White light, warm white light and yellow light -is there any evidence for a safety related difference at the category V level?

White light, warm white light and yellow light -is there any evidence for a safety related difference at the category V level?

Opus International Consultants Ltd
Opus Research
33 The Esplanade, Petone
PO Box 30 845, Lower Hutt 5040
New Zealand

Prepared by Bill Frith (Opus Research) and
Michael Jackett (Jackett Consultants)

Telephone: +64 4 587 0600
Facsimile: +64 4 587 0604

Date: 9/2/2015

Contents

Executive Summary

Since the 1980s most new road lighting has been of the high pressure sodium variety. This is yellow in colour. The new LED lighting which is much cheaper to run, easier to maintain and more flexible in its operation is white in colour.

However, LED lighting with its white light has different spectral properties from the yellow HPS light. These differences require investigation to discover any safety advantages or disadvantages. It is well known that the human eye shifts its spectral sensitivity in response to changes in lighting levels. This relates to how the light is received by the eye.

Above around 3 cd/m2, the dominant light receptors in the retina are the "cones." which are most sensitive to yellow light. These levels are referred to as "photopic." As lighting levels reduce below 3 cd/m2 the cones progressively lose their dominance and the rods become more important. At extremely low light levels like starlight only the rods are active and the levels are called "scotopic". In between levels are referred to as “mesopic”

Road lighting is almost always in the range 0.1 to 2 cd/m2 towards the top end of the mesopic range where both rods and cones are active. The sharp central vision required for driving primarily uses cones.

Evidence from laboratory trials and some specifically set up on-road scenarios supports the idea that visibility is improved by the wider spectrum achieved by “white” light sources of road lighting like LEDs. This effect is much more pronounced at category P lighting levels than at category V lighting levels. Because of this white light will make pedestrian areas more pleasant and its increased blue component will provide efficiency gains when used at the low light levels found in minor road (Category P) lighting.

The relation between road safety and the colour of light is multifactorial and no on-road studies been carried out to establish a direct linkage between the colour of light and crashes. At category V levels any change may be small and likely to relate to changed colour contrast.

With age, the lens of the human eye yellows meaning that blue light is largely absorbed in the lens, meaning the mesopic impact of blue-rich light is lessened for older drivers.

The British have stated in their lighting standard that there is not enough evidence at this stage to apply S/P ratios to traffic route (category V) lighting on the basis of the greater mesopic luminance associated with white light.

The colour rendition characteristics of both white light and warm white light as emitted by LEDs exceed by a wide margin that of HPS (LED CRI> 70%, HPS CRI ~24%).There is no evidence of any safety difference between white LED lighting and “warm white” LED lighting

1 Introduction

Since the 1980s most new road lighting has been of the high pressure sodium variety. This is yellow in colour. The new LED lighting which is much cheaper to run, easier to maintain and more flexible in its operation is white in colour.

High pressure sodium (HPS) lights have in the last few decades provided most of New Zealand's and the developed world's street lighting. Compared with alternatives they have had the advantages of long life, (hence less maintenance), low cost, energy efficiency and long range optical control[14]. (Lewin, 2003). However, now LED lighting which emits white light has been developed to the extent that it has significant advantages over HPS in terms of maintenance, energy efficiency and ease of dimming and brightening to suit changing circumstances via computer control systems. However, LED lighting with its white light has different spectral properties from the yellow HPS light. These differences require investigation to discover any safety advantages or disadvantages. All the work referred to in this document relates either directly or indirectly to visibility. There is nothing here related directly to safety. There is a large body of literature in which visibility is related in different ways to safety (Lewin, 2003). However, in terms of white light vis-vis yellow light safety linkages which can produce direct comparisons are absent. This research has yet to take place.

2 Spectral effects in lighting

2.1 Overview

Light emitted from luminaires is measured in lumens. The unit lumen may appear colour blind, but in reality each lumen of light is "the product of the emitted energy over the visible wavelength range, factored by the eye sensitivity curve, or the eye's spectral response" (Lewin, 2003 p6). It is well known that the human eye shifts its spectral sensitivity in response to changes in lighting levels. This relates to how the light is received by the eye.
According to Lewin, 2003 above around 3 cd/m2, the dominant light receptors in the retina are the "cones." which are most sensitive to yellow light. These levels are referred to as "photopic." As lighting levels reduce below 3 cd/m2 the cones progressively lose their dominance and the rods become more important. At extremely low light levels like starlight only the rods are active and the levels are called "scotopic." Road lighting is almost always in the range 0.1 to 2 cd/m2 , and in that range both rods and cones are active. This middle range is called "mesopic".
The relevant anatomy of the eye is shown in figure 1.

[14] Optical control refers to the ability to place lumens where the designer want them to be placed.(http://www.cree.com/OCF viewed 2/2/2015

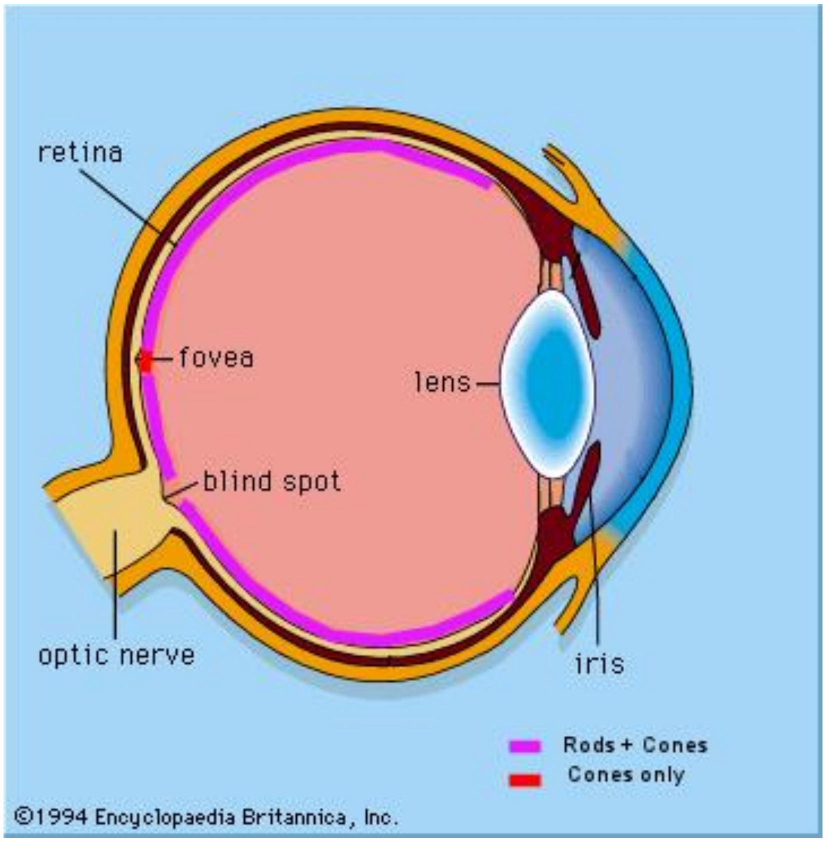

Figure 1: Anatomy of the eye

As shown in figure 1 the eye has a small central area containing only cones called the fovea. The cones in the fovea are responsible for sharp central vision required for activities where visual detail is primarily important like driving and reading.

