compromise is significant and this method has been used successfully in New Zealand for many years.

3.4.4 Photographic method

The advances in digital photographic technology since 1991 when the hand held luminance meter method was developed are such that photography is now a viable alternative. A digital single-lens reflex camera was field tested as an instrument to measure road luminance.

While camera sensors are not necessarily calibrated to standard CIE V(λ) spectral sensitivity calibration can be achieved for a specific light source using a luminance meter with established CIE V(λ) sensitivity and a series of grey scale targets. (See appendix 1).

Traffic route lighting in New Zealand (2010) is predominantly High Pressure Sodium (HPS) with a very small proportion of metal halide (MH) and low pressure sodium (LPS) lighting. Separate calibration equations were developed for the camera for each of these sources and in practice the difference in calibration proved to be quite small.

In trials the results from the photographic method were found to be comparable with those obtained from a hand held luminance meter. The photographic method has the following advantages over the hand held meter method:

- The measurement area and grid points can be more accurately identified and measured. The measurement area is represented by some 600,000 individual pixel measurements in a typical photo compared to just eight sampled measurements using the hand held meter.
- Field measurement time is reduced. Typically only a few minutes per site.
- Repeatability is improved.
- A permanent luminance record of the scene is obtained for future reference or checking.

For the above reasons the photographic method was used in this study.

4 Methodology Choices

A number of survey methodologies were investigated including:

4.1 Before and After Study:

A before and after study would identify new sections of road lighting and compare the change in lighting conditions with the change in crash experience. A study of this nature has potential to evaluate the full range of key parameters including Average luminance, Overall uniformity and Threshold increment by accessing the design calculations.

However it appears there are few sites where a clean before and after study can be carried out. Many lighting projects are part of new alignments or new roads so the Before condition may be either non-existent or not relevant. Site visits or site plans would be needed to confirm which projects are viable for inclusion.

A before and after study might be possible by contacting key people in provincial and metropolitan centres seeking information on new lighting schemes. To help eliminate sites that could not be successfully evaluated a protocol similar to that shown below could be used:

- at least 500m of new, category V lighting was installed
- the scheme resulted in a quantifiable change in the level of lighting
- the physical layout and traffic characteristics of the road remained largely unchanged for a specified number of years before and after the new lighting was installed.

4.2 Relation Study

By examining existing lighting which has been in place for 5 years it is possible to relate the crash experience in that time with the quality of the lighting provided. For example roads lit to a higher level of lighting might have a correspondingly lower night time crash risk.

This is similar to the method employed by Scott 1980 and is referred to as a “Relation Study” in Schreuder, DA (1998). As the crash history of all sites are measured over the same time period temporal adjustments to crash frequencies are unnecessary.

The quality of existing lighting can be obtained from a database (as outlined in section 3.3) or by field measurements (as outlined in section 3.4).

The advantage of field measurement is that it represents the actual light conditions in the street and can record issues such as:

- irregularities caused by street vegetation
- changes due to the vertical or horizontal alignment of the road
- actual rather than theoretical luminaire positions and output
- actual reflection properties of the road surface rather than theoretical tables.

The disadvantage of field measurement is that it represents the performance of the system at one particular point in time. When the lamps are replaced (3 to 5 year cycle for HPS) and the luminaire also cleaned the light output can increase by as much as 30%. Unless the position in the maintenance cycle is known at the time of measurement there will be an error of some ± 15% from the mean value. The crash data is typically an accumulation of 5 years data so could be expected to include at least one maintenance cycle.

For this study performance measures using both field and database were obtained and it was left to the regression equations to determine which was the most discriminating.

5 Method

It was agreed that this pilot study should:

- Examine the safety performance of existing road lighting in major population centres
- Use both field studies and locally held databases to establish the quality of existing lighting
- Analyse crash data using the NZTA Crash Analysis System (CAS) to establish the crash experience.

5.1 Road Controlling Authorities

The following nine Road Controlling Authorities kindly agreed to be part of the study and each contributed relevant parts of their road lighting and roadway inventory data to the study:

- Upper Hutt
- Lower Hutt
- Wellington
- Porirua
- Palmerston North
- Hastings
- Napier
- New Plymouth, and
- Nelson.

5.2 Road and Lighting Data

The following data was collected from field studies (as outlined in Appendix 1):

- Average luminance
- Overall uniformity
- Longitudinal uniformity
- Threshold increment.

The following data was provided by RCAs from SLIM and RAMM databases. This data was used in site selection and subsequently to provide the data to calculate the lighting quantity measure “lamp lumens per square metre of carriageway”.

- Suburb
- street name
- location (within the street)
- Left/Right location
- luminaire type
- lamp type and wattage

- mounting height (bracket height)
- pole type
- carriageway width
- traffic volume.

Data on typical lamp output was drawn from the RightLight website (http://www.rightlight.govt.nz/) to allow the calculations of "lamp lumens per square metre of carriageway" to be made.

5.3 Crash Data

Crash data for each RCA covering the years 2006 to 2010 was extracted from the NZTA's Crash Analysis System (CAS). This data was matched for each site with data from the field studies and RAMM/ SLIM inventories.

CAS provided data on a number of crash variables including:

- Injury severity - non injury, minor, serious and fatal crashes
- Light conditions – Light or Dark
- Location - Midblock or intersection
- Road Type – Minor Urban Road, Major Urban Road
- Junction type – crashes at Roundabouts
- Control type – crashes at Traffic signals
- Markings – crashes at pedestrian crossings
- Surface wetness – crashes where the road surface was either wet or dry
- Movement code – the CAS movement and the types of vehicle involved.

Data from all sources was combined in linked spreadsheets for subsequent analysis.

5.4 Method of analysis:

5.4.1 Night to Day ratio:

The number of crashes on any section of road relates to many factors, some local, some geometric some related to traffic some to the surrounding environment. Data to accurately estimate the underlying crash rate on a section of road is rarely available in the quantity or quality needed.

Rather than attempt such an estimate for each road at night this study utilises the fact that street lighting only influences night time crashes. Day time crashes are unaffected by the street lighting and can be used as a uniform measure of crash frequency across all roads in the study. The ratio of night to day crashes in this study forms the measure of crash frequency at night.

For the majority of roads in the study there was no reliable data on the relative traffic flow by day and by night. If this data becomes more widely available in future it is a refinement which could be included.

5.4.2 Establishing a reliable Night to Day ratio:

When the crash numbers from individual sites are small the ratio of night to day crashes can take extreme values. A lower limit of 10, reported injury + non-injury crashes per site was used in the site selection process but even at this level the data is somewhat noisy.

The data noise increases substantially when subsets of the full dataset are selected, such as injury crashes or midblock crashes. Many sites that had useful numbers of total reported crashes failed to establish a reasonably stable night to day ratio when only injury or midblock crashes were considered.

For this reason two analysis methods have been adopted in this report:

- Generalised linear models using data points for streets in the dataset with at least 10 crashes are used to explore the relationship between road lighting variables and night crash frequencies in order to decide on which variables are worth further analysis using grouped data.
- Analysis of grouped data in which night and day crashes from streets with similar average luminance are combined to produce a single data point. The night to day ratio is more stable in this group as it represents the sum of crash numbers from all streets in the luminance group. This method was used to examine the relationship between average luminance (which the generalised linear modelling identified as the most important parameter) and night crashes.

5.4.3 Use of non-injury crash data:

One of the strengths of the New Zealand CAS system is that it allows analysis of all details on all crashes reported to the NZ police from fatal right through to non-injury crashes. Of the reported crashes within the RCAs selected for this study:

- 4% involved serious or fatal injuries
- 21% involved minor injuries, and
- 75% involved no injuries.

The bulk of crash records available on CAS come from the reported non-injury crashes. Making use of this data can dramatically enhance the sensitivity of statistical tests and therefore the confidence in the results.

It has been traditional to use only injury crashes in NZ road safety research as injury crashes have a higher reporting rate and likely have less bias in the type of crash reported. However this study does not use the absolute number of crashes but rather the ratio of night crashes to day crashes. As can be seen from Table 2 the Night to Day ratio of reported non-injury crashes is similar to that of reported injury crashes in all the RCAs studied. The average night to day crash ratio for injury crashes is 0.45 and that for non-injury crashes is 0.47.

Provided the non-injury crash statistics behave in a similar way to those with a more serious injury outcome their greater numbers can provide valuable insights on the effect road lighting has on crashes. This study uses crashes of all severities but also analyses minor injury and fatal + serious injury crashes separately.

Table 2 The average Night to Day ratio of non injury crashes and injury crashes for the RCAs in the study.

	Non-Injury Crashes Night/ Day ratio	*Injury Crashes Night / Day ratio*
Upper Hutt City	*0.55*	*0.49*
Hutt City	*0.41*	*0.44*
Wellington City	*0.48*	*0.48*
Porirua City	*0.48*	*0.55*
Palmerston North City	*0.54*	*0.44*
Hastings District	*0.41*	*0.37*
Napier City	*0.50*	*0.46*
New Plymouth District	*0.52*	*0.47*
Nelson City	*0.51*	*0.39*
Average	*0.47*	*0.45*

5.4.4 Size of the Database:

The field surveys were carried out during 2010/2011 and included nine RCAs.

Site selection used the CAS, SLIM and RAMM data to select road sections (sites) which:

- had no substantive road lighting changes in the period 2006-2010
- had 10 or more injury + non-injury crashes 2006-2010
- had consistency in lighting along the full length
- had safe places to stop and measure lighting.

Following the field studies some sites were shortened, subdivided into several sites or simply deleted to maintain consistency of lighting.

It is questionable whether sites with an average luminance below 0.25cd/m^2 can truly be regarded as road safety lighting. The NZ standard specifies a minimum of 0.5 cd/m^2 for category V lighting and the Australian standard 0.35 cd/m^2. A more inclusive lower limit of 0.25 cd/m^2 was chosen to include lighting designed to category V but for various reasons not actually delivering to category V. Sites with an average luminance below 0.25 cd/m^2 were regarded as more likely to be category P lighting and were subsequently deleted from the database.

There are 152 sites in the final database having an average luminance in the range 0.25 to 2.25 cd/m^2. The total road length under study is 270 km and the total number of crashes in the database is 7,944.

6 Results

These results examine the data from two different perspectives:

- Generalised Linear Models examine the data from each street to find relationships between the lighting variables and the night to day crash ratio.
- Grouped data combines streets of similar average luminance to find relationships between average luminance and the night to day crash ratio.

6.1 Generalised Linear Models (GLM)

6.1.1 Model Structure:

The Poisson multiplicative regression model was selected for modelling with the form:

$$N/D = e^{(a + b\bar{L} + c\,Uo + d\,Ul. + e\,TI + f\,Cl + g\,Lm/m2)} + \varepsilon$$

Where: N= number of night crashes (dependent variable)

D = number of day crashes

a, b, c, d, e, f and g are parameter estimates of the model

ε is the random error of the dependent variable.

$\bar{L}$, U_o, $U_{l,}$ TI, Cl & Lm/m^2 are the independent variables:

Average luminance ($\bar{L}$)

Overall uniformity (Uo)

Longitudinal uniformity (Ul)

Threshold increment (TI)

Colour (Cl) a dummy variable where Cl=1 for a white light source (Metal Halide) and Cl=0 otherwise

Lamp lumens per square metre of carriageway (Lm/m^2).

The structure of the model is log-linear, as in general the absolute size of impact of a crash countermeasure will depend on the size of the crash problem it is attacking. This situation is best described by a model such as the log-linear model where the factors act multiplicatively (see D'Elia et al. (2007)).

A value of 2 standard deviations (p=0.05) was adopted for statistical significance.

6.1.2 Model Results

The results of the modelling are summarised in Table 3, where Model 1 contains all the independent variables and Models 2, 3 and 4 contain fewer as the less significant variables are removed.

Table 3 Summary results of four models using the Poisson Multiplicative Model to predict the number of night time crashes.

		Independent variables					
Model No.	*Constant term (a)*	*$\bar{L}$, Average Luminance*	*TI, Threshold Increment*	*Uo , Overall Uniformity*	*Ul, Longitudinal Uniformity*	*Colour (White=1)*	*Lamp lumens/m^2*
1	*-0.83*	*-.035***	*1.05**	*0.13*	*-0.07*	*0.36**	*-0.001*
2	*-0.81*	*-.039***	*0.96**	*0.10*	*-0.09*		
3	*-0.81*	*-0.38***	*0.95**				
4	*-0.62*	*-0.44***					

Notes: The number of * indicates the significance of the parameter. * = two standard errors (significant at p<=0.05), ** = three+ standard errors (highly significant)

A description of the results follows:

- Average Luminance ($\bar{L}$) was statistically highly significant in all models. A higher value for average luminance was related to fewer night time crashes. The dominance of average luminance in predicting the night to day crash ratio was obvious in all models tested.
- Threshold Increment (TI) was statistically significant in all models with a lower value of threshold increment being related to fewer night time crashes.
- Overall uniformity (Uo) and Longitudinal uniformity (Ul) were not statistically significant in any of the models tested.
- Colour of light source (Cl) was statistically significant with the use of a white light being related to an increase in night crashes but the sample size was too small for credibility.
- Lamp lumens per square metre of carriageway was not statistically significant.

While the variable "colour of light source" did achieve statistical significance in the model the sample size (6 sites) is too small for the result to be given credibility. Further sites/studies are required to explore this aspect of lighting.

The null result for both uniformity measures is similar to that found in the Scott (1980) study but from a designer's perspective it is still a surprising result. In a conventional sense uniformity is what distinguishes a quality road lighting installation from a poor one. However, a mild degree of non-uniformity in road lighting may well help road safety as it can aid distance perception and provide an additional dynamic.

To test whether uniformity had a nonlinear, step function type relationship to crash frequency, dummy variables were created to identify Uo and Ul as a factor only when at low values (e.g. below the NZ standard values of 0.33 and 0.3). Even when using dummy variables in this way neither uniformity variable was found to be statistically significant.

While the design based variable "Lamp lumens per square metre of carriageway" shows correlation with the field measured "average luminance" (see Figure 2) in regression modelling it was not statistically significant in any model where average luminance was also present. This result tends to support the notion that field measurements are a superior means of assessing the safety value of an installation to design based variables.

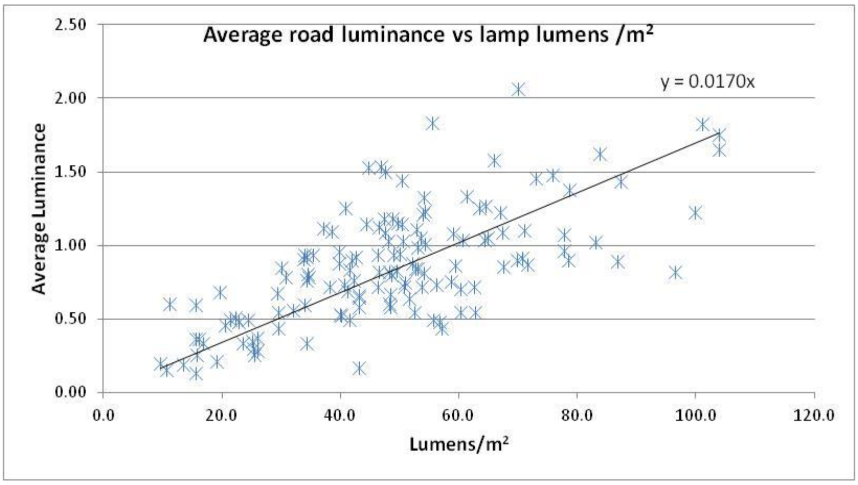


Figure 2 Average luminance vs Lamp lumens per square metre of carriageway. An approximate conversion between the two measures can be obtained from the best fit line.

Traffic volume is also a potential independent variable but one which is difficult to separate from average luminance as best practice in road lighting design is to adopt higher levels of lighting on the more highly trafficked sections of the network. Rather than incorporate traffic volume in the regression modelling its effect has been examined by stratifying the grouped data by traffic volume in section 6.2.2 below.

6.2 Grouped data

The regression models identified average luminance as the most important road safety variable. Using average luminance as the sole measure sites were grouped into seven 0.25cd/m^2 wide bands of average luminance for more detailed analysis. Table 4 summarises the data.

Table 4 Summary of all grouped data

Average luminance range (cd/m²)	*Lighting Category*	*No. of sites in group*	*No. of Night crashes*	*No. of Day crashes*	*Total crashes*
0.25 - 0.5	*Below V4*	*31*	*248*	*565*	*813*
0.5 - 0.75	*V4*	*38*	*463*	*1121*	*1584*
0.75 - 1.0	*V3*	*40*	*724*	*1998*	*2722*
1.0 - 1.25	*V2*	*27*	*379*	*1113*	*1492*
1.25 - 1.5		*13*	*161*	*542*	*703*
1.5 - 1.75	*V1*	*5*	*80*	*310*	*390*
1.75 - 2.25		*4*	*54*	*223*	*277*
All Groups		*158*	*2109*	*5872*	*7981*

Note: Six sites rejected from GLM modelling due to their small crash sample were reincorporated in this analysis to bring the sample size to 158 sites.

The night to day crash ratio for each group was plotted against the average luminance and a negative exponential curve fitted following the form:

$$y = a\, e^{-b\,x} + \epsilon$$

where y = night/day crash ratio

x= average luminance

a = crash parameter. A constant term but also provides an indication of the proportion of crashes that would occur at night without street lights

b = luminance parameter. A constant term which describes the slope of the graph. A highly negative value indicates a strong dose-response relationship between road luminance and night crash frequency. A low value (flat curve) suggests there is no relationship.

ϵ = the random error.

The negative exponential was chosen as its general shape approximated the downward slope to the right with increased luminance which would be expected if one had a positive effect with diminishing returns.

The graphical format of Figure 3 is used throughout the report to explore, for a range of road and traffic variables, the dose-response relationship between average road luminance and the night to day crash ratio. The decision on the strength of the dose-response was a judgement call based on:

- The regularity and overall visual appearance of the fit
- The size of the correlation coefficient (R^2)
- The sample size of crashes in the analysis
- The number of data points available.

For consistency data points were not plotted unless the night to day ratio was calculated on 20 or more crashes. Where this value was not achieved, two adjacent groups would be amalgamated and the number of data points reduced by one. Typically the two highest luminance groups (1.5 - 1.75 and 1.75- 2.25) would be amalgamated with small subsets of data.

6.2.1 All data

Combining all injury and non-injury crashes in the database gives the result shown in Figure 3 and a best fit negative exponential curve of:

$$y = 0.53\ e^{-0.43\ x}$$

where: y = night/day crash ratio, and

x = average road luminance.

This result is similar to the output of regression modelling in section 6.1 which, when expressed in the same mathematical form, gives $y = 0.54\ e^{-0.44\ x}$. While the mathematics involved is different the fact that the final answers are in close agreement provides some mutual support.

There is a dose-response relationship evident in Figure 3. Roads with higher average luminance have a lower night to day crash ratio.

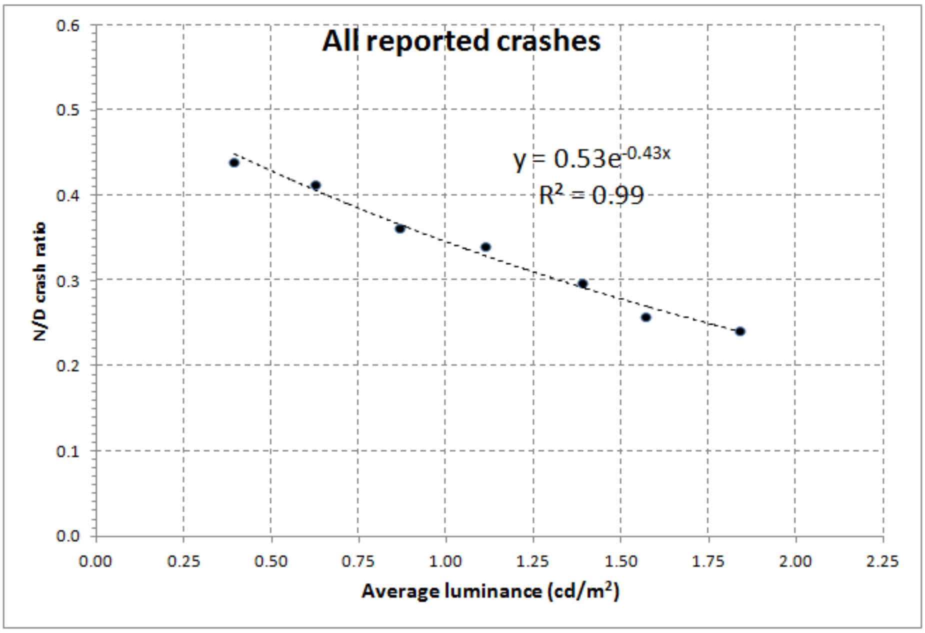


Figure 3 The relationship between average luminance and the night to day crash ratio for all reported crashes. The downward slope of the line indicates a reduction in night crashes with an increase in average luminance.

Description	*Parameter, a*	*Parameter, b*	*Sample size, n*	R^2	*Crash reduction**
All crashes	*0.53*	*-0.43*	*7,981*	*0.99*	*19%*

* % crash reduction expected for each 0.5 cd/m^2 increase in average luminance

6.2.2 Traffic volume

To examine possible effects of traffic volume on the luminance – crash relationship, grouped data was separated into three similarly sized, average daily traffic (ADT) groups.

The results are shown graphed in Figures 4 to 6 and tabulated below the figures.

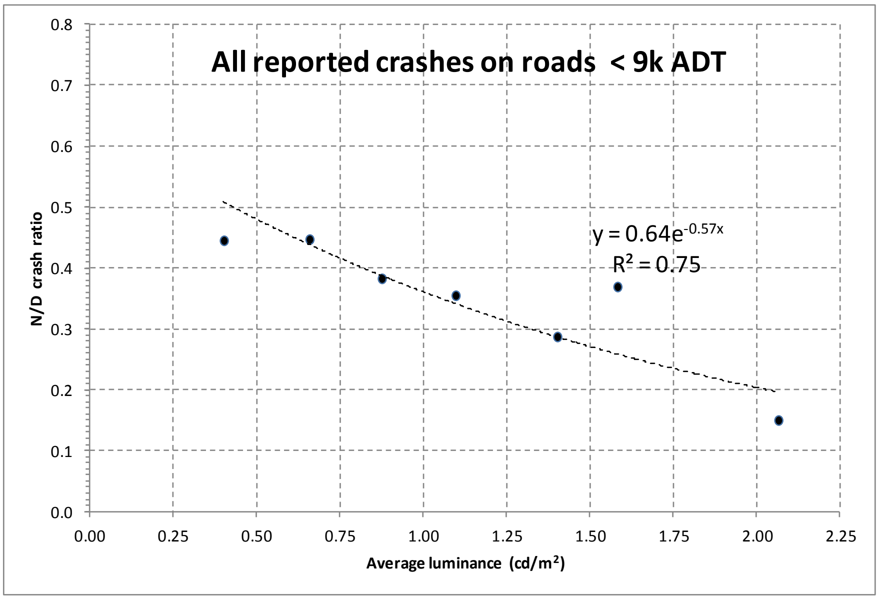


Figure 4 The relationship between average luminance and the night to day crash ratio on low volume (ADT < 9,000 vpd) roads