Figure 2 from Lewin (2003) shows the photopic, mesopic and scotopic ranges and the road lighting levels at that time recommended by CIE and IESNA.

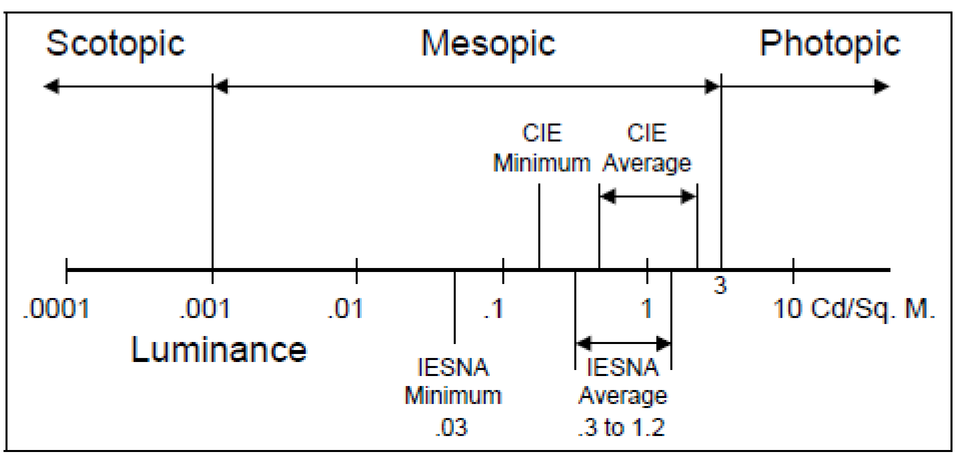

Figure 2: The range of photopic, mesopic and scotopic light levels

Figure 3 from Jackett and Culling (2014) relates this to some practical situations

	Condition	Illuminance (lux)	Luminance (cd/m^2)
Photopic (cones)	Bright Sunlight	100,000	
	Overcast Day	10,000	
	Work desktop	400	
Mesopic	Floodlit Pedestrian Xing	30	3
	Category V lighting	10	1
	Category P lighting	2	0.2
Scotopic (rods)	Full moon	0.2	0.02
	Starlight	0.001	

Figure 3: The different light intensities associated with various situations

From figure 3 it is apparent that for route lighting we are dealing only with the upper end of the mesopic range. This is important as most of the fairly sparse mesopic research applies to lower down in the mesopic range, category p in New Zealand parlance.

Figure 4 from Institute of Lighting Professionals (2012), illustrates CIE photopic and scotopic luminous efficiency functions V (λ) and V' (λ). The chart illustrates spectral response of the rods and cones. The vertical axis refers to luminous spectral efficiency, a measure of how effectively the rods or cones react to the light of differing wavelengths. V (λ) refers to the response of the cones while V' (λ) refers to the response of the rods.

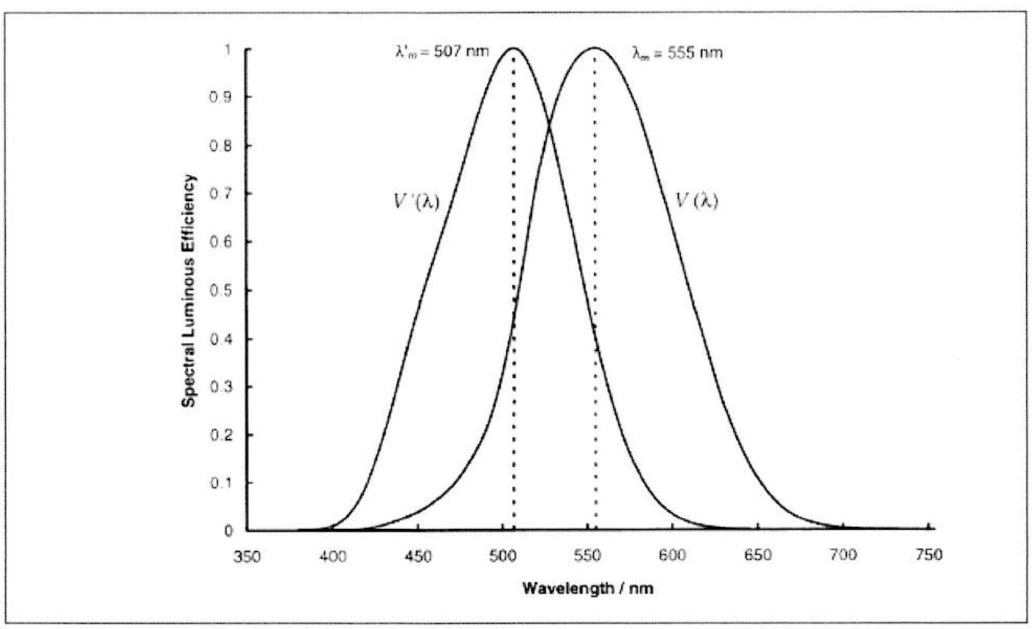

Figure 4: Spectral response of rods and cones

In mesopic conditions both rods and cones come into play and it would seem that light sources which can most optimally utilise them together would be preferred. Given the historic preponderance of sodium light which uses rods inefficiently Lewin, 2003 asks the question "to what extent rod response provides significant visibility of roadway hazards at practical roadway lighting levels"

Also, as Lewin (2003) mentions the distribution of cones and rods is not uniform throughout the retina. Only cones lie at the exact centre of the field of view, while rods are significant in the peripheral field. The location of the object to be seen, therefore affects visibility. Thus a source which makes good use of rods may improve peripheral vision but not improve centre field vision at all. Figure 5 depicts the rod and cone density on the retina