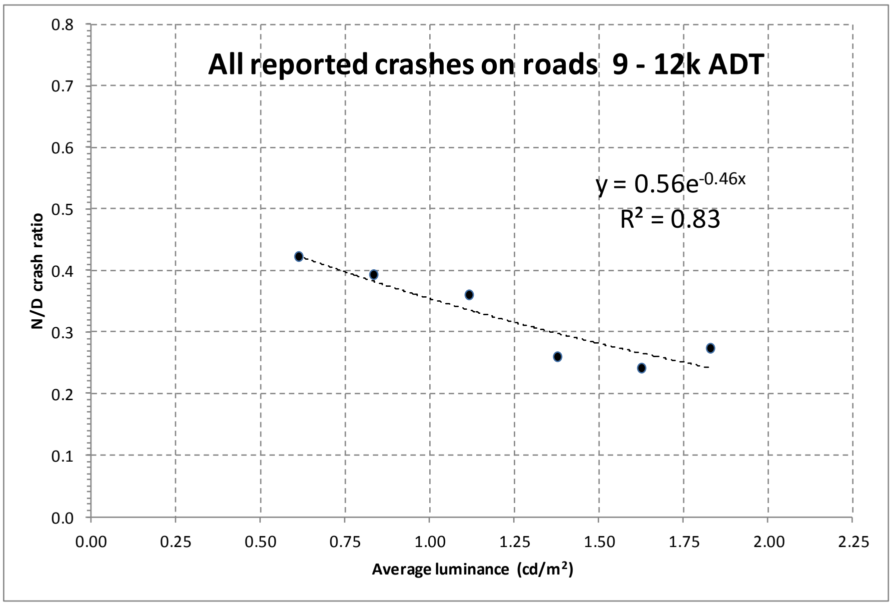


Figure 5 The relationship between average luminance and the night to day crash ratio on moderate (ADT 9 – 12,000 vpd) volume roads

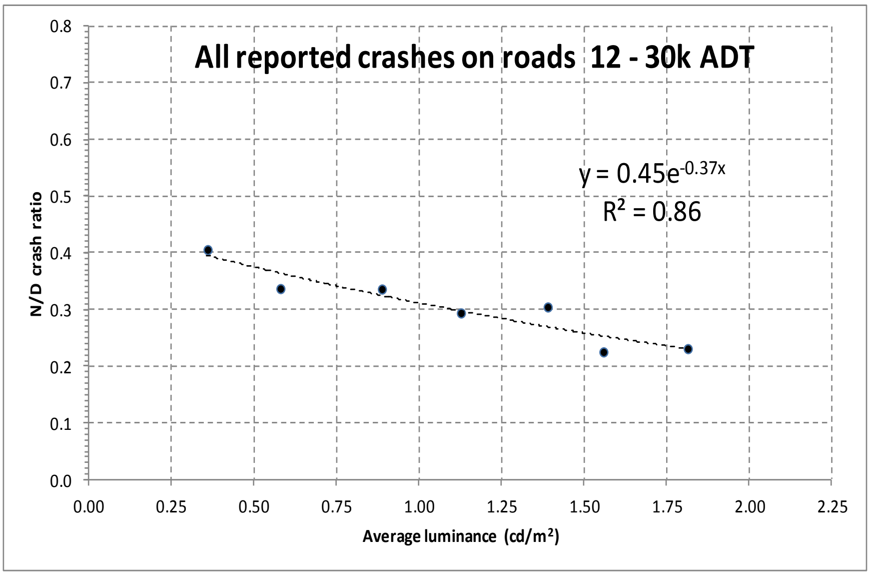


Figure 6 The relationship between average luminance and the night to day crash ratio on high (ADT 12 – 30,000 vpd) volume roads

Description	***Parameter, a***	***Parameter, b***	***Sample size, n***	R^2	***Crash reduction****
Low volume roads (ADT 3 – 9,000)	*0.64*	*-0.57*	*2,720*	*0.75*	*25%*
Moderate volume roads (ADT 9 – 12,000)	*0.56*	*-0.46*	*2,115*	*0.83*	*21%*
High volume roads (ADT 12 – 30,000)	*0.45*	*-0.37*	*3,146*	*0.86*	*17%*

* % crash reduction expected for each 0.5 cd/m^2 increase in average luminance

The relationships in Figures 4 to 6 suggest the dose-response relationship between average luminance and the night to day crash ratio is consistent across traffic volume groups. This result is important because average luminance and traffic volume are correlated.

6.2.3 Midblock crashes

The field measurements of average luminance in this study were made at midblock locations. This provides a suitable measure of luminance for comparison against midblock crashes but is only relevant to intersections by inference of consistent design. At intersections light levels can be somewhat higher than at midblock locations and following the guidance of AS/NZS1158 would ensure that. However, light measurement at intersections requires illuminance readings and this was beyond the scope of this project.

This section deals with aspects of midblock crashes – defined here as any crash in the CAS system that does not have the intersection locator "I".

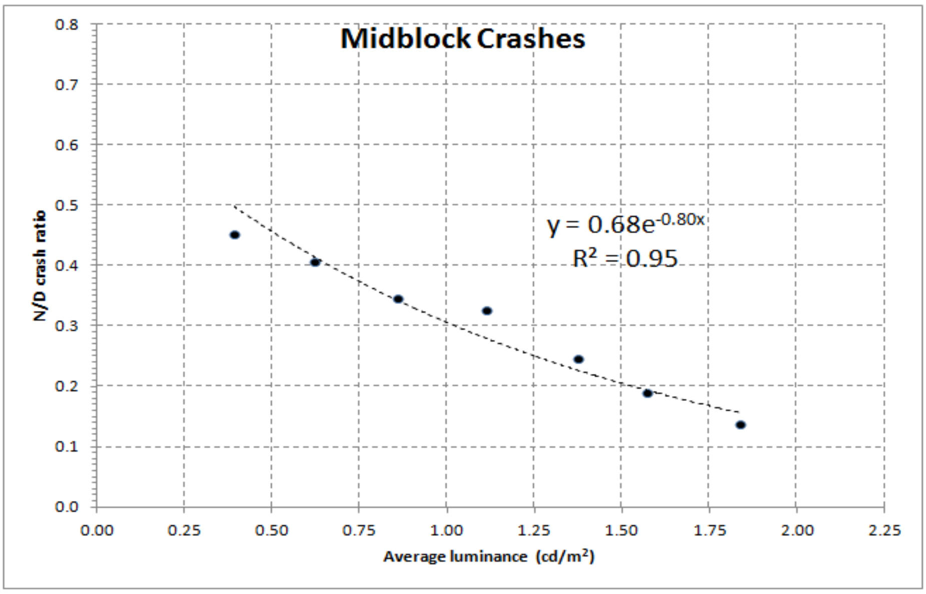


Figure 7 The relationship between average luminance and the night to day crash ratio for all midblock crashes

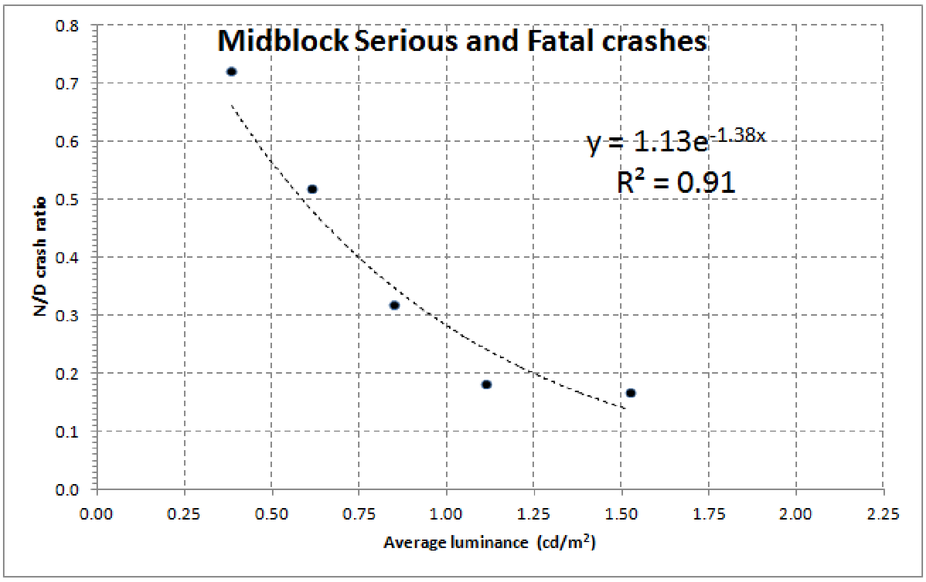


Figure 8 The relationship between average luminance and the night to day ratio of midblock serious and fatal crashes. (Note: Despite the high R^2 value the sample size here is quite small)

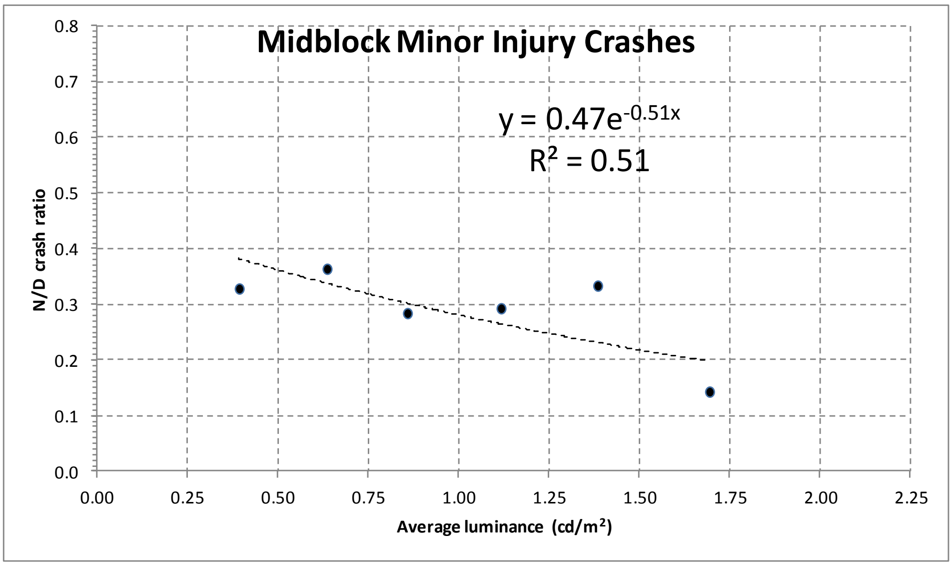


Figure 9 The relationship between average luminance and the night to day ratio of midblock minor injury crashes

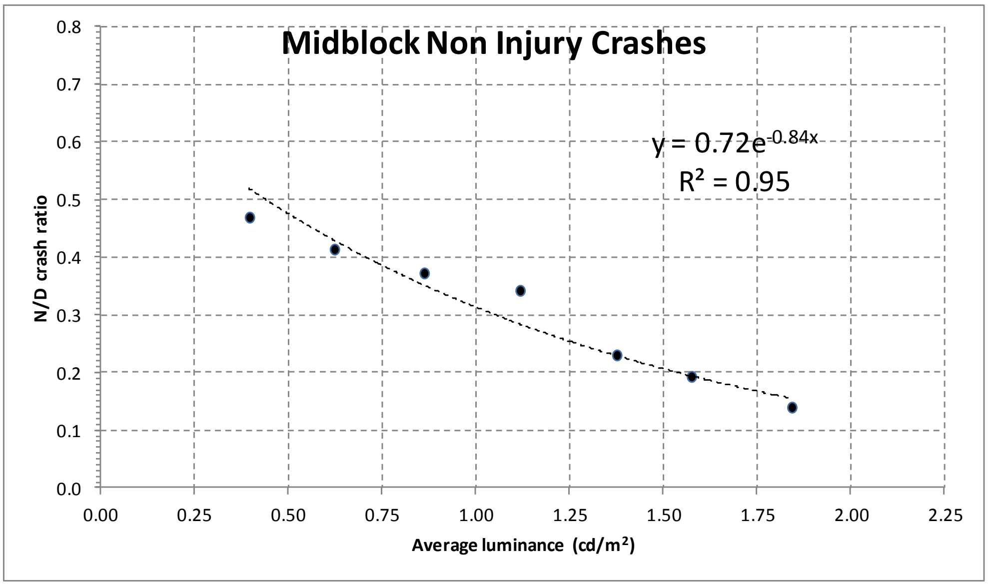


Figure 10 The relationship between average luminance and the night to day ratio of midblock non injury crashes

Description	***Parameter, a***	***Parameter, b***	***Sample size, n***	R^2	***Crash reduction****
All severities midblock crashes	*0.68*	*-0.80*	*3,557*	*0.95*	*33%*
Fatal + Serious midblock crashes	*1.13*	*-1.38*	*162*	*0.91*	*50%*
Minor injury midblock crashes	*0.47*	*-0.51*	*833*	*0.51*	*23%*
Non-injury midblock crashes	*0.72*	*-0.84*	*2,562*	*0.95*	*34%*

* % crash reduction expected for each 0.5 cd/m^2 increase in average luminance

The relationships in Figures 7 to 10 are for crash severity at midblock locations.

- All three injury severities show a dose-response to average luminance.
- Fatal and serious crashes show the steepest dose-response relationship but the sample is small.

6.2.4 Midblock Crash Movements

The CAS movement code system provides a ready classification of crashes according to the types of vehicle and the movements involved (see Appendix 4). To test where the dose-response relationships were stronger, crashes were divided into the following broad categories using the CAS classifications:

- Midblock Pedestrian crashes: Crashes involving pedestrians crossing or walking along a road, but excluding intersections and pedestrian crossings as in both of these situations supplementary lighting is likely to be in place. CAS movement types “P” and “N”.
- Midblock Cycle crashes: All midblock crashes where a cycle is involved. The sample size is very small (23 night crashes) and is only included here because the presence of cyclists as vulnerable users can be a reason for improving lighting. CAS vehicle type “S”.
- Midblock collision with obstruction: A single vehicle crash involving a collision with some object on the roadway. The object is usually a parked car but can be signs, traffic signals, road work obstructions, animals etc. Collisions with utility poles would not normally be included here as they are located off the roadway. CAS movement type “E”.
- Midblock Rear end crashes: Approximately half of all rear end crashes occur at midblock locations. These involve crashes where a vehicle from behind ran into the rear or side of another vehicle. CAS movement types “F” and “G”.
- Midblock Manoeuvring crashes: These crashes are usually associated with parking, U-turning or driveway-type manoeuvres. The movements or intentions of the other party can be unpredictable or difficult to identify. CAS movement type “M”.

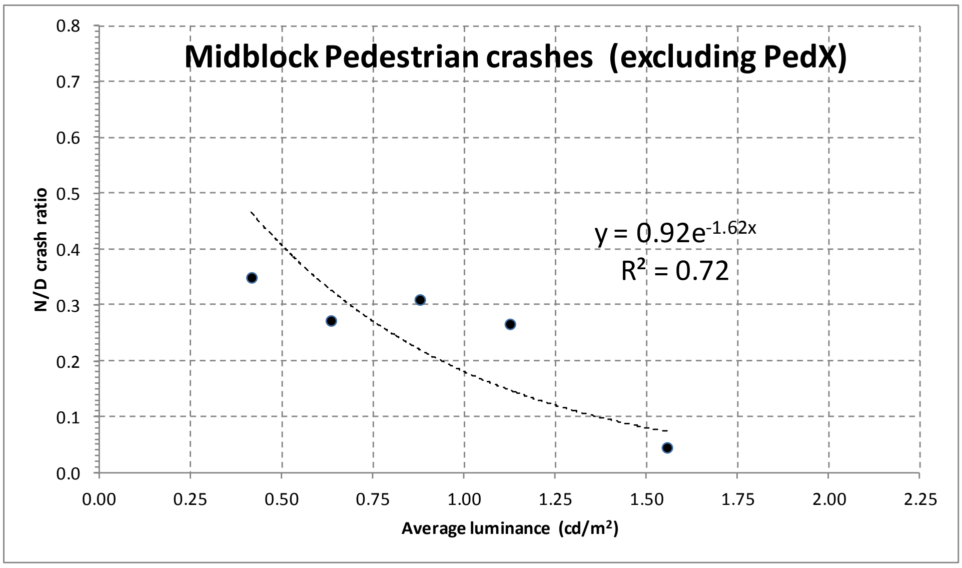


Figure 11 The relationship between average luminance and the night to day ratio for midblock Pedestrian crashes

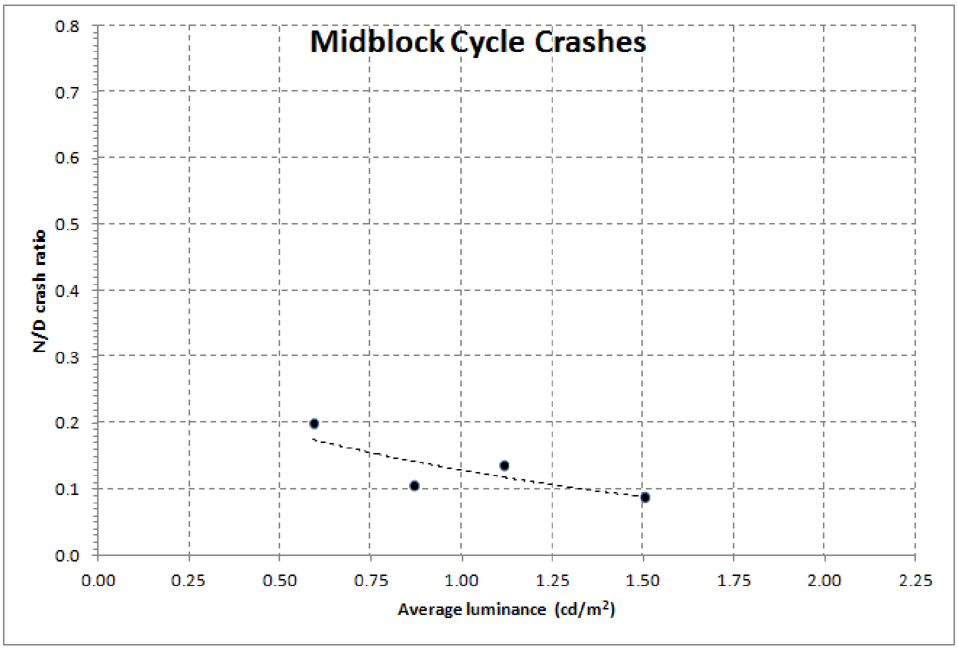


Figure 12 The relationship between average luminance and the night to day ratio for Cycle crashes.

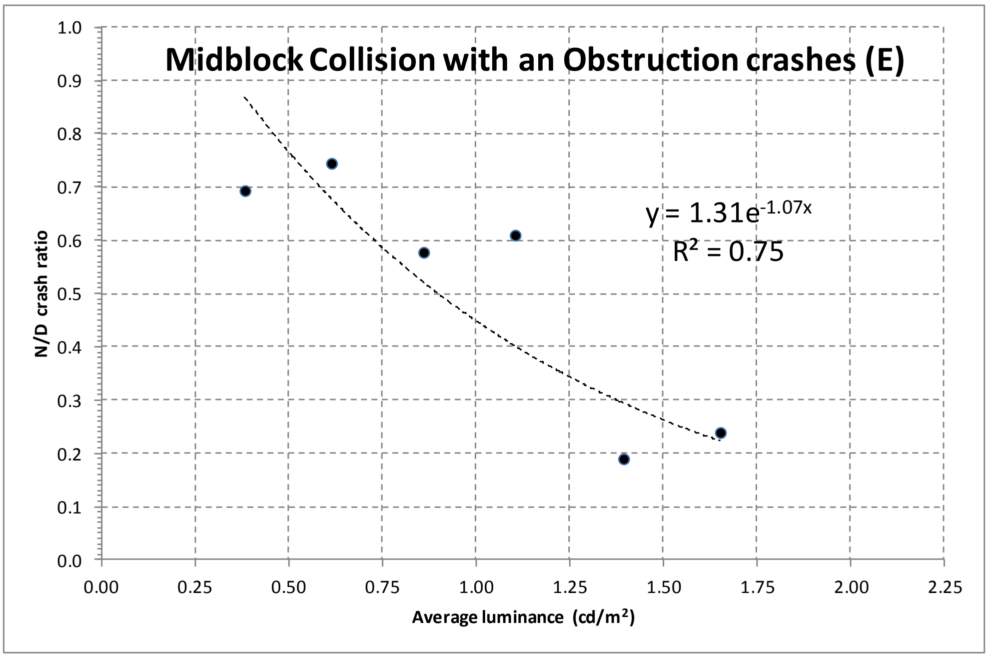


Figure 13 The relationship between average luminance and the night to day ratio for Collision with obstruction crashes

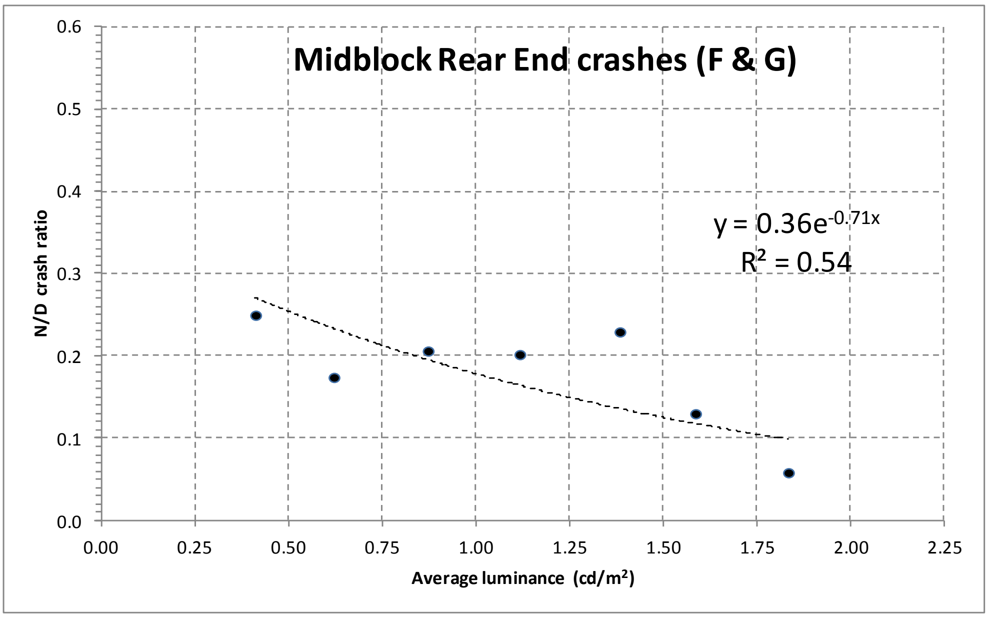


Figure 14 The relationship between average luminance and the night to day ratio for midblock Rear end crashes (F & G)

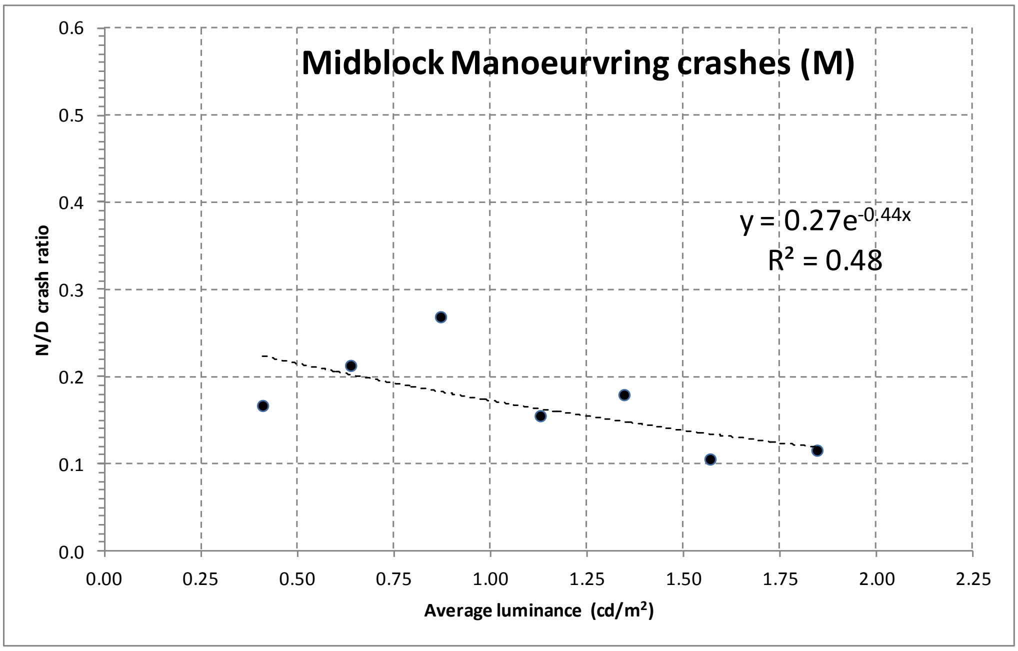


Figure 15 The relationship between average luminance and the night to day ratio for midblock Manoeuvring type crashes (M).