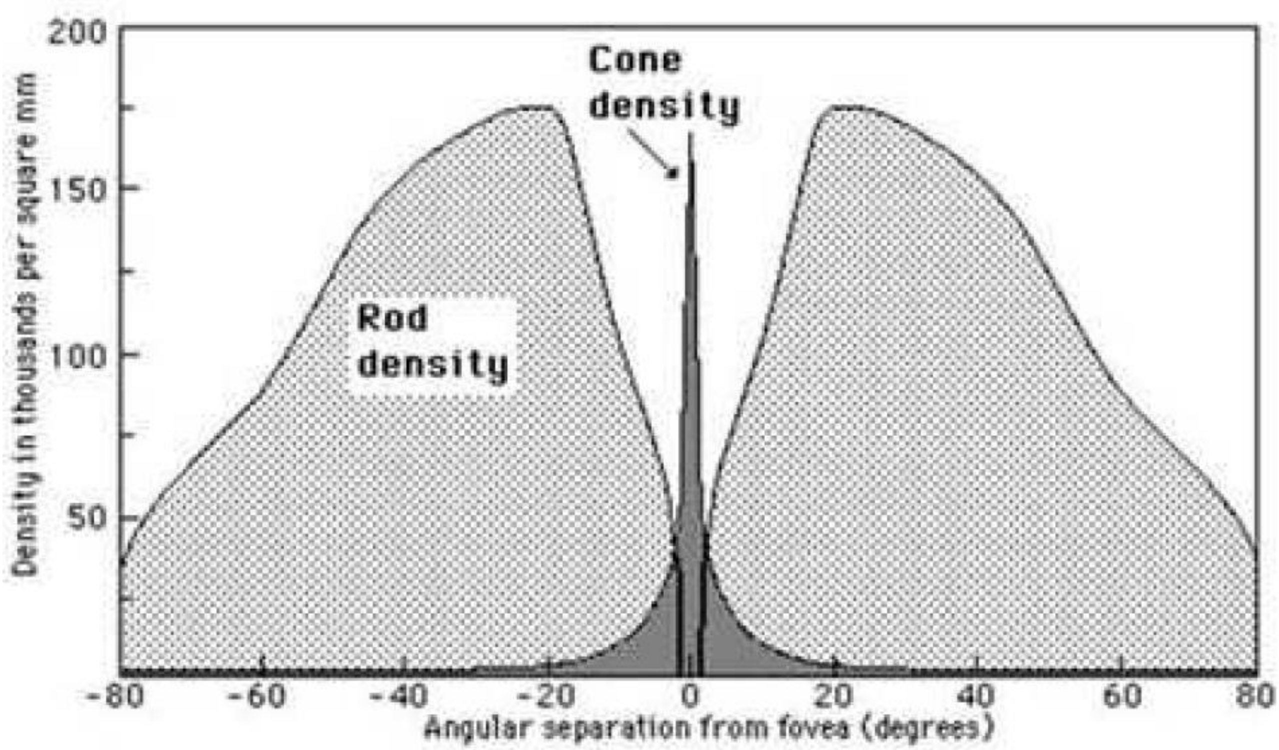

Figure 5: Road and cone density on retina[15]

2.2 White light (LED) and Yellow light (HPS)

Compared to sodium sources white sources have much greater output at shorter wavelengths. Figure 6, figure 7 and figure 8 are spectral power distribution charts for HPS, Metal halide and LED respectively.

[15] source www.ledroadwaylighting.com

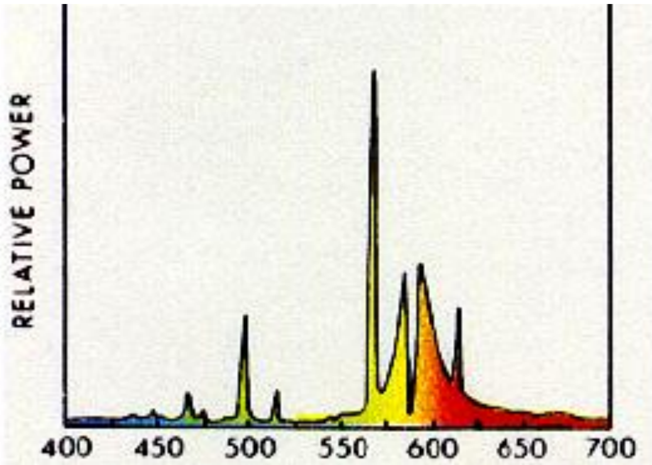

Figure 6: HPS spectral power distribution chart

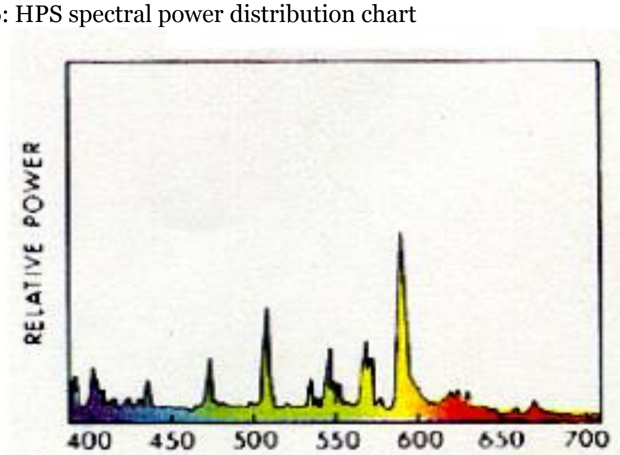

Figure 7: Metal halide spectral power distribution chart

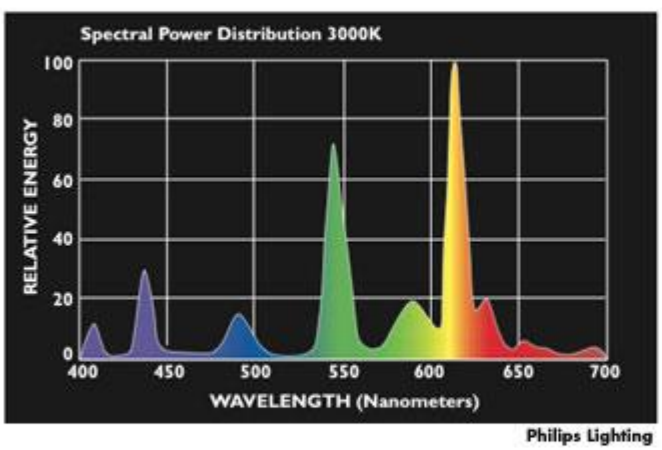

Figure 8: LED spectral power distribution[16]

It is apparent that the LED and metal halide have broadly similar distributions with both considerably broader than that for HPS.