Description	***Parameter, a***	***Parameter, b***	***Sample size, n***	R^2	***Crash reduction****
Midblock Pedestrian (N&P) crashes	*0.92*	*-1.62*	*140*	*0.74*	*56%*
Midblock Cyclist crashes	*Data limited*	*Data limited*	*201*	*Data limited*	*Data limited*
Midblock Collision with obstruction (E) crashes	*1.31*	*-1.07*	*409*	*.0.75*	*41%*
Midblock Rear end (F&G) crashes	*0.36*	*-0.71*	*950*	*0.54*	*30%*
Midblock Manoeuvring (M) crashes	*0.27*	*-0.44*	*801*	*0.48*	*20%*

* % crash reduction expected for each 0.5 cd/m^2 increase in average luminance

In summary:

- Midblock pedestrian crashes demonstrated a dose-response relationship but on a small sample. Similarly with midblock cycle crashes although the night crash sample was too small for meaningful analysis.
- The single vehicle collision with obstruction crashes exhibited a strong dose-response. This movement type involves a vehicle colliding with some stationary object located within the carriageway. As the object will rarely be internally lit it is intuitive that this type of crash should be influenced by lighting.

- Both rear end (F&G) and Manoeuvring (M) type midblock crashes exhibited a dose-response relationship.
- Types of midblock crashes that did not show any clear dose-response relationship to average luminance were:
    - Overtaking and Head on (A&B)
    - Lost control and Cornering (C&D).

6.2.5 Intersection Crashes

In the analysis intersections have been classified on the basis of CAS identifiers as either:

- Major (controlled by traffic signals or roundabouts), or
- Minor (uncontrolled or controlled by stop or give way signs).

Many of the intersections classified as Minor may have a "midblock" level of lighting and be generally compatible with the average luminance found in this study. Major intersections, however, would tend to have a separate lighting design and may be somewhat less compatible.

Figure 16 illustrates that a dose-response relationship exists at both Minor and Major junctions with the dose-response at Minor intersections being somewhat stronger than that for Major intersections.

The all intersection dose-response surprisingly appears weaker than that for either Minor or Major intersections and is attributed to a different distribution in intersection control (roundabouts and traffic signals tend to have a higher proportion of crashes at night and are more commonly found on well-lit roads. See the dotted regression line in Figure 16).

Intersection lighting overall appears to have a weaker dose-response than midblock lighting but further intersection-specific measurements would help confirm this.

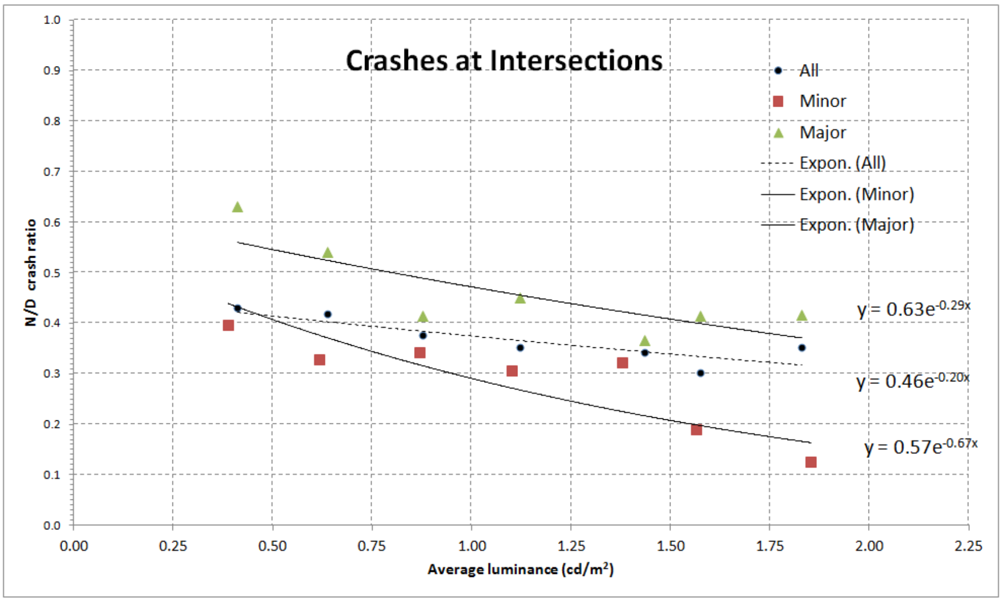


Figure 16 The relationship between average luminance and the night to day ratio for intersection crashes for Major (traffic signals and roundabouts), Minor (other intersections) and All (all intersections combined).

Description	*Parameter, a*	*Parameter, b*	*Sample size, n*	R^2	*Crash reduction**
Minor intersection crashes	*0.57*	*-0.67*	*2,513*	*0.75*	*28%*
Major intersection crashes	*0.63*	*-0.29*	*1,917*	*0.64*	*13%*
All intersection crashes	*0.46*	*-0.20*	*4,430*	*0.72*	*10%*

* % crash reduction expected for each 0.5 cd/m^2 increase in average luminance

6.2.6 Wet road surface

Road lighting design in New Zealand (and internationally) is based on achieving a satisfactory luminance distribution when the road is dry. Road surface reflection properties change dramatically in the wet and, although wet surface designs are possible, they are rarely undertaken. For this reason the Scott 1980 study only included crashes on a dry road surface. This database allows the effect of wet and dry pavements on crash rates to be examined independently.

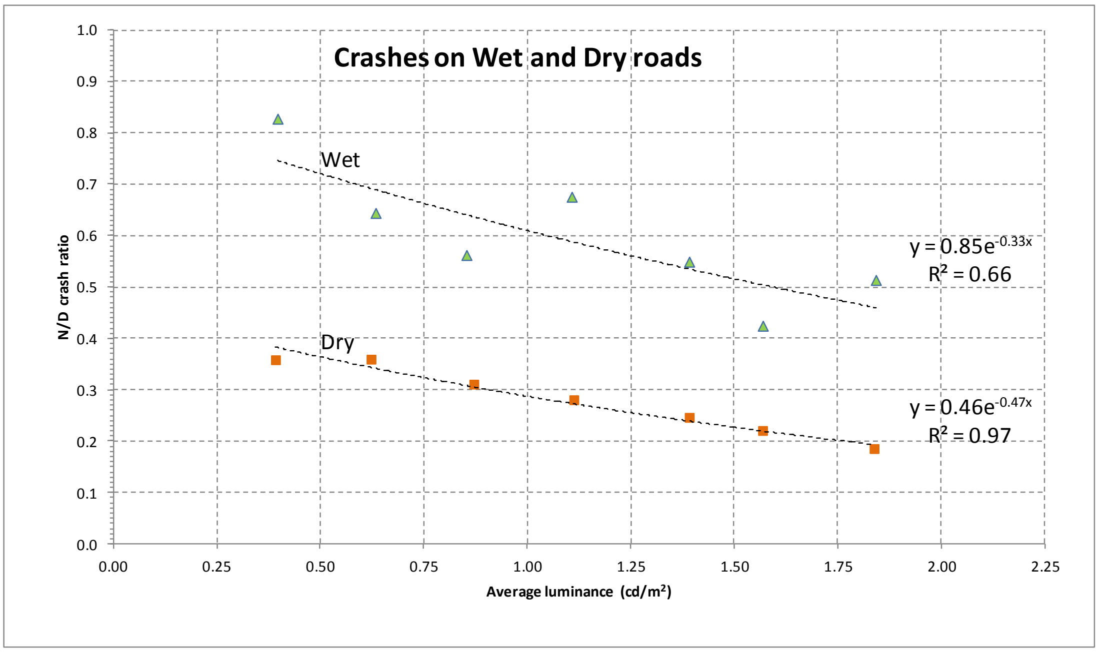


Figure 17 The relationship between average luminance and the night to day ratio for crashes on both dry roads and wet roads

Description	*Parameter, a*	*Parameter, b*	*Sample size, n*	R^2	*Crash reduction**
Crashes on dry roads	*0.46*	*-0.47*	*6,249*	*0.97*	*21%*
Crashes on wet roads	*0.85*	*-0.33*	*1,717*	*0.66*	*15%*

The following observations are made on the influence of road lighting on wet and dry roads:

- The night to day ratio of crashes is consistently higher on wet roads than on dry roads. The extent to which this result is exposure related (rainfall is more common at night), risk related (wet surfaces at night present greater risk), or traffic related (people may be less inclined to go out on wet nights), has not been explored.
- Increasing average luminance showed a corresponding decrease in the night to day crash ratio, both when the surface was dry and when the surface was wet. This is some consolation that our design methods, based purely on dry surface luminance conditions, still produce crash savings even when the road surface is wet.
- As might be expected the fit of the curves in Figure 17 for dry road crashes is tighter than the fit for wet road crashes as all luminance measurements were made for the dry road condition.

6.2.7 Crashes pre and post midnight:

It is now technically feasible to lower the level of lighting in the early hours of the morning to save energy when crash numbers are lower. To assist the choice of period the data has been examined for any temporal variations in the dose-response to road lighting. Figure 18 presents the Night to Day ratio of crashes with the night crashes divided into two groups – pre-midnight crashes and post-midnight crashes. The curves in Figure 18 suggest that the relative benefit of road lighting is greater in the post-midnight period than the pre-midnight period. Within an economic model this result can be balanced against the reduced number of crashes in the post-midnight period.

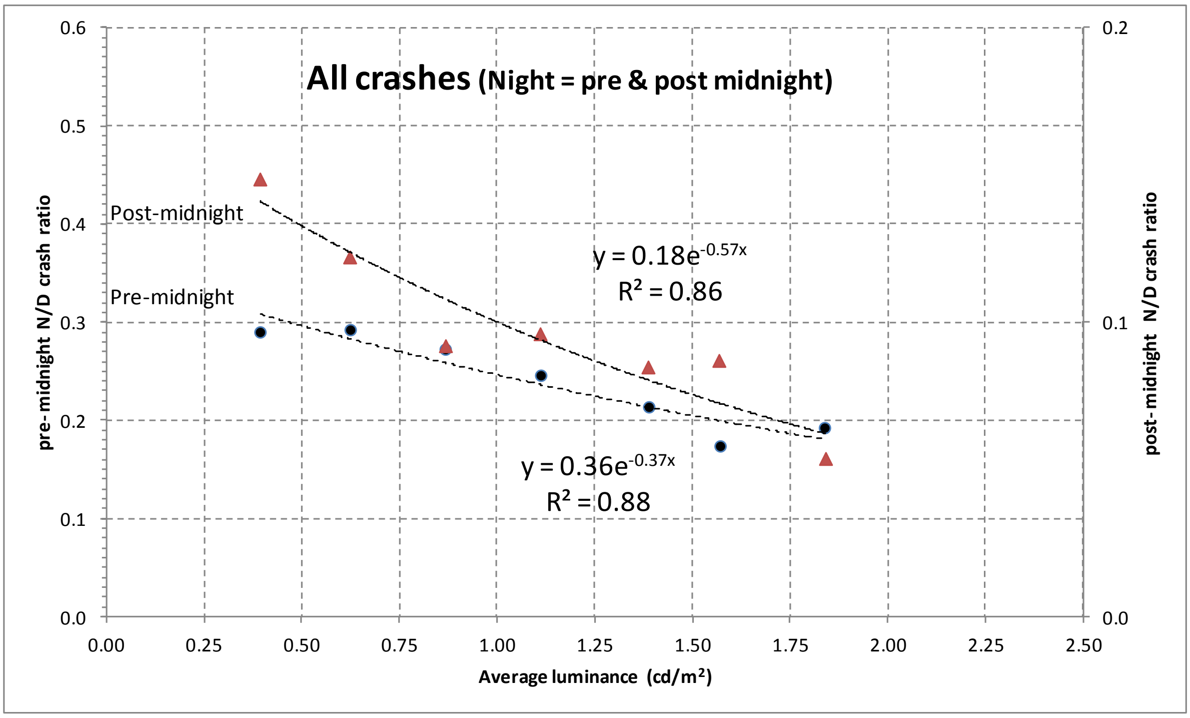


Figure 18 The relationship between average luminance and the ratio of night crashes (pre and post midnight) to day crashes. Note the two curves are plotted on different axes as there are three times more crashes pre-midnight than post midnight.

7 Crash Savings from Lighting

7.1 Existing Guidance

7.1.1 EEM guidance

Guidance on the crash savings to be expected from upgrading or installing new road lighting can be found in the NZTA Economic Evaluation Manual (EEM) Table A6.18 (a,b,d,& e). Typical crash reductions expected for new or upgraded installations are given as:

- Mid-block treatments in urban areas – 35% of night time accidents that are due to poor lighting
- Intersection treatments in urban areas – 35% of night time accidents that are due to poor lighting.
- Mid-block treatments in high-speed areas – 30% of night-time accidents that are due to poor lighting.
- Intersection treatments in high-speed areas – 30 to 50% of night-time accidents at intersections that are due to poor lighting.

This guidance does not differentiate in safety expectation between the basic V4 level of lighting and the highest V1 level. At the time this advice was drafted there was no New Zealand data available on the dose-response relationship between lighting levels and night time crashes.

7.1.2 AS/NZS1158 recommendations

The AS/NZS1158 standard recommends a strategic rather than a crash-based assessment of needs. It provides RCAs with general guidance on the lighting levels to adopt for roads in the network based on many factors including: traffic volumes, pedestrian volumes, vehicle speeds, the mix of local and through traffic, traffic generation from abutting properties, and the frequency of parked cars.

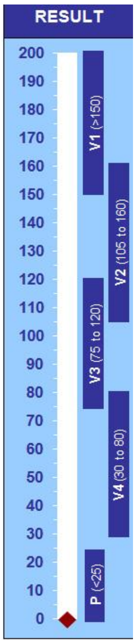
The highest level of lighting is recommended for city centres or areas with mixtures of high pedestrian and traffic volumes. The lowest level of lighting is recommended for sub-arterials carrying moderate levels of traffic at low to moderate speeds.

7.1.3 RightLight recommendations

The Energy Efficiency and Conservation Authority (EECA) website provides a New Zealand "best practice" guidance on the level of lighting to apply to roads in a network (See Table 5).

Table 5 EECA Category V network section tool.

	Parameter	Options		Weighting	Score
EXPOSURE	**Vehicle Volume**	Very High	>20,000	60	0
		High	12,000 to 25,000	50	
		Moderate	6,500 to 15,000	40	
		Low	3,000 to 7,500	20	
		Very Low	<3,500	0	
	Road Designation (Lighting should support the road network hierarchy and encourage traffic to use the main routes which are designed to carry higher volumes of traffic)	Motorway/Freeway		30	0
		Major Arterial		25	
		Arterial		15	
		Collector		10	
		Local		0	
RISK	**Traffic Composition** (A mix of motorised and non motorised traffic increases need for improved visibility)	Mixed with very high proportion of non-motorised		30	0
		Mixed	A mix of motorised and non motorised traffic	10	
		Vehicles only	Very few cyclists or pedestrians present	0	
	Pedestrian and Cycle Volumes (Road lighting is particularly effective at reducing pedestrian and cycle accidents)	Very High	Major central city road	20	0
		High	Busy town centre or suburban road	10	
		Moderate	Urban cycle route or Rural where pedestrians/cyclists are present (eg school)	5	
		Low	Residential road	0	
	Speed Limit	Very High	90 or 100 km/h	20	0
		High	70 or 80 km/h	15	
		Moderate	60 km/h	5	
		Low	50 km/h or less	0	
	Parked Vehicles (Increased number of parked vehicles on the road generates more pedestrian movements including road	Many	Main central city road	10	0
		Some	Urban with some on-road parked vehicles or Rural with few on-road parked vehicle	5	
		Few - None	Urban road with few/no cars parked on road	0	
	Traffic Generation from Abutting Properties (High levels of traffic to and from abutting properties increases the number of potential conflicts)	High	Busy commercial area, supermarket, shops etc	10	0
		Moderate	Some small businesses along road	5	
		Low	Traffic generated from residential properties/farms in neighbourhood	0	
	Ambient Luminance (Higher ambient luminance raises the adaption level and therefore higher levels of road lighting are required to compensate)	Very High	Central city shopping area creating high vertical illuminance	20	0
		High	Arterial road with small shopping centre	15	
		Moderate	Urban residential industrial area with minimal private lighting	5	
		Low	Rural /semi rural area, dark surrounds	0	
	TOTAL SCORE				0



The tool is spreadsheet based and allows individual streets to be classified into one of the four available V subcategories according to risk. There are eight inputs required, two related to traffic exposure and six related to risk. The tool draws on AS/NZS1158 and CIE guidelines to give practical guidance in what is still a somewhat exploratory area. Its form allows easy updating as further evidence or experience becomes available.

7.2 Guidance from this study

The results of this study provide further guidance on the types, locations and severity of crashes that can be influenced by road lighting. These relationships are summarised in Table 6.

In the grouped analysis of section 6 the fitted line followed took the form:

$$y = a\, e^{b x} \qquad (1)$$

where: y = night to day crash ratio

x = average luminance

a = crash parameter

b = luminance parameter.

The right-hand column in Table 6 shows the percentage reduction in crashes expected from increasing the average luminance in a street by 0.50 cd/m^2 and is derived as follows:

$$\text{Percentage change in night crashes} = 1 - y_2 / y_1 \qquad (2)$$

where: y_1 = the night to day crash ratio for the initial condition

y_2 = the condition with average luminance increased by 0.5 cd/m^2.

Then by definition:

luminance $x_2 = x_1 + 0.5$

By substitution of (1) in equation (2) and with simplification then:

$$\text{Percentage change in night crashes} = 1 - e^{0.5\,b}$$

Table 6 The reduction in night crashes expected for a range of crash groups for each 0.5 cd/m² increase in road luminance

Description of Crash Group	*% reduction in night crashes expected for each 0.5 cd/m² increase in luminance*
All reported crashes	*19%*
Midblock crashes	*33%*
Major Intersection crashes	*13%*
Minor intersection crashes	*28%*
Serious & Fatal midblock crashes	*50%**
Minor midblock crashes	*23%*
Non injury midblock crashes	*34%*
Pedestrian (N&P) midblock crashes	*56%**
Hit obstruction (E) midblock crashes	*41%*
Rear end (F&G) midblock crashes	*30%*
Manoeuvring (M) midblock crashes	*20%*
Pre-midnight night crashes	*17%*
Post-midnight night crashes	*25%*

Note: The data used to derive this table had an average luminance ranging from 0.25 cd/m^2 to 2.25 cd/m^2. The validity of the results lies in that range.

* Figures based on a small sample

These results provide more guidance than is available in the current EEM as they indicate the likely crash savings expected from providing higher lighting levels. Conversely they also provide information on the effect on crashes if street lights are dimmed; technology that is now readily available in association with LED luminaires.

The crash savings from these results are slightly more conservative than the existing EEM across-the-board 35% reduction in crashes from good street lighting. However this data is from existing streets already lit with an average luminance between 0.25 to 2.25 cd/m^2 and relates to increases in light output rather than installing new lighting in an otherwise unlit area. Further work may be needed to determine an appropriate value for the transition from unlit or category P lighting to a category V lighting condition.

8 Conclusions

Where road lighting is provided night crashes tend to reduce:

- when average luminance ($\overline{L}$) is increased. Average luminance more than any other LTP determines the relative night crash frequency.
- when glare (TI) is reduced.

This study also found the following general relationships between crashes and average luminance. Not all of these observations have tested positively for statistical significance.

When average luminance is increased night crashes tend to reduce:

- for roads of all traffic volumes. Three hierarchical groupings by traffic volume showed similar crash reductions with increasing average luminance.
- both when the road surface is dry and when it is wet.
- more strongly for fatal and serious crashes than for minor or non-injury crashes.
- more strongly at midblock locations than at intersections (a full study of intersection crashes and lighting has not yet been undertaken).
- more strongly when the crash movement is of type E or midblock N&P. Type E crashes involve a moving vehicle striking a stationary object within the carriageway and midblock N&P crashes involve a midblock pedestrian crash but not on a pedestrian crossing.
- moderately for crash movement types F, G, and M. These are rear end and manoeuvring type crashes.
- there was insufficient evidence to indicate whether cycle, motorcycle, head-on, cornering or overtaking type crashes reduced with increasing road luminance.

9 Recommendations

- This pilot study has developed a simple and reliable field method to examine the effect of road lighting on crashes and should now be extended to include:
  - the safety benefits of lighting intersections (illuminance measurement)
  - the safety benefits of lighting rural roads and state highways
  - quantifying any benefits arising from the use of white light in preference to coloured (HPS) light.
- Review the NZTA Economic Evaluation Manual advice on crash savings from installing street lighting on the basis of results from this study.
- Develop “new technology” guidelines to maximise both safety and energy efficiency through the use of adaptive lighting switching at the appropriate times and levels.
- Review the New Zealand Lighting Standard road reflection tables in the knowledge that significant additional crash savings are available at higher levels of road luminance than are currently being provided.

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Appendix 1: Field Method for Measuring Glare and Luminance

Luminance Calibration

Equipment:

- Camera, Canon 550D DSLR, 50mm lens
- Luminance meter, Minolta LS110, 1/3 degree, (MSL calibrated)
- Illuminance meter, Hagner EC1, (MSL calibrated)
- Greyscale targets.

The camera was used in the field with a standard exposure of 1/50 sec, f /3.2, ISO3200 and bracketed +1 and -1 stop to extend the range of luminance measurement. All auto functions were turned off and white balance was set to “Daylight, 5,200°K”.

Pixel to luminance calibration required a set of 6 grey scale targets (Figure 19) placed in a uniformly illuminated environment and lit exclusively by the type of light source being calibrated. To achieve a wider calibration range calibrations were carried out in both 10 lux and 5 lux environments.