[16] source http://www.ledaladdin.com/light_guides/led_light_colour_rendering_index_cri.html

Lewis (1999) investigated light level, sensitivity to contrast, and reaction time for mercury, metal halide, incandescent, high pressure sodium and low pressure sodium. Observers were asked to detect the appearance of a pedestrian standing at the curb and to determine whether the person was a possible hazard (pedestrian facing the roadway) or not (facing away). The time taken for observers to decide was measured. At levels of 3 cd/sq. m. and more, light source type has no effect. As lighting levels decreased the sodium sources require increasingly longer reaction times versus the white MH source. At very low levels, the difference is very significant.
Figure 9, reproduced in Lewin (2004) illustrates the time taken by the observers to make this determination versus luminance level, for the various sources.

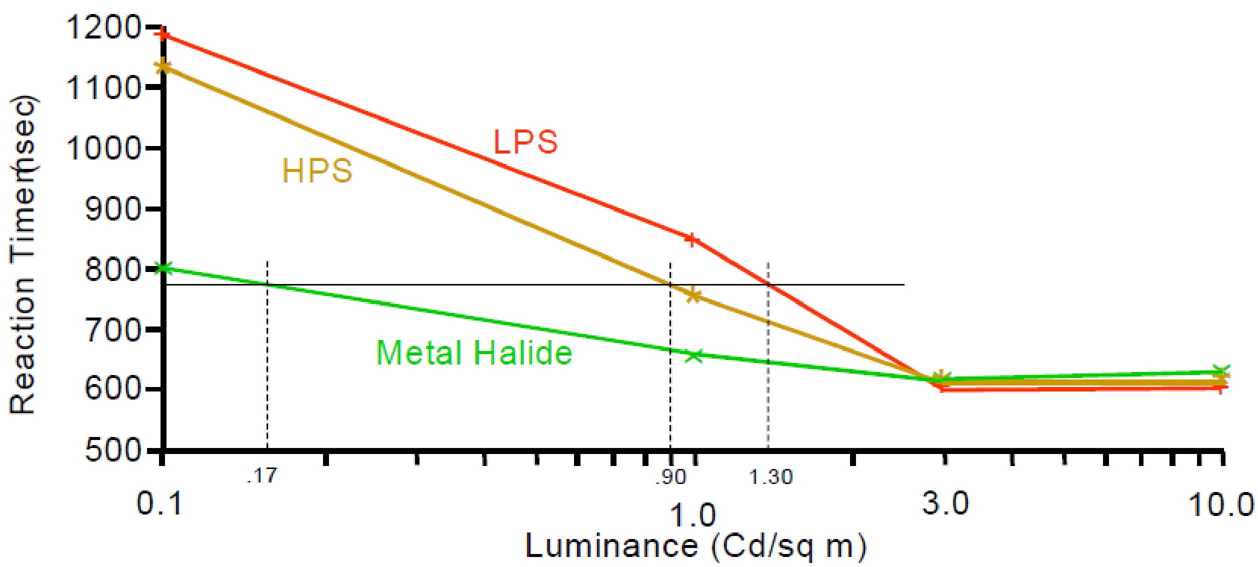

Figure 9: Reaction time versus luminance for HPS, LPS (both yellow) and metal halide (white) from Lewis (1999)

The horizontal line representing 775 msec reaction time intersects all three curves. Dropping vertical lines from each curve to the X-axis provides the luminance level needed to produce that reaction time in this experiment for each source. This visibility can be produced by a much lower level of MH than HPS. For LPS, a higher lighting level is needed to produce the illustrated reaction time.

It can be seen from figure 9 that most of the reaction time divergence between HPS and the white light sources is in the category p or lower range. However, this work is a laboratory experiment and Lewin (2003) warns (p 9) that:

"…many factors are involved in determining the extent to which such visibility characteristics apply in real world situations. The nature of the driver's visual task can strongly influence such effects."

Various authors[17] have reported dramatic improvements in the visibility of slightly off-axis small tasks under white light versus sodium. At the same time no increase in visibility associated with

[17] He et al(undated), He et al(1997), He et al (1998) Bullough and Rea (2000), Rea and Boyce(1998)

the use of white light versus sodium in cases involving small on axis tasks has also been reported (Harvard and Janoff (1997)). Lewin's explanation for this is that the fovea, consisting of cones, is used to provide the visibility of such objects, and therefore no benefit would be expected. Lewin also observed that it appears logical that tasks exist including those analysed by the Fovea that are best perceived by rods system, and others that are viewed by some combination of the fovea and peripheral retina.
Lewin summarised the state of play at the time by indicating that that for roadway visual tasks, the effect of lamp spectral distribution could not be definitively stated. However he thought that the following (paraphrased) points could be made[18] regarding such tasks.

- No research results indicate lower visibility using metal halide sources, and some report much higher visibility, for equal lighting levels.
- Where a positive impact in using metal halide is indicated, results show a lower lighting level can be used while maintaining equivalent visibility.
- To the extent, however, that foveal tasks are important on roadways at night, cone vision is significant. In such a case, lowering the lighting level is likely to reduce the visibility of such tasks.
- Any visibility benefits to be obtained by converting from sodium to metal halide lighting, and retaining present lighting levels, cannot be quantified.
- For low spatial frequency tasks, substantial visibility increases for such tasks are to be expected, along with commensurate safety improvement.
- For high spatial frequency tasks, there is likely to be no improvement.

His explanation includes the following points:

- In a driving task much information comes from outside of the small central field of view. As an example, a pedestrian stepping off the curb may be initially detected in the peripheral field of view, followed by the driver directing his/her view to more clearly discern the hazard.
- There is debate and much uncertainty on the relative importance of foveal versus peripheral vision for driving tasks, with some authors feeling that foveal vision is of primary importance (Berman and Clear, 1998). However, Owsley and McGwin, 1999 state "Visual acuity is only weakly related to crash involvement, whereas peripheral vision appears to play a more critical role."
- Until recently, it has been assumed that the spectral effects apply only to objects seen in the off-axis field. This is because rods dominate the off-axis portion of the retina, while cones are concentrated in the fovea, or central area of the retina. In fact, exactly in the centre, no rods are present.

[18] Lewin's white light source was metal halide.

- Off-axis tasks are extremely important at night, and are believed to be closely related to issues of safety. Also, there is evidence that rod vision is important for almost *all* visual tasks, even those that are looked at directly.(Lewis, 1998, Lewis 1999)

Since then there have been a small number of research projects in this area. Akashi et al (2007) conducted a field study where subjects drove a vehicle along a lit street while performing a high-order decision-making task. They identified the direction of an off-axis target, toward or away from the street, and braked or accelerated, accordingly. Three light sources were compared, two metal halide, the other HPS. Table 1 shows the target luminances for the three sources. The unified luminance of the HPS and CMH_L were the same while CMH_H had a higher unified luminance. The experiment was also conducted under daytime conditions.

Table 1: Target luminances for three types of lighting[19]

Lighting condition	S/P ratio	Photopic luminance (cd/m²)	Unified luminance (cd/m²)
1. HPS	0.55	**0.057**	**0.035**
2. CMH_H	1.17	**0.057**	0.065
3. CMH_L	1.17	0.030	**0.035**

[19] The S/P ratio is the ratio of the luminous output evaluated according to the scotopic V' (λ), to the luminous output evaluated according to the photopic V (λ). This is dealt with in more detail later in the document

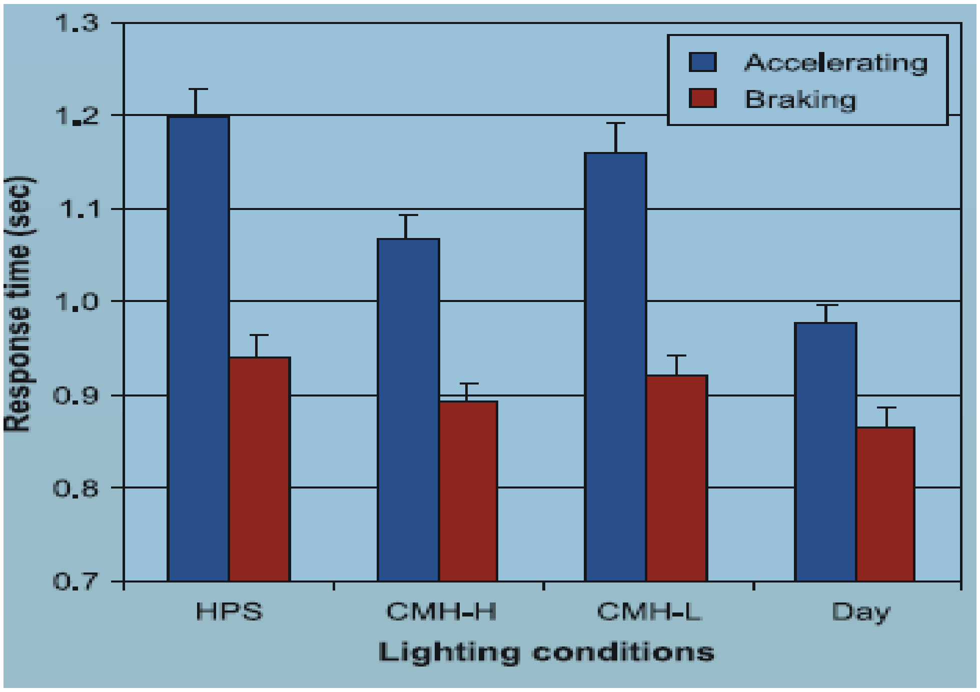

Figure 10: Mean response times for braking and accelerating

The results demonstrated that both braking and acceleration response times decreased monotonically as unified luminance[20] increased (figure 10). To put these results into perspective, these are all very low lighting levels, an order of magnitude below the design levels for category V lighting and are thus not relevant to route lighting in New Zealand.

2.3 Colour rendition and colour contrast

General discussion

Another aspect mentioned by Lewin (2003) is colour rendition. This refers to the support the lighting provides the eye to distinguish colours as measured by the Colour Rendering Index or CRI. (See Bridger et al, 2012).

Objects like signs, road markings are colour coded and it is good for these colours to be well discernible at night. Use of a narrow spectrum source like HPS may make colours look different at night vis-a-vis daytime. The extent or impact of colour rendering within the context of roadway lighting is not well understood. It is complicated by the fact that road markings and signs are usually retro reflective thus enhancing their ability to reflect light. This means they are illuminated both by the street lighting and headlamps - a hard to analyse combination.

In terms of colour contrast Lewin (2003) points out that by adding colour contrast to a visual scene, visibility is increased. A white, wide spectrum light source will add more colour to a coloured scene than a light source which is colour deficient in some parts of the spectrum. He then concludes that that it is reasonable that, if colour is a visibility-producing component in a

20 Unified luminance is an American measure of lighting which is optimised to the human eye's performance at all levels of lighting through photopic, mesopic to scotopic.

scene, white sources will inherently create a greater increase in visibility through colour contrast than spectrally deficient sodium sources.

Lewin (2003) suggests that white light might show up the colours of blue and green objects better than HPS. He also suggests this may be of minor impact given the confounding presence of headlights.

White LED lighting and "warm white" LED lighting

In terms of LED lighting there has been some discussion as to the comparative colour rendition of warm white light and cold white light and any possible safety implications. Warm white light appears to be more environmentally acceptable in terms of light pollution than cold white light and is thus becoming a preferred option in some quarters.

White light is any light that appears white to the human eye. There are no robust definitions but usually to qualify as "white light" a source needs to have a CRI of 70% or better. This CRI >= 70% has now been incorporated into AS/NZS1158 to define white light from LEDs.

Both warm white light and cold white light have a CRIs of 70% or better. The two types of source are differentiated by CCT – the colour temperature of the source measured in degrees K[21]. As it is possible to get greater lumen efficiency using cold light there is economic pressure to opt for cold sources (higher CCT) rather than warm sources (lower CCT). There is no known safety differential between cold sources and warm sources.

2.4 At what practical lighting levels does the wider spectrum white light provide advantages over HPS?

We have seen from the experimental research conducted that the visibility related advantages of white light increase as the lighting level decreases. At some level there must be a point where white light becomes better than HPS.

Unfortunately, traditionally the lumen value of lighting has been calculated only under photopic which is obviously going to be inaccurate to some degree under mesopic conditions. The CIE traditionally has used the sensitivity of the retinal cones by wavelength (V-lambda Curve, or V (λ)) to define the lumen value of lighting, ignoring the sensitivity of the retinal rods by wavelength (V-lambda Prime Curve or V' (λ)). This has recently changed with the CIE now recommending a linear combination of the two (CIE, 2010).

The ratio of the luminous output evaluated according to the scotopic V' (λ) to the luminous output evaluated according to the photopic V (λ) is required to make mesopic photometry possible. This ratio is called the S/P ratio. The S/P ratio only gives the ratio of Scotopic to Photopic luminance. It is a scaling factor to reduce or boost photometry made under photopic assumptions to align with the mesopic conditions that apply for the design. The CIE has

21 The colour temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source.

published a table which relates the differences in effective luminance at various lighting levels between using photopic photometry and mesopic photometry. This as reported in Puolakka and Halonen, 2010 is shown in table 2.

Table 2: percentage differences between mesopic and photopic luminances calculated according to CIE system for a range of S/P

		Photopic luminance cd·m^{-2}									
	S/P	0,01	0,03	0,1	0,3	0,5	1	1,5	2	3	5
LPS ~	0,25	-75 %	-52 %	-29 %	-18 %	-14 %	-9 %	-6 %	-5 %	-2 %	0 %
	0,45	-55 %	-34 %	-21 %	-13 %	-10 %	-6 %	-4 %	-3 %	-2 %	0 %
HPS ~	0,65	-31 %	-20 %	-13 %	-8 %	-6 %	-4 %	-3 %	-2 %	-1 %	0 %
	0,85	-12 %	-8 %	-5 %	-3 %	-3 %	-2 %	-1 %	-1 %	0 %	0 %
	1,05	4 %	3 %	2 %	1 %	1 %	1 %	0 %	0 %	0 %	0 %
MH warm white ~	1,25	18 %	13 %	8 %	5 %	4 %	3 %	2 %	1 %	1 %	0 %
	1,45	32 %	22 %	15 %	9 %	7 %	5 %	3 %	3 %	1 %	0 %
	1,65	45 %	32 %	21 %	13 %	10 %	7 %	5 %	4 %	2 %	0 %
	1,85	57 %	40 %	27 %	17 %	13 %	9 %	6 %	5 %	3 %	0 %
	2,05	69 %	49 %	32 %	21 %	16 %	11 %	8 %	6 %	3 %	0 %
LED cool white ~	2,25	80 %	57 %	38 %	24 %	19 %	12 %	9 %	7 %	4 %	0 %
MH daylight ~	2,45	91 %	65 %	43 %	28 %	22 %	14 %	10 %	8 %	4 %	0 %
	2,65	101 %	73 %	49 %	31 %	24 %	16 %	12 %	9 %	5 %	0 %

The range of normal road lighting levels are shown within the rectangle with a black border and the background coloured for differences 5%.or greater. For our purposes it is worthwhile to concentrate only on HPS and LED. It can be seen that using mesopic photometry changes little for HPS in the road lighting range. LED white light is well suited to Category P level lighting (0.1 and 0.3 cd/m^2) and as can be seen in Table 1 boosts of 10% to 30% above the calculated photopic values are then appropriate.
Note that the British standard does not extend the use of S/P ratios into traffic route lighting (Category V lighting in NZ). As the British Road lighting standard remarks (BSI, 2013 page 53) for traffic route lighting there is insufficient evidence to specify the situations in which the trade-off between light level and S/P can safely be applied.

For lower levels the British Standard indicates the trade-off may be carefully applied. Thus is reflected also in the current standard AS/NZS1158 which provides for de-rating light from HPS lights by 25% in minor road (Category P) lighting but not for LED (or MH) white light.

Van Bommel (2015) also points out that the studies leading to the CIE adjustment factors in table 1 were carried out using subjects in the 20-35 age range. With age, the lens of the human eye yellows meaning that blue light is largely absorbed in the lens, meaning the mesopic impact of blue-rich light is lessened for older drivers compared to that shown in table 1.

3 Conclusions

- Evidence from laboratory trials and some specifically set up on-road scenarios supports the idea that visibility is improved by the wider spectrum achieved by “white” light sources of road lighting like LEDs. This effect is much more pronounced at category P lighting levels than at category V lighting levels. Because of this white light will make pedestrian areas more pleasant and its increased blue component will provide efficiency gains when used at the low light levels found in minor road (Category P) lighting.

- The relation between road safety and the colour of light is multifactorial and no on-road studies been carried out to establish a direct linkage between the colour of light and crashes. At category V levels any change may be small and likely to relate to changed colour contrast.
- With age, the lens of the human eye yellows meaning that blue light is largely absorbed in the lens, meaning the mesopic impact of blue-rich light is lessened for older drivers compared to the sample of 20-35 year olds used in producing CIE correction factors
- A field trial relating light colour to crashes was proposed by Lewin (2003) but never carried out. Lewin's design as proposed to the Arizona Department of Transportation is described in the appendix. This design could input to any future New Zealand field trial.
- The British have stated in their lighting standard that there is not enough evidence at this stage to apply S/P ratios to traffic route (category V) lighting on the basis of the greater mesopic luminance associated with white light.
- The colour rendition characteristics of both white light and warm white light as emitted by LEDs exceed by a wide margin that of HPS (LED CRI> 70%, HPS CRI ~24%)
- There is no evidence of any safety difference between white LED lighting and "warm white" LED lighting

References

Adrian, Werner (1998). "The Influence of Spectral Power Distribution for Equal Visual Performance in Roadway Lighting Levels." In Proceedings of the 4th International Lighting Research Symposium, Orlando, 85-100. Cleveland Heights, Ohio: Lighting Research Office of the Electrical Producers' Research Institute, 1999.Akashi, Yukio, Rea, M. S. and Bullough, J. D. (2007) Driver decision making in response to peripheral moving targets under mesopic light levels Lighting Research and Technology vol. 39 no. 1 53-67

Berman, S., Clear, R. (1998)"Some Vision and Lighting Issues at Mesopic Light Levels. Proceedings of the 4th International Lighting Research Symposium, Orlando, P. 123-148. Lighting Research Office of the Electric Power Research Institute. Cleveland Heights, Ohio.

Bridger, Godfrey (2012) Strategic Road Lighting Opportunities for New Zealand A report written for the New Zealand Transport Agency Road Maintenance Task Force

Bullough, John; Rea, Mark. "Simulated Driving Performance and Peripheral Detection at Mesopic Light Levels." (2000) Lighting Research and Technology vol. 32 no. 4 194-198.
CIE (2010) Recommended System for Mesopic Photometry Based on Visual Performance CIE 191

Havard, James and Janoff, Michael (1997). The Effect of Lamp Color on Visibility of Small Targets. Journal of the Illuminating Engineering Society, Winter, P. 173-181.Illuminating Engineering Society of North America, New York

He, Junjian; Rea, Mark; Bierman, Andrew; Bullough, John. "Evaluating Light Source Efficacy under Mesopic Conditions Using Reaction Times. Journal of the Illuminating Engineering Society, Winter 1997, Vol. 26, No. 1. P. 125-138.Illuminating Engineering Society of North America, New York.

He, Junjian; Rea, Mark; Bierman, Andrew; Bullough, John. "Visual Reaction Times: Method for Measuring Small Differences." International Journal of Lighting Research and Technology. Vol. 30, no. 4. 1998. Chartered Institution of Building Services Engineers, London, United Kingdom.

Institute of Lighting Professionals (2012) Professional Lighting Guide, PLG 03 Lighting for Subsidiary Roads

Jackett, Michael and Culling Graeme (2014) PowerPoint presentation for NZIHT Road Lighting Course

Lewin, Ian, Box, Paul and .Stark, Richard E (2003) Roadway Lighting: An Investigation and Evaluation of Three Different Light Sources Final Report 522 Prepared for Arizona Department of Transportation
Lewis, Alan 1998) "Equating Light Sources for Visual Performance at Low Luminances. Journal of the Illuminating Engineering Society, Winter 1998. P. 80-84. Illuminating Engineering Society of North America, New York

Lewis, Alan. (1999) Visual Performance as a Function of Spectral Power Distribution of Light Sources at Luminances Used for General Outdoor Lighting. Journal of the Illuminating Engineering Society 28 (1): 37-42

Owsley, C and McGwin, G (1999) "Vision Impairment and Driving." Public Health and the Eye, Survey of Ophthalmology volume 43, no. 6. P. 535-550. Elsevier Science,

Puolakka, L and Halonen, M (2010) “CIE new system for mesopic photometry”, CIE Lighting Quality and Energy Efficiency conference, Sun City, South Africa

Rea, M S, Bullough, J D, Freyssinier-Nova, J P and; Bierman, A. (**2004)** “Lighting Research and Technology **vol**. 36 no. 2 **85-109** 12.

Rea, Mark; Boyce, Peter. "Different Sources for Different Courses under Mesopic Lighting Levels." Proceedings of the 4th International Lighting Research Symposium, Orlando, Florida. P. 101-122. Lighting Research Office of the Electric Power Research Institute. May 1998.

Van Bommel (2015) Road Lighting Fundamentals, Technology and Application Springer

APPENDIX: Lewin's Research Plan Submitted to the Arizona Department of Transportation.

RESEARCH PLAN FOR THE FIELD STUDY OF LIGHT SOURCE TYPES AS RELATED TO ACCIDENTS

Reference: Research Topic SPR 522-2

Lighting Sciences Inc.
7830 East Evans Road
Scottsdale, Arizona 85260
Telephone: 480-991-9260 Fax: 480-991-0375

- **April 2003**

APPENDIX D RESEARCH PLAN FOR THE FIELD STUDY OF LIGHT SOURCE TYPE AS RELATED TO ACCIDENTS

D1. PROBLEM STATEMENT

D1.1 Roadway lighting provides increased safety at night by providing better visibility. Factors involved in roadway lighting include effectiveness, life-cycle cost, light pollution and trespass, and object recognition.

D1.2 Light source type has previously been related to economic factors such as lamp lumen output, lumen depreciation, maintenance, lamp life and fixture cost. However, evidence now suggests that different light sources may affect the visibility created, and therefore may influence safety. The different spectral characteristics of the various light sources may be the dependent variable.

D1.3 Comparisons of light source spectral distributions as related to visibility have been carried out under laboratory conditions. However, no field studies have been conducted to determine whether the visibility characteristics found in the laboratory will affect safety in actual field applications. Through laboratory experiments several factors, including lighting level and the nature of visual task, have been shown to influence visibility. However, the extent of their impact in the field is not fully understood.

D1.4 A study is needed to determine if there is a relationship between spectral light source characteristics and nighttime safety. The three different sources proposed for study are high pressure sodium (HPS), low pressure sodium (LPS), and metal halide (MH).

D1.5 Different visual tasks have varying significance for different roadways. For example, peripheral tasks may be more important in a major suburban roadway than for a limited access highway. It is further recognized that the types of accidents will vary by roadway type. A full study of lamp spectral effects therefore requires consideration of various roadway types. This study is likely to be limited to one particular roadway type because of limited availability of suitable test sites and funding.

D2. RESEARCH OBJECTIVES

The objective of this program is to look for a correlation between nighttime crash rates and light sources. The proposed research will install the three types of lighting (HPS, LPS and MH) on roadways with similar physical characteristics and usage patterns. The aim is to achieve the objectives with modest research funding.

D3. RESEARCH TASKS

D3.1 Select a route with the following characteristics: a) consistent cross-section geometry; b) uniform traffic volume and composition; c) high level of abutting land use (high volumes of pedestrian and entering/exiting/turning vehicular activity); and d) long enough to be divided into three sections having a total of 400 reported crashes over the expected time period of the research (see Section D4.1.1).

D3.2 Design and install the three types of lighting systems along the roadway. After installation, verify that the lighting levels are as designed.

D3.3 Collect and analyze traffic volumes and crash reports.

D3.4 Write research paper detailing findings in accordance with Arizona Transportation Research Center guidelines.

D4. SITE REQUIREMENTS

D4.1 For safety studies to achieve statistical significance there must be a large number of crashes studied. These are related to the following three elements: traffic volume, length of roadway section, and length of study period. Initially it is estimated that the roadway section lengths will be a minimum of five miles in order to gather the necessary data.

D4.1.1 Number of Accidents

For a "Before-and-After" improvement study's findings to be significant, there needs to be a crash sample of 100 for the starting condition (HPS lighting). There then needs to be a difference of 16 crashes (plus or minus) in the comparative light sources (LPS and MH) to be significant at a Poisson distribution 95% confidence level or a difference of 25 crashes (plus or minus) for the more conservative Chi-square test[1]. The nighttime traffic volume is approximately twenty-five percent (25%) of the total daily volume[2,3] and well lit urban and suburban routes have approximately twenty-three percent (23%) of their crashes at night. Therefore, a minimum of 400 total crashes are needed to generate the 100 nighttime crashes.

D4.1.2 Duration of Study

The estimated study period is thirty six months. This study length allows for a "regression to the mean" analysis of the collected data. A longer study period may be needed to generate sufficient data to provide statistically significant findings.

D4.1.3 Type of Study

A primary factor related to lamp spectral distribution is peripheral vision object detection, and therefore routes with pedestrians, bicycles, frequent driveways and cross streets are likely to show the greatest change with lamp type. Routes with rural land use have little entering conflict from the roadside, apart from animals. Similarly, freeways present few peripheral entry conflicts, and mesopic spectral effects are likely to be minimized. The research program should address this issue by recognizing the impact of selected test site.

D4.1.4 Other Route Characteristics

In addition to the roadway characteristics detailed in Section D3.1.1, routes with existing overhead power lines present an advantage. Easily accessible electricity minimizes construction costs and time. It also facilitates changing pole spacing as a research variable.

D5. IMPLEMENTATION

D5.1 Several types of study sites along with their advantages and disadvantages are shown below.

D5.1.1 Use of Existing Freeways

An existing, lighted freeway would be divided into three sections based on traffic volumes and length. Each section would be lit at equivalent levels using the three types of lighting sources under review.

Advantages: a) high traffic volumes; and b) if Loop 101 is chosen, reduction in cost as HPS lighting is already installed and could be used on one section;

Disadvantages: a) freeways do not have any pedestrian conflicts nor significant numbers of side conflicts; and b) if Loop 101 is chosen, the existing light poles would have to be relocated/replaced to provide for equivalent lighting levels using LPS and MH light sources.

D5.1.2 Use of an Unlit Freeway

Either an existing, unlit freeway or a new freeway would be divided into three sections and lit with the three types of light sources.

Advantages: a) high traffic volumes; and b) no removal of existing facilities prior to installation of test lighting.

Disadvantages: a) freeways do not have any pedestrian conflicts nor significant numbers of side conflicts; and b) additional cost to light one section with HPS.

D5.1.3 Use of an Unlit Major Arterial Roadway

An unlit major arterial (SR 87, McDowell Road to Ft. McDowell Road; US 60 west of Van Buren St.; or SR 89 through Flagstaff.)

SR 87:
Advantages: a) consistent roadway cross-section; b) large volume of traffic; and c) accessible overhead electric power.

Disadvantage: a) extremely low volume of turning, entering, and exiting traffic; and b) total lack of pedestrian traffic.

US 60, west of Camelback Road:

Advantage: existing LPS lighting from Camelback Road to Northern Avenue is easily upgradable to test levels for this research.

Disadvantages: roadway cross-section west of Northern Avenue are different, thus introducing another variable; and b) the abutting land use to the west is industrial with low volumes of pedestrian traffic and a minimal number of conflicting movements.

SR 89 Through Flagstaff:
Advantages: a) existing LPS lighting; b) high traffic and conflicting movement volumes; c) high volume of pedestrian activity; and d) consistent roadway cross-section.

Disadvantages: a) the section through Flagstaff is relatively short; b) vehicle speeds are low; c) the section is heavily signaled, which minimizes turning movement conflicts; and d) the use of HPS and MH lighting is discouraged within the City limits.

Possible Alternatives: identify and evaluate alternate, potential sites outside of the Phoenix metropolitan area.

D5.1.4 Need for Site Search.

Other cities such as Tucson and Yuma should be searched for potential routes. Another potential would be lighting county or city major routes that are being improved in newly developing parts of the Phoenix metro area. The disadvantage of such a selection would be the rapid increase in conflict activity as the new area development proceeds. This could invalidate the results of multi-year analysis to reduce regression to the mean problems.

The study sections will each require traffic volume data to be made available. A permanent counter station with hourly counts for a full year is not essential, if the 25% night value found in numerous other studies is accepted.

Hard-copy accident reports will be essential to the analysis, in order to assess the entry of conflicting elements first detectable in peripheral vision. Reports of all accidents reported to the police are highly desirable; not just the ones with a personal injury or State-reportable $1,000 property damage limit.

It is recognized that the selection of the site is likely to be influenced by convenience and availability, and that ideal locations may not be obtained.

D6. SPECIFICATION OF EQUIPMENT

Develop complete set of contract documents, signed and sealed, for the installation of the roadway lighting test sections.

D7. DATA COLLECTION, TABULATION AND ANALYSIS

Collect and tabulate, on an annual basis, all crash reports. Analyze reports to adjust length of study to produce significant results. Compile, tabulate, and analyze data at project end.

D8. RESEARCH REPORT

The project research report shall be in accordance with the Arizona Transportation Research Center guidelines and contain the following elements.

D8.1 Describe the criteria used in study site selection.

D8.2 Describe and illustrate the following existing roadway conditions at a minimum: a) roadway cross-sections; b) abutting land use; c) traffic volume and composition; d) posted speed and average running speed; e) intersections and driveway frequency; f) study section lengths; and g) volume of pedestrian traffic.

D8.3 Detailed in detail the lighting systems used on each segment of the test roadway. The comparison of modeled vs. field lighting values should be reported.

D8.4 Detail the life-cycle costs of the three lighting systems.

D8.5 Present crash data, including the following: a) number; b) type; and c) relevance to peripheral vision tasks. Calculate the statistical significance confidence level.

D8.6 Suggest further research as appropriate.

D9. RESEARCH FUNDING

The estimated cost for conducting the research is shown in Table 1. This does not include the cost of providing the infrastructure for the three lighting types.

TABLE D1. ESTIMATED MAN-HOURS AND COSTS

Reference Section		Engineer	Engineering Assistant	Cost
3.1.1	Site Selection	80	10	$11,300
3.1.2	Design and Implementation	90	30	$14,400
3.1.3	Annual Data Collection (2 years)	200	20	$27,800
3.1.4	Summary Report	40	20	$7,000
Misc.	Meetings and Project Management	80		$10,400
Total		490	80	

Cost	Costs are based on an hourly rate of $130 for an engineer and $90 for an engineer assistant.	$63,700	$7,200	$70,900

Traffic Engineering and Roadway Design are the critical ADOT sections that may support this effort. These also are the ADOT sections that primarily will benefit from the research program.

D10. POTENTIAL PARTNERSHIPS

D10.1 FHWA is reported to have funds available for lighting-related research, and ADOT-FHWA sponsorship should be considered.

D10.2 NCHRP has funded prior lighting research projects, as proposed by states. Given the universal applicability of the work, NCHRP sponsorship could be available for the project.

D10.3 Local counties and/or municipalities might participate by making traffic volume and/or accident reports available.

D11. RESEARCH DURATION

Research duration is estimated as 36 months, exclusive of lighting systems installation.

REFERENCES

1. Michaels, Richard M., Two Simple Techniques for Determining Significance of Accident Reducing Measures, Traffic Engineering, Sept. 1966.

2. Billion, C.E. and N.C. Parsons, Median Accident Study-Long Island, N.Y.; Highway Research Bulletin 308, Highway Research Board, 1962.

3. McCoy, P.T., J.A. Bonneson, et al; Guidelines for Right-Turn Lanes on Urban Roadways, Transportation Research Board annual meeting, 9-13 January 1994.

4. Box, Paul C.; Major Road Accident Reduction by Illumination, Transportation Research Record 1247, Transportation Research Board, 1990.

5. American National Standard Practice for Roadway Lighting, ANSI/IESNA RP-8-00, Illuminating Engineering Society, 2000.

Opus International Consultants Ltd
33 The Esplanade, Petone
PO Box 30 845, Lower Hutt 5040
New Zealand

t: +64 4 587 0600
f: +64 4 587 0604
w: www.opus.co.nz