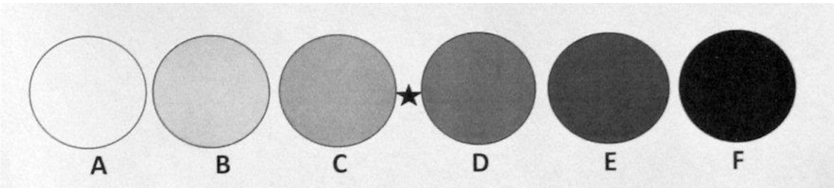


Figure 19 Grey scale targets used for calibration

The grey scale targets were photographed with the camera mounted on a tripod vertically above the targets and the camera then replaced by the luminance meter in the same focal plane position. Luminance readings were recorded for each of the greyscale disks. An illuminance meter located adjacent to the targets ensured the light output did not vary over the period the readings were taken.

The grey scale pixel value obtained from the photograph (0-255) was compared to the average luminance (cd/m^2) obtained from the luminance meter. This gave a total of 12 calibration points with which to fit a 3^{rd} order polynomial calibration equation.

The relationship between greyscale pixel and luminance was found to be linear at low exposure values and relatively insensitive to changes in the type of light source (see Figure 20).

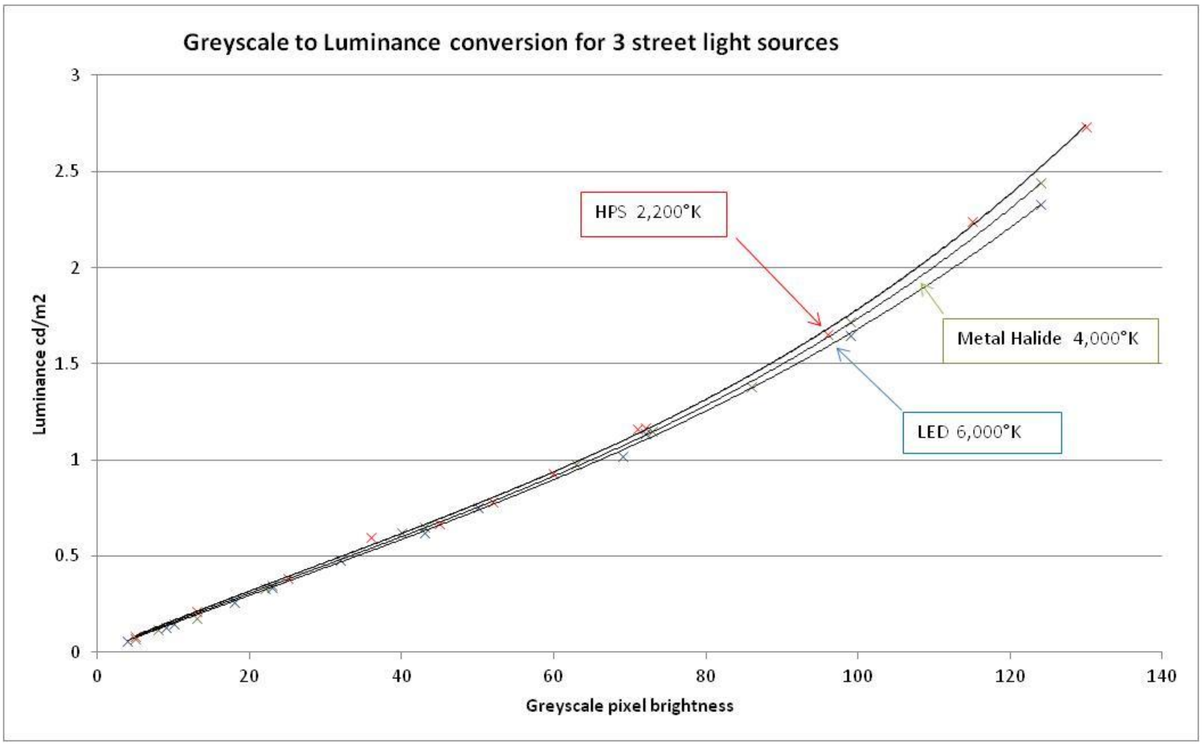


Figure 20 Calibration relationships between greyscale pixel value and luminance for three light sources

Field Measurement

Equipment:

- Camera, Canon 550D DSLR with 50mm lens
- Illuminance meter, for glare measurements
- Inclinometer.

Photographs (1/50 sec, f /3.2, ISO3200, WB=daylight, f=50mm) were taken from the survey car parked on the LHS of the carriageway. Photographs were made with the camera held against a pad positioned on the external structure of the car at a height of 1.25 metres above the road surface as in Figure 21.

Figure 21 Photograph / Luminance measurement position showing the camera 1.25m above the road surface 0, the 19° elevation to the first luminaire, and the measurement area between the second and third luminaires.

The car was positioned in the street such that the line from the first luminaire to the driver's eye subtended an angle of 19 degrees to the longitudinal axis of the car/road. This is the maximum angle for inclusion of glare measurements (CIE) and represents the point where the maximum TI from an individual luminaire will be recorded. This point was used for surveying both glare and luminance. The bright transverse band of light on the road surface from the second luminaire formed the start of the measurement area. This band is typically some 50 metres from the camera so the CIE geometry with observation angles ranging from 0.5° to 1.4° is generally maintained.

An issue with any road luminance measurement is the need to avoid spurious direct light from oncoming vehicle headlights or adjacent bright street lights. Additional lens shielding assisted to reduce direct light from adjacent street lights and care was taken to ensure cars vacated the scene before photographs were taken.

Desk Analysis

Subsequent to the field measurement a desk analysis phase is required to extract the luminance values from the photographs. Standard photo processing software (e.g. Paint Shop Pro, Photoshop, GIMP) can be used to convert the photo to a greyscale image and then select specific areas of the road surface for measurement of average pixel brightness.

The start and end limits of the measurement area followed the centre of two bright luminance bands across the road transverse to the direction of traffic. The measurement area included at least one fully symmetrical span of lighting but up to three spans could be included if viewing conditions permitted. With more spans included minor spacing discrepancies will average out. Starting and ending a selection along the centre of a bright band also assists even out perspective effects. These effects are minimised when the front and rear halves of the measurement area contain an equal mix of bright and dark areas.

The edge of the measurement area also required definition in order to maintain consistency with respect to parked cars. If parked cars were present, or where car parking areas were marked out along the edge of the road, the measurement area excluded areas designated for parked cars. On roads without parked cars or markings the measurement area extended edge line to edge line, or kerb to kerb if no edge line was present.

Due to the need to avoid parked cars the measurement area adopted for this study is probably a little more restricted than the measurement area used in road lighting design calculations. For this reason the average luminance values found in this study may be a little higher than those expected in design calculations.

The average greyscale value of any defined measurement area is output from the photo processing software. The darkest region (minimum luminance) can be found by moving a 100+ pixel selection area over the photo. The greyscale values obtained from this process can be converted to luminance (cd/m^2) using calibration equations held within the analysis spreadsheet.

Glare Measurements

As stated earlier glare measurements are difficult to make in the field and are also subject to greater random variation. Several options were field tested and the one described below was the one finally adopted.

1st luminaire: The survey vehicle was placed so that line of sight to the first luminaire subtended an angle of 19 degrees to the horizontal axis of the vehicle to an observer in the driver's seat.

An illuminance meter was used to measure the incident light from this luminaire at the observer's eye in a plane normal to the line of sight. The illuminance meter was attached to a hollow shielding tube which provided an unobstructed field of view of 2° and fully shielded zone beyond 9.5°. This proved satisfactory to gather all light emitted from the target luminaire and obscure all light from adjacent luminaires.

2nd, 3rd and 4th luminaires: The shielded illuminance method described above was not sufficiently sensitive or discriminatory to measure light from the 2nd, 3rd and 4th luminaires. The luminance meter with its 1/3° acceptance angle was used to measure the light emitted from these luminaires. However, use of the luminance meter in this way was a time consuming operation and potentially error prone.

Light emitted from the 2nd, 3rd and 4th luminaires was captured in the luminance photographs and it was noted that the size and intensity of the flare associated with each luminaire in the photograph was closely related to the light output as measured by the luminance meter. A simple photographic index of flare versus luminance meter readings was compiled and field tested. Under uniform exposure conditions the visual combination of flare and physical size of the luminaire provided a measure of glare contribution sufficient for the purposes of this survey.

The TI derived from computer design is found by summing the contribution from all luminaires on an idealised straight section of road for a distance of 500 metres but the contribution from luminaires beyond the first 4 becomes increasingly small. This study summed only the TI contribution from the first 4 visible luminaires. Due to obscuration by trees or a curvilinear alignment some sites had even less than 4 visible luminaires and in these cases the TI summed the maximum number of luminaires visible.

Averaged over the sample 56% of the total TI came from the first luminaire and 44% from the sum of the 2nd, 3rd and 4th luminaires.

Appendix 2: International Comparison of New Zealand's Light Technical Parameters

Relevant CIE Publications

The CIE (Commission Internationale De L'Éclairage) is the international body that deals with lighting and illumination. It has a membership of some 40 countries (including New Zealand) and is based in Vienna. The work of the CIE is carried out by seven divisions and the one most pertinent to road lighting is Division 4 "Lighting and Signalling for Transport". CIE publications relevant to this project are outlined in the following three sections.

CIE 115:2010 Lighting of Roads for Motor and Pedestrian Traffic

This document describes the basic CIE luminance method for lighting roads. With some minor variation this is the same method that the New Zealand and Australian standard follow. The key parameters identified are Average Luminance, Overall Uniformity, Longitudinal Uniformity, Threshold Increment, and Surround Ratio, the same set that New Zealand and Australia use.

There are three lighting classes described in CIE 115:2010. These are:

- Class M: Luminance based traffic route lighting equivalent to the NZ category V lighting
- Class C: Lighting for conflict areas equivalent to the NZ illuminance requirements for intersection lighting in category V lighting
- Class P: Lighting for minor routes equivalent to the NZ category P lighting.

As this project is concerned with the luminance generated from the road surface it is class M lighting that is of interest. The values of the Light Technical Parameters recommended by CIE 115:2010 for class M lighting are shown in Table 7 below.

Table 7 CIE Light Technical Parameter recommendations (CIE 115:2010)

CIE Category	$\bar{L}$	*Uo*	*Ul*	*TI*	*Es*
M1	*2.00*	*0.4*	*0.7*	*10%*	*50%*
M2	*1.50*	*0.4*	*0.7*	*10%*	*50%*
M3	*1.00*	*0.4*	*0.6*	*15%*	*50%*
M4	*0.75*	*0.4*	*0.6*	*15%*	*50%*
M5	*0.50*	*0.35*	*0.4*	*15%*	*50%*
M6	*0.30*	*0.35*	*0.4*	*20%*	*50%*

The report contains some general advice on the particular category of lighting to apply to any given road but this advice is expected to be covered in more detail in the standard or guidelines issued by each member country. For New Zealand the M5 to M2 categories match in terms of average luminance with the V4 to V1 subcategories of the New Zealand standard.

CIE 194:2011 On Site Measurement of the Photometric Properties of Road and Tunnel Lighting

This document, released this year, includes information on current methods to measure both luminance and illuminance. The emphasis is on mobile measurements as this is a relatively new technology.

Luminance measurement: Mobile "Image Luminance Measuring Devices" (ILMD) are now available to provide luminance contours from the driver's perspective. The standard identifies the technology generically and specifies the conditions for its use. As far as is known mobile equipment of this nature is not yet available in New Zealand.

The document also identifies the optical constraints that arise from photographic measurement of luminance, including linearity, pixel saturation, noise, lens flare, and ghost images. These are common issues that need to be addressed in both static and mobile measurement of luminance. These issues have been addressed in the photographic method used to determine luminance in this report.

CIE 093-1992 Road Lighting as an Accident Countermeasure

This report investigated 62 studies from 15 countries and found that, of all the light technical parameters, the one with the strongest effect on night time accident frequency was average luminance. Overall the reduction in night time crashes that could be attributed to the effect of road lighting was 30%. No study was able to provide reliable information on the safety effects of uniformity or glare although logically there would be an effect. Perhaps the advent of lighting standards now restricts the range of glare and uniformity found on roads.

How does New Zealand Compare?

New Zealand's light technical parameters from AS/NZS1158.1:2005 are shown in Table 8.

Table 8 Light Technical Parameter values from the New Zealand Lighting Standards (AS/NZS1158.1.1: 2005)

NZ Category	$\bar{L}$	*Uo*	*Ul*	*TI*	*Es*
V1	*1.50*	*0.33*	*0.3*	*20%*	*50%*
V2	*1.00*	*0.33*	*0.3*	*20%*	*50%*
V3	*0.75*	*0.33*	*0.3*	*20%*	*50%*
V4	*0.50*	*0.33*	*0.3*	*20%*	*50%*

NZ uses LTP values below CIE recommendations for overall uniformity (Uo), longitudinal uniformity (Ul) and glare (TI) but matches CIE in surround illuminance (Es) (see Table 9).

Table 9 Light Technical Parameters of the NZ standard (AS/NZS1158.1.1:2005) as a percentage of the CIE recommendation in CIE 115:2010 (Table 8)

NZ Category	*CIE Category*	*Uo*	*Ul*	*TI**	*Es*
V1	*M2*	*83%*	*43%*	*50%*	*100%*
V2	*M3*	*83%*	*50%*	*75%*	*100%*
V3	*M4*	*83%*	*50%*	*75%*	*100%*
V4	*M5*	*94%*	*75%*	*75%*	*100%*

* As a low TI is a higher standard the comparison here is of 1/TI

An attempt was made to match UK lighting classes with the NZ lighting subcategories by comparing the traffic volume and hierarchy recommendations in UK standard BS 5489 with similar recommendations adopted by a major NZ city, Christchurch (Table 10). The match was difficult because of differing definitions but similar roads did appear to be lit to approximately the same average luminance. If the Christchurch recommendations are typical of NZ, the main differences in lighting between NZ and the UK may lie in the uniformity and glare values rather than in average luminance.

Table 10 Lighting categories related to traffic volume and hierarchy for Christchurch City

Road classification	*Traffic volume*	*Lighting category*
Urban		
Arterial Major shopping area with bright surroundings	*> 20,000*	*V1*
Arterial	*> 15,000*	*V2*
Arterial	*7,000 to 15,000*	*V3*
Arterial	*3,000 to 7,000*	*V3*
Collector	*> 15,000*	*V2*
Collector	*7,000 to 15,000*	*V3*
Collector	*3,000 to 7,000*	*V4*
Rural		
Arterial	*> 15,000*	*V3*
Arterial	*7,000 to 15,000*	*V3*
Arterial	*3,000 to 7,000*	*V4*
Collector	*> 15,000*	*V3*
Collector	*7,000 to 15,000*	*V4*
Collector	*3,000 to 7,000*	*V4*

Source: http://resources.ccc.govt.nz/files/IDS/IDS11LightingJuly2010.pdf

The comparison with Australia is a little easier as we share a common standard. However the light technical parameters values used in Australia differ from New Zealand in two areas:

- Australia uses a longitudinal uniformity Ul = 0.5 for all categories of lighting while New Zealand uses Ul = 0.3. Some of the difference in the value of Ul (but not all) can be accounted for by the less stringent observer position adopted in Australia.
- A lower level of category V lighting, V5, is permitted in Australia which is not recommended for use in New Zealand. This category appears to be a legacy category for Australia similar to what the low level ME6 appears to be in the UK.

Summary:

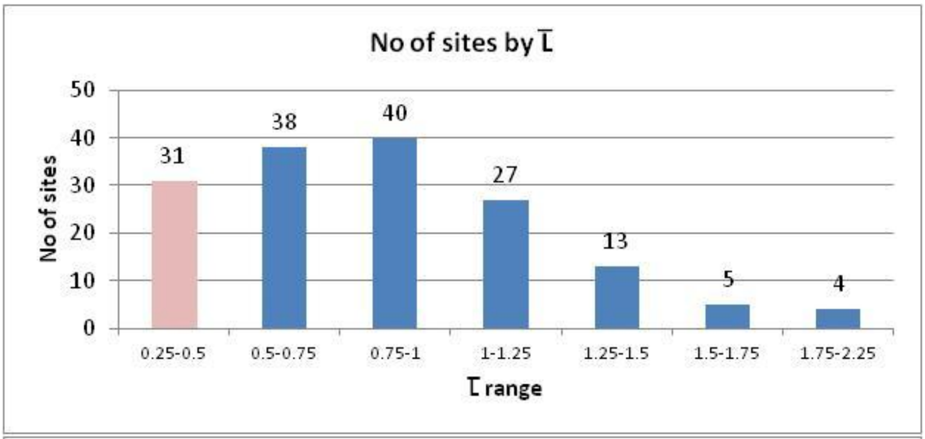
- Average luminance: In relation to traffic volume the level of average luminance adopted in New Zealand is reasonably comparable with those adopted internationally.
- Overall uniformity: The New Zealand Uo value of 0.33 is the same as Australia's and 80% of the CIE recommendation (0.4).
- Longitudinal uniformity: The New Zealand Ul value of 0.30 is 40% lower than Australia's (0.5) and around 50% lower than the typical CIE recommendation (0.6).
- Threshold Increment: The New Zealand TI maximum of 20% is less stringent than the CIE recommendations of 10% to 15% maximum.
- Surround illuminance: New Zealand, Australia and the CIE share a common 50% value for surround illuminance.

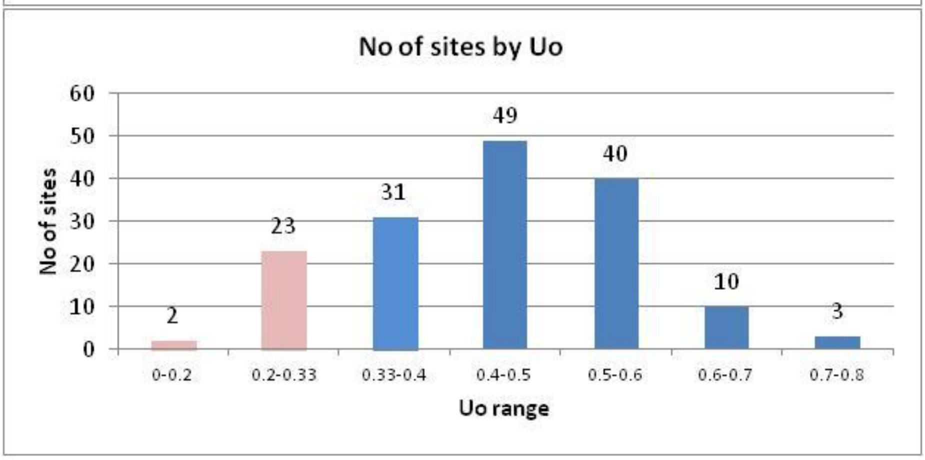
Appendix 3: Field values of Light Technical Parameters

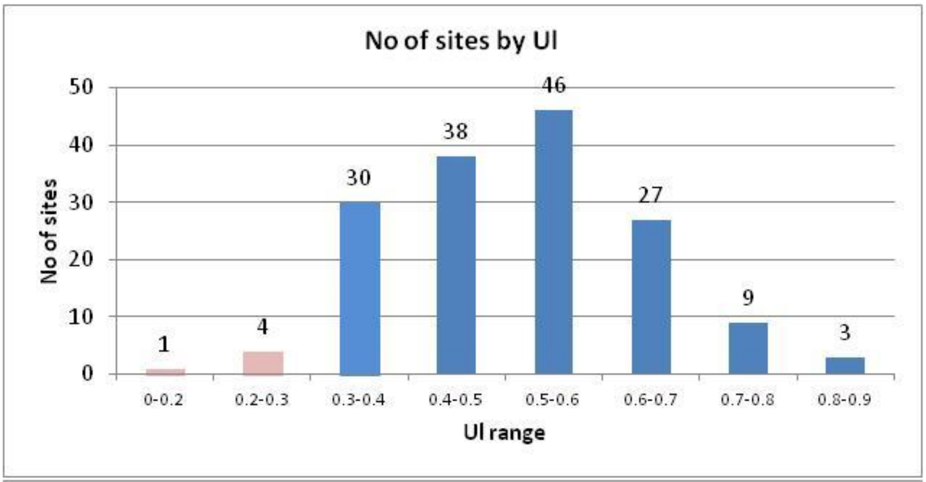
Below are histograms for the site field measurements of the light technical parameters Average luminance ($\bar{L}$), Overall uniformity (Uo), Longitudinal uniformity (Ul) and Threshold increment (TI).

Sites which do not meet current AS/NZS1158 defined minimums are shown in light shading. However, in making comparisons with current design minimums, the following should be noted:

- The field values represent a snapshot at one point in time – when the survey was made.
- Most sites will have been designed with AS/NZS1158 r-tables NZN4 and NZR2. Recent research suggests these r-tables usually overestimate average luminance and underestimate threshold increment.
- Field measurements include the influence of environmental factors such as grade changes, overhanging trees, manmade structures etc. which cannot be taken into account in design calculations.
- The field measurements excluded marked kerbside parking lanes. These areas may or may not have been included in the original design calculations.
- Field measurements of Threshold increment (TI) summed the contribution from only the first four luminaires visible and may underestimate the calculated TI by some 10%.



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No of sites
UI range
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0.2-0.3
0.3-0.4
0.4-0.5
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4
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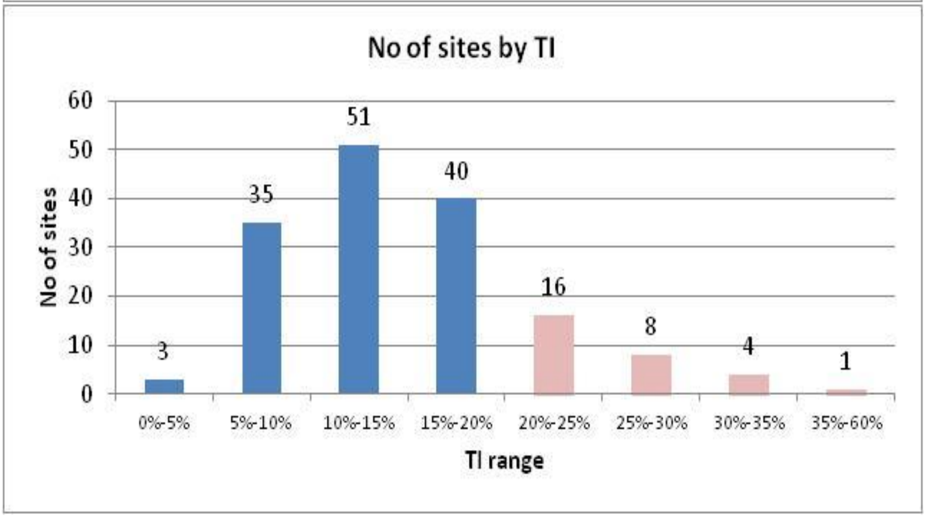
38
46
27
9
3


No of sites by TI
No of sites
TI range
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10%-15%
15%-20%
20%-25%
25%-30%
30%-35%
35%-60%
3
35
51
40
16
8
4
1

Appendix 4: CAS Movement Codes

	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	CRASH OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOW VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT TURN SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE	OBSOLETE	TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	"U" TURN	"U" TURN	DRIVEWAY MANOEUVRE	PARKING OPPOSITE	ENTERING OR LEAVING	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER