

## Lighting the way to road safety – A policy blindspot ?

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### Abstract

With 9.4 fatalities per billion vehicle-kilometres travelled, NZ is 19th out of 23 OECD countries. This poor performance is generally explained by NZ's low population density and lack of economic ability to spend enough per km of roading. Evidence supports insufficient road lighting and its low quality being a significant contributor NZ's poor injury and fatality statistics.

Analysis of a 2011 NZ Ministry of Transport survey indicates that the risk of death and injury from driving at night in NZ is 5.8 times greater than during daytime in contrast to international experience, which shows it is only twice the risk. Despite international research quoting improvements of up to 87% on fatalities with introduction of road lighting, apart from Canada, no evidence of a systematic strategic asset management approach was found for road lighting worldwide, and certainly not in NZ. Road lighting practice in NZ follows AS/NZS 1158 but this standard uses incorrect pavement reflectance values, does not use CIE's recommended approach to Scotopic/Photopic ratios to correct for the eye's reduced sensitivity to low intensity coloured lighting, and excludes LED road lighting.

Modern LED lighting is a disruptive technology that will rapidly replace older technologies. It allows modern computerised approaches to integrate up to date crime and accident statistics with traffic flows, lighting levels from a commercially available Lux Mapping service, community feedback and events to provide night time improvements in crime, traffic accidents and community satisfaction. Using NZTA's improvement factor from its Economic Evaluation Manual for reduction in night time fatalities and injuries for a national upgrade to modern road lighting shows a Benefit Cost Ratio of 10.3 without factoring in electricity or maintenance savings. This substantial benefit would make a significant contribution to the NZTA's Road Maintenance Task Force initiative.

**Key words:** Road safety; injuries; economic impact; research; road lighting, colour; strategy, BCR, nighttime driving risks, Road Maintenance Task Force.

## 1. Introduction

This paper arises from a study completed for the NZ Transport Agency (NZTA) by the authors and published in a report called "Strategic Road Lighting Opportunities for NZ" (Bridger, 2012) available on NZTA's website. The study was commissioned by the NZTA's Road Maintenance Task Force established "to identify opportunities for efficiencies in delivery of operations, road maintenance and renewals, including innovative services, products and methods of procurement, and to encourage their consistent uptake through the country" (Minister of Transport, 2011). Note that while the NZTA report was the reason for this paper, this paper predominantly represents the authors' own work subsequent to the NZTA report.

### 1.1. NZ Transport Governance

In New Zealand land, air and marine transport is governed by the Minister of Transport with the advice of the Ministry of Transport (MoT). Investment, maintenance and operations on land are the responsibility of the NZ Transport Agency (NZTA) which receives its strategic guidance from the Minister through the Ministry of Transport's *Government Policy Statement (GPS)* which is published every three years, the most recent becoming operational on the 1<sup>st</sup>

July 2012. The GPS provides three-year funding guidance to the NZTA based on the Government's strategic priorities for the land transport sector.

Like most countries, the New Zealand Government is highly focused on safety. One of the GPS's seven goals is to make "A continued reduction in deaths and serious injuries that occur on the network" as a "Short to medium term impact" funding goal (MoT 2011 para 17). It recognises that "The safety priority acknowledges the substantial burden road crashes place on the economy and the health sector each year. The current annual social cost of road deaths and injuries is approximately \$3.8 billion. Reducing this cost is important not only to the economy but in its own right. The majority of road deaths and serious injuries are avoidable tragedies for the people and families involved."

The importance of safety is recognised across all political parties and the Ministry of Transport has published a 43 page long term strategy document called *Safer Journeys; New Zealand's Safety Strategy 2010-2020* in which it suggests "New Zealand's roads are not as safe as those in other countries. Our road network is comparatively long, with much of it built when we had fewer vehicles travelling at lower speeds. Our geography is challenging, and our population base is small. This means it is difficult to spend the same amount per kilometre of road as the best-performing countries." (MoT, 2010, Page 14)<sup>27</sup>

This is relevant because New Zealand has economically fallen behind its OECD peers - "The negative gap between New Zealand's GDP per capita and many other OECD countries widened considerably between the 1970s and early 1990s, but has been broadly stable since" (NZ Treasury, 2011). The Government has recognised that things need to change. It has increased emphasis on innovation, effectiveness, and efficiency and has moved to fund many such initiatives across a range of sectors. This paper focuses on land transport.

## **1.2. Land Transport**

Government spends about \$3 billion every year on land transport (GPS 2012). It has recognised that "To gain the most from our land transport investment, GPS 2012 requires a sharpened and broadened focus on value for money. In doing so it raises expectations beyond those set by GPS 2009 which tend to focus on value for money at the level of prioritising projects and activities for funding. In contrast GPS 2012 will also require demonstrable value for money across all aspects of the development, delivery and management of the National Land Transport Programme." (MoT 2011 paragraph 46).

## **1.3. Road Maintenance Task Force**

The NZTA's Road Maintenance Task Force was established for that purpose and the study completed by the authors of "Strategic Road Lighting Opportunities for NZ" contributed to that objective for the NZTA. The framework used by the study corresponded to that determined by Government's overarching goal for transport which is "an effective, efficient, safe, secure, accessible and resilient transport system that supports the growth of our country's economy in order to deliver greater prosperity, security and opportunities for all New Zealanders." (GPS 2012, paragraph 11).

The road lighting study for NZTA was therefore organised around the three areas of: safety; value for money; and economic development. This paper focuses on the first which the authors believe uncovered an unexpected "blind-spot" in land transport strategy which led to additional investigation on their own behalf for this paper.

## **1.4. Traffic Risks**

United Nation's World Health Organisation suggests that "Worldwide, the number of people killed in road traffic crashes each year is estimated at almost 1.2 million, while the number injured could be as high as 50 million – the combined population of five of the world's large cities. The tragedy behind these figures regularly attracts less media attention than other, less frequent but more unusual types of tragedy." (WHO 2004)

The most fundamental traffic related statistic quoted by a country is the number of road fatalities or injuries per year. However, exposure to the risk of a traffic accident is dependent on a country's total population, number of vehicles and the distance travelled by those vehicles. The greater the number of each, the greater the number of fatalities or injuries one can expect to occur. In statistical terms, total accidents have a dependent relationship with population, registered vehicles or total distance travelled.

The relationship may not be linear, but it is most certainly dependent. Thus in order to obtain a statistic that provides an indication of the success or otherwise of a national road safety strategy, the number of fatalities (and/or injuries) need to be divided by population, registered vehicles and total distance travelled. Each of these provides insight into transport safety policies of a country.

### **1.5. Road fatalities per 100,000 population, per 10,000 vehicles**

When quoted in terms of fatalities per hundred thousand population, New Zealand is 23<sup>rd</sup> out of 34 OECD countries as reported in 2010 by the OECD (IRTAD, 2011) at 8.6 fatalities per 100,000 population. This is identified as the mortality "Health Risk" from traffic accidents because it can be compared with other mortality risks such as fatalities from heart disease.

New Zealand vehicle ownership is amongst the highest in the world but with 1.2 fatalities per 10,000 vehicles owned it only<sup>1</sup> ranks 19<sup>th</sup> out of 32 OECD countries (IRTAD, 2011). Note that the original source for these figures is the Ministry of Transport whose crash statistics data is considered to be among the best in the world.

### **1.6. Road fatalities per billion vehicle-kilometres**

The Ministry of Environment reports (MfE 2009) that suggests "Vehicle kilometres travelled" is a widely used international proxy for the pressures of road transport on the environment and human health." On a per capita basis in 2002 New Zealanders travelled further than any other nation except USA (MfE 2009) and in 2010 we travelled 40 billion vehicle kilometres (MoT, 2011). New Zealanders are highly dependent on vehicle transportation.

From a traffic safety perspective the international measure of "Traffic Risk" to compare between OECD countries is deaths per billion vehicle kilometres (veh-km). This measure removes dependent variables from the statistics as mentioned above. By this measure New Zealand is 19<sup>th</sup> out of 23 OECD countries reported by IRTAD (2011) with 9.4 fatalities per billion vehicle-kilometres, ahead only of Belgium, Czech Republic, Malaysia and Korea - as shown in Figure 1.

### **1.7. Opportunity from adversity?**

New Zealand traffic accident statistics are not good, but it is only 48<sup>th</sup> out of 226 countries in the world in terms of GDP per capita (CIA 2012) and is 39<sup>th</sup> least densely populated country in the world's 242 countries and dependencies (Wikipedia 2012) so this makes it very difficult to improve them. This paper argues that a significant contributor to its poor traffic accident performance is highly likely to be its road lighting. The authors suggest that reducing night time traffic accidents through improvements in road lighting provides a major opportunity to embark on a path that has a very high Benefit/Cost ratio of greater than 10.

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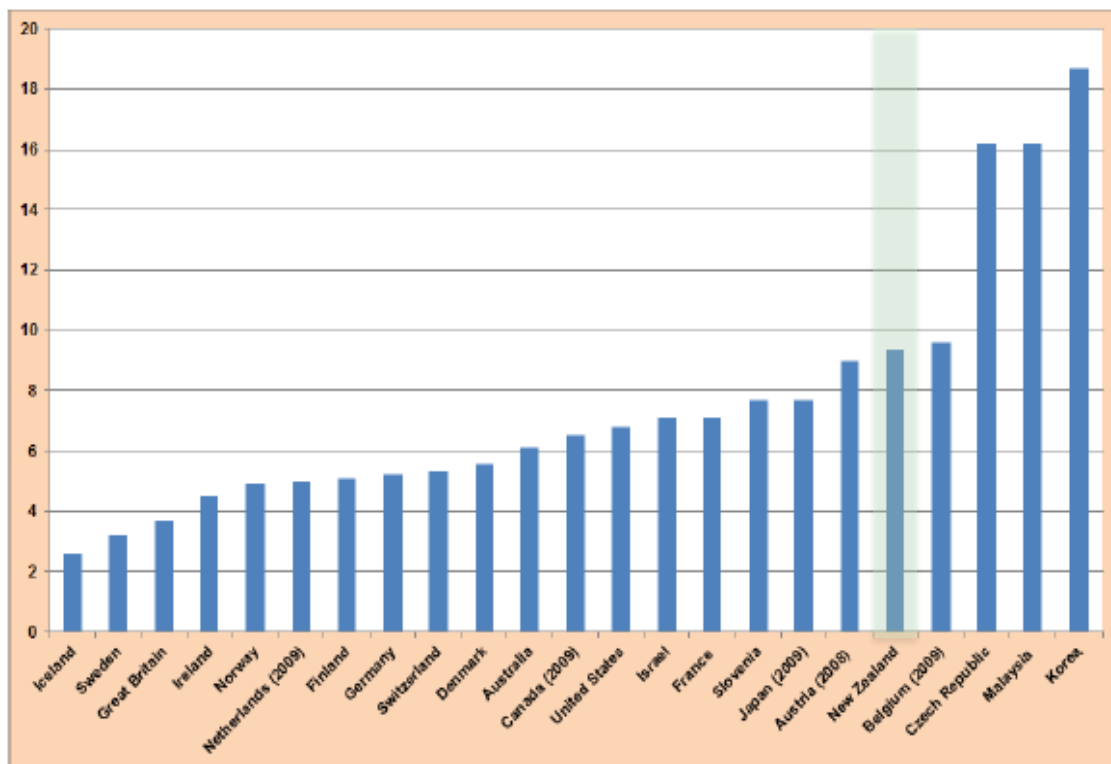
<sup>1</sup> One might expect that the higher number of vehicles reduces the risk of accident per vehicle, but even when adjusted for vehicle ownership, NZ still does not compare well and this paper suggests a possible cause.

## 2. Night Driving

### 2.1. International Research

It is well established that most road travel takes place during the day. In the UK over 70 percent of the mileage driven by males is between the hours of 8am and 6.59pm. For females the corresponding figure is 80 percent (Ward, 2005). The widely acknowledged and utilised reference book on safety measures by Rune Elvik and his Norwegian colleagues from the Norwegian Institute of Transport Economics (Elvik 2009) suggest that “the risk of having an accident in darkness is 1.5 – 2 times higher than in daylight” (p 272, quoting other research).

**Figure 1 OECD Road Fatality's per billion vehicle kilometres in 2010 (Source: IRTAD 2011)**



In the same paragraph they observe, “The risk in the darkness increases more for more serious accidents. According to a study from the USA, about 25% of all traffic travels in the darkness while 50% of all fatal accidents occur in darkness.” This is supported by the AA Foundation in the UK, which observes “Only a quarter of all travel by car drivers is undertaken between the hours of 7pm and 8am, but it is in this period that 40 percent of fatal and serious injuries are sustained by drivers.” (Ward, 2005).

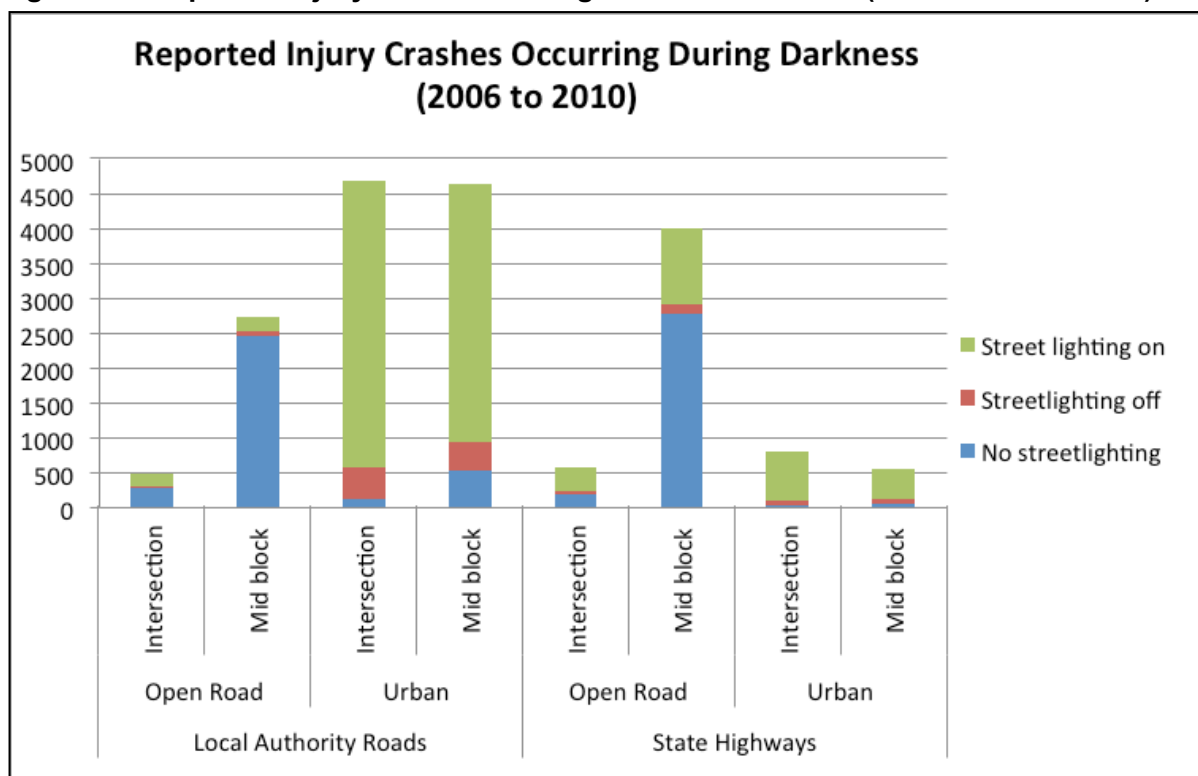
### 2.2. New Zealand Reported Injury Crashes

New Zealand has a sophisticated database of accident statistics called the Crash Analysis System or CAS. Between 2006 and 2010, 57,551 crashes occurred on New Zealand roads and 18,437 of them or 32% (Tate, 2012) were during the time when road lighting is normally switched on. The location type, the existence of street lighting, and whether the lighting was on or off, are factors graphed in Figure 2 below. The graph captures the lighting conditions in which night-time injury crashes occurred in the period 2006-2010. In the same period, night time injury crashes incurred between \$3 and \$5 billion dollars worth of negative economic

impact (based on current Government estimates<sup>2</sup>). Accordingly, the following three avenues of investigation would appear worthwhile for a systematic street lighting approach to night time safety across the country:

- Why was the existing street lighting off for the 1,240 crash injuries that occurred during darkness? (The red-brown shaded parts of the graph) How could this be avoided?;
- Where street lighting existed and was on, could improvements be made to reduce the 10,794 accidents that occurred as shown by the green shaded parts of the graph? For example, were the light levels high enough? Would white lighting reduce accidents (See section 3.7)? Is the design and location of the lighting optimum?
- Should installing street lighting be investigated in those areas where 6,403 crash injuries occurred but no street lighting exists (the blue areas in the graph)?

**Figure 2 Reported Injury Crashes During Darkness 2006–10 (Source: NZTA 2012)**



### 2.3. Risks of driving at night time in New Zealand

In New Zealand the Ministry of Transport conducts a Household Travel Survey every year on 4,600 households (MoT, 2012) from which Figure 3 was taken. The graph shows the risk of injury or fatality for a driver during the week (in blue) and at the weekend (green). As the graph shows, based on statistics from 2006 to 2010 it is very much more likely for injuries and fatalities to occur in darkness.

Using the statistics from the Ministry of Transport that generated the graphs, and defining “night-time” to be between the hours of 9pm and 6am, the ratio between night-time fatal or injury crashes and day-time fatal/injury crashes is 5.8. This suggests therefore that driving 4 wheeled vehicles at night-time in New Zealand is 5.8 times more dangerous than during the day. This is a very large number that is not found in international literature but the ratio is

<sup>2</sup> In 2011 the Minister reported that road accidents cost the country \$3.8 billion per year (MoT 2010). Simple arithmetic shows that over four years accidents during darkness (32%) cost NZ \$4.86 billion.

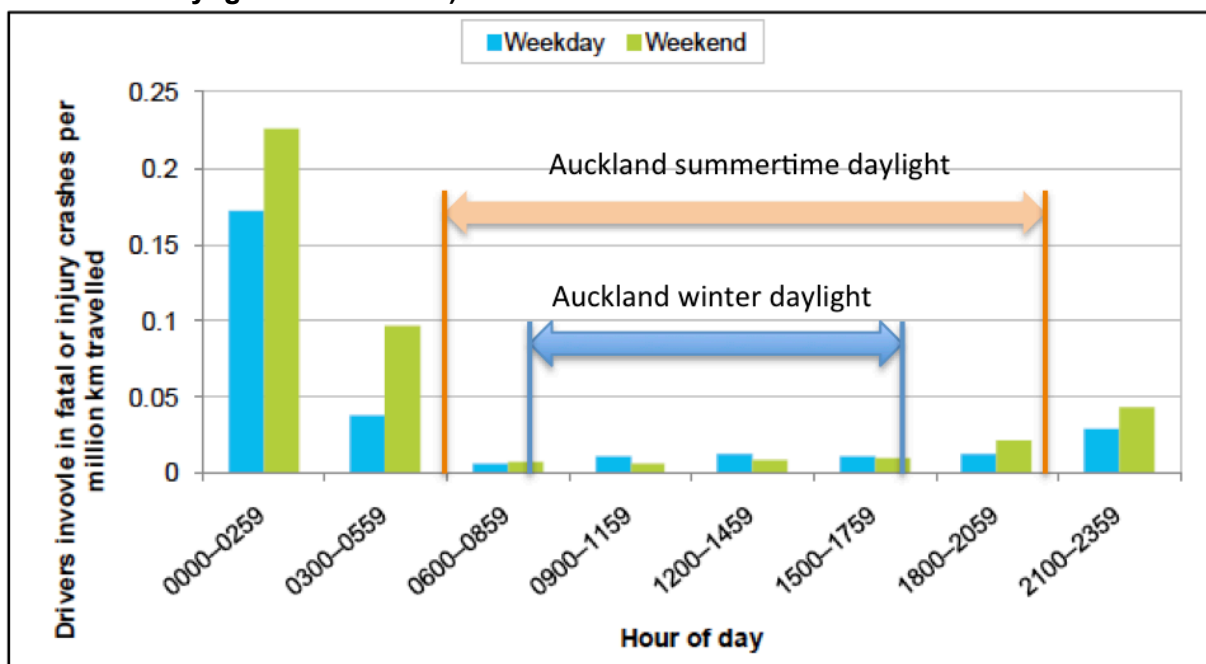
affected by the duration of daylight which are different for different times of the year and locations in NZ.

The MoT survey was designed to give annual estimates at a regional level and provides a national annual average of travel by time of day. In winter the latest sunrise in Auckland is 7.34 am in July, and sunset is 5.17pm. In summer the earliest sunrise is in December at 5.55am and the latest sunset 8.43pm (Christie, 2012). These times are drawn on top of Figure 3. Moving South increases summer daylight and shortens winter daylight so the more data in the survey that was included from the South, the lower the offending ratio would be.

Elvik et al cite four other European research papers showing that the international figure for *all* vehicles travelling in the dark ranges between 1.5 and 2 times the risk of travelling during the day (Elvik 2009 p272). If the NZ risks identified above and illustrated in Figure 3 held when averaged across all vehicle types (including motorcycles), New Zealand night driving would appear to be between 2.9 and 3.8 times more dangerous than night driving in other countries – an extraordinarily large and alarming factor. This observation is based on calculations made from desk-based research on field results, and therefore requires validation and further research.

On any of the internationally accepted measures New Zealand is a more dangerous place to drive than most OECD countries. Driving in the dark is a particularly dangerous activity in New Zealand so any research-based safety strategy applied to night time driving deserves serious consideration.

**Figure 3 NZ Light 4 wheeled vehicle drivers involved in fatal or injury crashes per million km driven (Source: Ministry of Transport October 2011 seasonal daylight times added)**



### 3. Road lighting

#### 3.1. International experience

The use of road lighting as a safety measure has been well researched internationally. The *Handbook of Road Safety Measures* (Elvik 2009) tables 20 measures on page 146 listing measures ranging from cycle ways to motorways and roundabouts to horizontal curve improvements and of course, road lighting. For road lighting it reports in Table 1.0.1 that as at 2007, there have been 70 studies, 503 results, and the sum of statistical weights are

163,306. In reference to this the handbook observes; “The statistical weights are based on the accident sample used in the evaluation studies. The largest number of studies are available for road lighting and cross sectional improvements” (Elvik 2009).

These studies confirm intuitive observations that road lighting is an effective safety measure, but Table 1.18.1 in the *Handbook of Road Safety Measures* quantitatively lists the reductions in risk of accidents relating to road lighting ranging from 87% for fatal accidents in rural roads to 4% for injury accidents on motorways (Elvik 2009). In summary they observe: “According to table 1.18.1, road lighting reduces fatal accidents by 60% and injury and property accidents by 15%. These effects are statistically significant.” (p 275).

### 3.2. New Zealand research

The relatively sparse New Zealand research largely confirms these results with statistically significant results at the 95% confidence level showing improvements ranging from 41.4% reduction in night crashes at intersections down to 30.2% reduction in route lighting (LTSA 1997). Research presented at this conference (Jackett & Frith 2012) provides new evidence for a high confidence relationship between light levels and the reduction of crashes. The evidence suggests that for highway lighting for every increase in road lighting levels of 0.5 candela per square metre ( $\text{cd/m}^2$ ), a reduction of 33% in midblock night time crashes will result.

To the authors this is ground-breaking research as it establishes a causal relationship between road luminance and crash accident rates, seems to be easily replicated by the innovative use of a calibrated digital camera, and it is research that appears very cost effective to conduct. This promises to provide a scientific basis for illumination levels that hasn't been applied before, and should probably be used to inform the current review of the Australia New Zealand road lighting standard AS/NZS 1158.

### 3.3. Lux mapping

New Zealand has led the way in technology that can rapidly survey road lighting at legal speeds of 50km/hr in urban areas and 100km/hr on the open road. Conceived ahead of its time, this commercial service provides performance based monitoring that could directly relate to road safety when linked to the research mentioned above (Jackett and Frith 2012).

In 2006 Roger Loveless of Odyssey Energy presented a paper to the 7<sup>th</sup> Annual NZ Institute of Highway Technology Conference called *Strategic Planning for Upgrade and Renewal of Street Lighting*. This paper reported on several year's experience with the automatic High Speed Lighting Assessment Technology (HiSLAT), which has subsequently been superseded in 2011 by a Lux Mapping service developed by Raven and Draca, the current principals of Odyssey. The new service maps lighting levels in lux to GPS co-ordinates which can be imported into the Road Assessment and Maintenance Management (RAMM) databases used in New Zealand and much of Australia. This Lux Mapping service shown overlayed on Google Earth in Figure 4 can complete a survey of all road lighting in a city the size of Hamilton (approx. 400km) in about 8 to 10 nights at a cost of about NZ\$130 - 160 per km.

In November 2011 Hamilton City Council (HCC) commissioned Odyssey to complete a Lux Map survey of their street lights against GPS co-ordinates. As far as the authors are aware this has never been done on this scale anywhere in the world and now allows HCC to embark on a program that could achieve the following unique strategies:

- a) Monitor the performance of the contractor responsible for road lighting maintenance and link payments to the levels of that performance;
- b) Provide a quantifiable basis for lighting design improvement where lighting is deemed inadequate by traffic engineers *or the community*, and provide quantifiable before-and-after comparisons;

- c) Match night time crime statistics to lighting levels to discover *quantifiable* relationships that should for the first time drive lighting location, lighting design, and lighting levels;
- d) Match night time traffic accidents to lighting levels and provide further empirical data to link lighting levels directly to road safety as per Jackett and Frith 2012.

**Figure 4 Odyssey Energy's Lux Mapping service showing road lighting levels**



### 3.4. Accident mapping

Traffic accident statistics are regularly gathered and reported by Police and Hospital authorities worldwide to provide the foundation for the accident statistics mentioned above. This data is usually available in easily imported forms of data and often published widely for citizen's use. In New Zealand the Councils receive this information and in Hamilton's case this information has been overlayed on top of the Lux Mapping service shown in Figure 5. Note that the information in Figure 5 has been manually entered and only illustrates where accidents occurred and where the Lux Mapping records existed at the time the illustration was put together.

If this were done on a regular and systematic basis, this information would provide valuable input into the location, design, type, operation and maintenance of street lighting to minimise night time accidents – of both vehicle and non-vehicle types (eg between a pedestrian and a bicycle).

### 3.5. Crime mapping

Road lighting in urban areas has a security purpose as well as traffic safety. As observed by the US Department of Justice "A recent authoritative review, which used a well-established methodology to combine the results of all the studies from the United States and the United Kingdom, concluded that improved street lighting led to a 21 percent decrease in crime compared with comparable control areas." (Clark 2008).

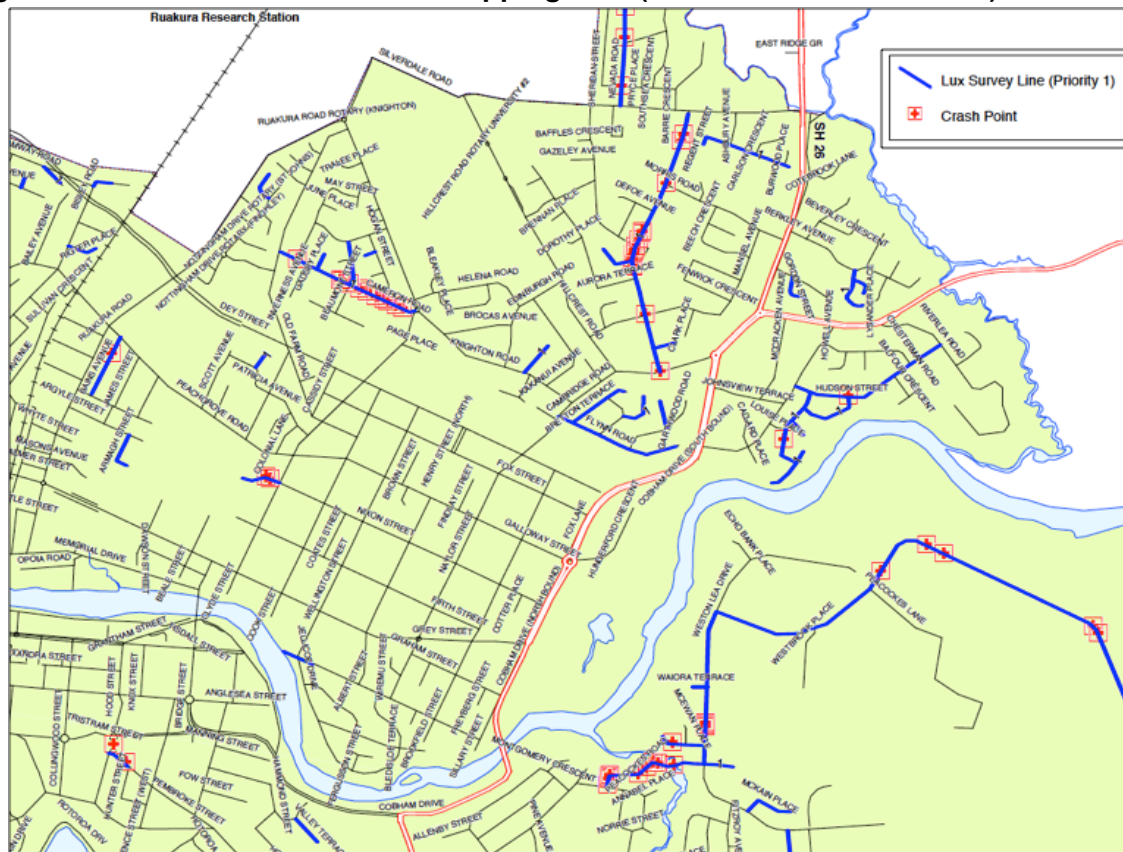
In the same way as traffic accidents are reported, crime statistics are widely recorded and published in some detail. In the UK for example, the Police provide their own website<sup>3</sup> to publish crime statistics and applications are available for mobile phones<sup>4</sup> to discover what

<sup>3</sup> Eg [www.police.uk/crime/?q=Guildford,%20Surrey%20GU1%20SX,%20UK#streets/2012-06](http://www.police.uk/crime/?q=Guildford,%20Surrey%20GU1%20SX,%20UK#streets/2012-06)

<sup>4</sup> For example <http://itunes.apple.com/us/app/crime-spy-uk/id420241073?mt=8&ls=1>

areas to avoid or to be particularly diligent to personal security. In New Zealand, the Police routinely provide property crime information local community newspapers for reporting on a geographic basis, so it would be a small step to provide geographic information for other crimes as well.

**Figure 5 HCC Accident and Lux Mapping data (Source: Consedine 2012)**



If this information was systematically input into the same Council database as identified above and illustrated in Figure 6, crime and security events could logically also drive the location, design, type, operation and maintenance of street lighting to minimise night time crime.

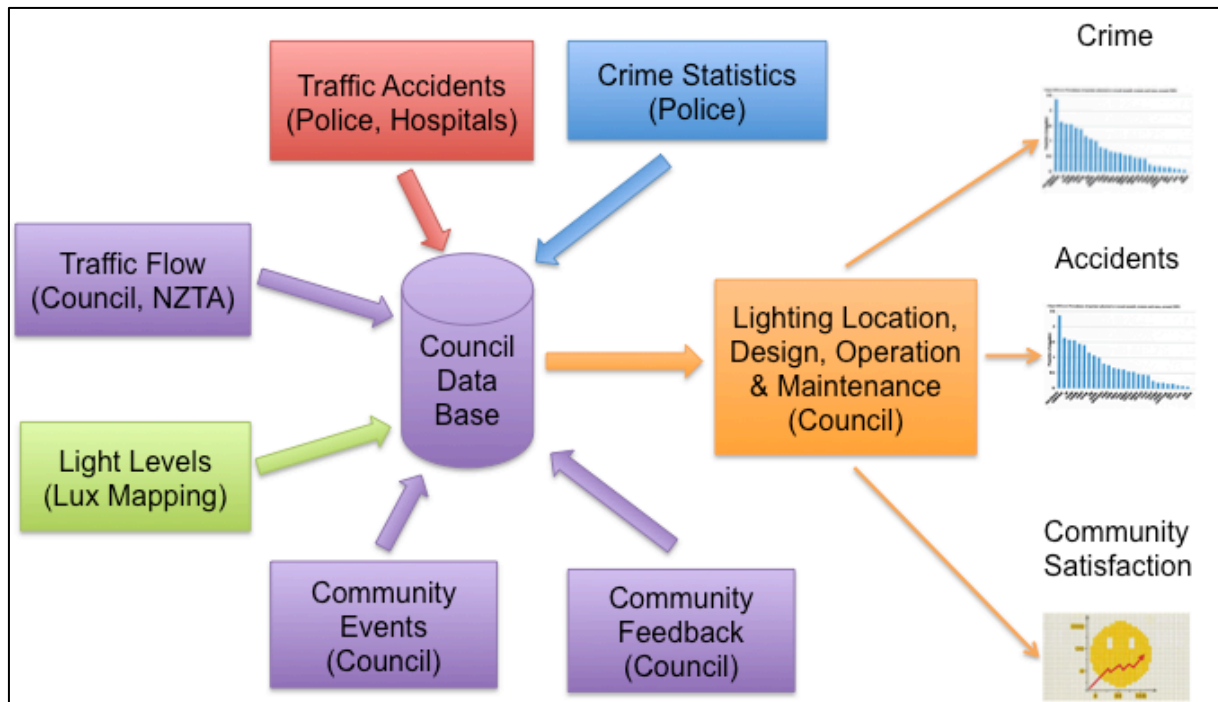
### 3.6. Eye Sensitivity to colour

The eye's sensitivity varies according to the colour or the wavelength of the light being observed. But more importantly and relevantly to the subject of this paper, this spectral sensitivity *also* changes according to lighting levels. Thus in daylight the eye is most sensitive to yellow-green light. This is scientifically referred to as "photopic" vision.

At very low levels of light such as those encountered driving at night in a street-lit environment, the human eye observes light "scotopically" and at in-between lighting conditions the eye observes light "mesopically". In both these periods the eye is most sensitive to blue or blue-green light. As Figure 7 shows, at night (close to the black line) the eye perceives light of 600nm<sup>5</sup> wavelength (similar to yellow High Pressure Sodium HPS) at about 10% of the lighting levels that it perceives blue/green light even though they are the same light level.

<sup>5</sup> A nm is a nano metre or a billionth of a metre, also a millionth of a millimetre

**Figure 6 Using existing data to reduce night time accidents and crime, and increase community satisfaction**



For this reason the International CIE<sup>6</sup> lighting standards have recently begun to use Scotopic/Photopic ratios ("S/P") that favours white lighting at the luminance levels encountered during night time driving on highways. These S/P ratios *de-rate* the yellow HPS coloured lights in most use today by up to 75% (at very low background illumination levels of 0.01 cd/m<sup>2</sup>), and *up-rate* white lighting such as that produced by modern Metal Halide (MH) and Light Emitting Diodes (LEDs) by up to 101% also at 0.01 cd/m<sup>2</sup> (Table 1 Puolakka 2010).

### 3.7. Improved human reaction times with white light

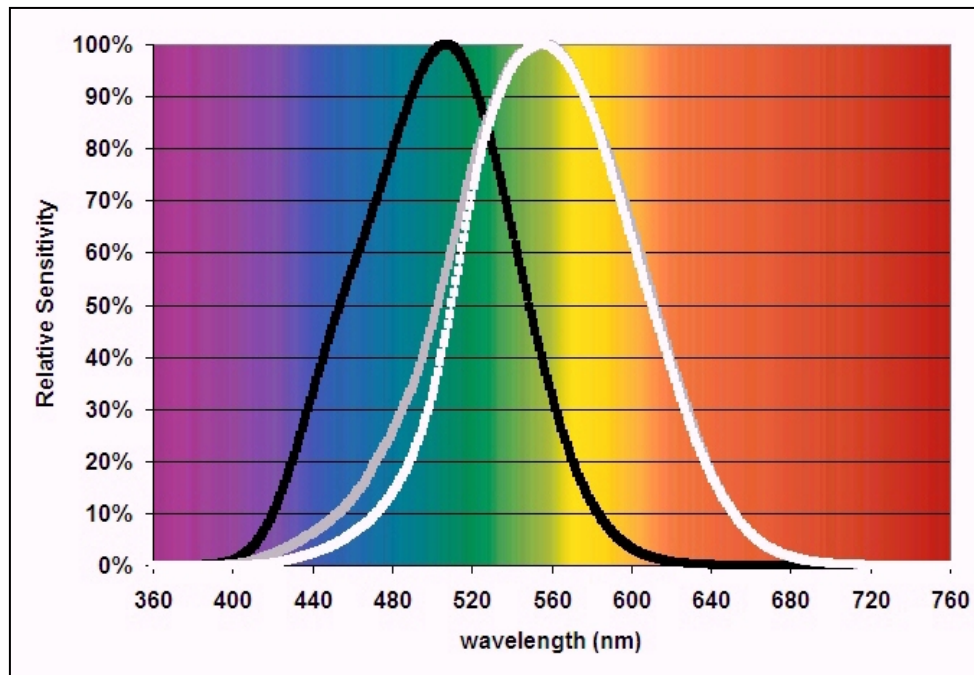
Many studies have been conducted to verify that cool white lighting improves peripheral (scientific literature calls it "off-axis") vision and LED vehicle headlights are especially well-researched (eg Van Derlofske 2005) from whence Figure 9 is taken. This shows slower driver reaction times in "warm" colour conditions than in "cool" (blue end of the spectrum) colour conditions, particularly at peripheral target angles. Earlier light colour sensitivity research was conducted (ADT 2003) for drivers in differing road lighting colours resulting in similar conclusions as illustrated in Figure 8.

In another report commissioned by Transport for London and funded by several others, Transport Research Laboratories suggests that "The MOVE<sup>7</sup> project has confirmed a relative benefit of "white" light for off-axis (or peripheral) vision, which increases as the lighting level falls" (Crabb 2009).

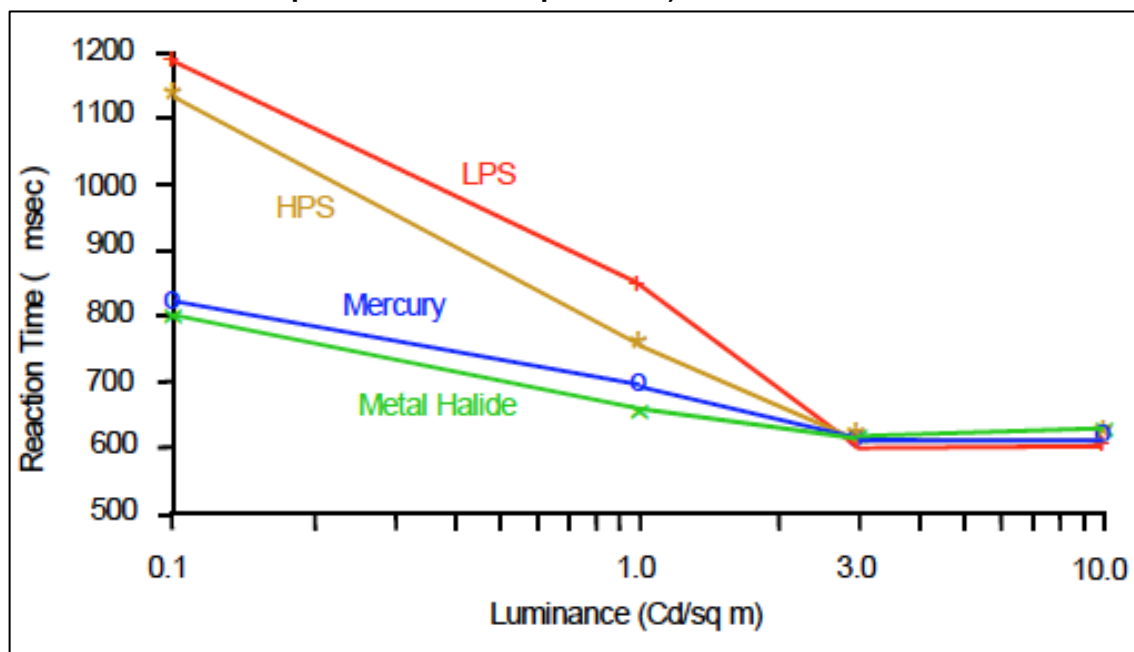
<sup>6</sup> Commission International de L'Eclairage or International Commission on Illumination.

<sup>7</sup> MOVE stands for Mesopic Optimisation of Visual Efficiency, a project funded by the European Commission.

**Figure 7** The different response of the eye at different lighting levels. White line is daylight, black line is night (Source: website<sup>8</sup>)

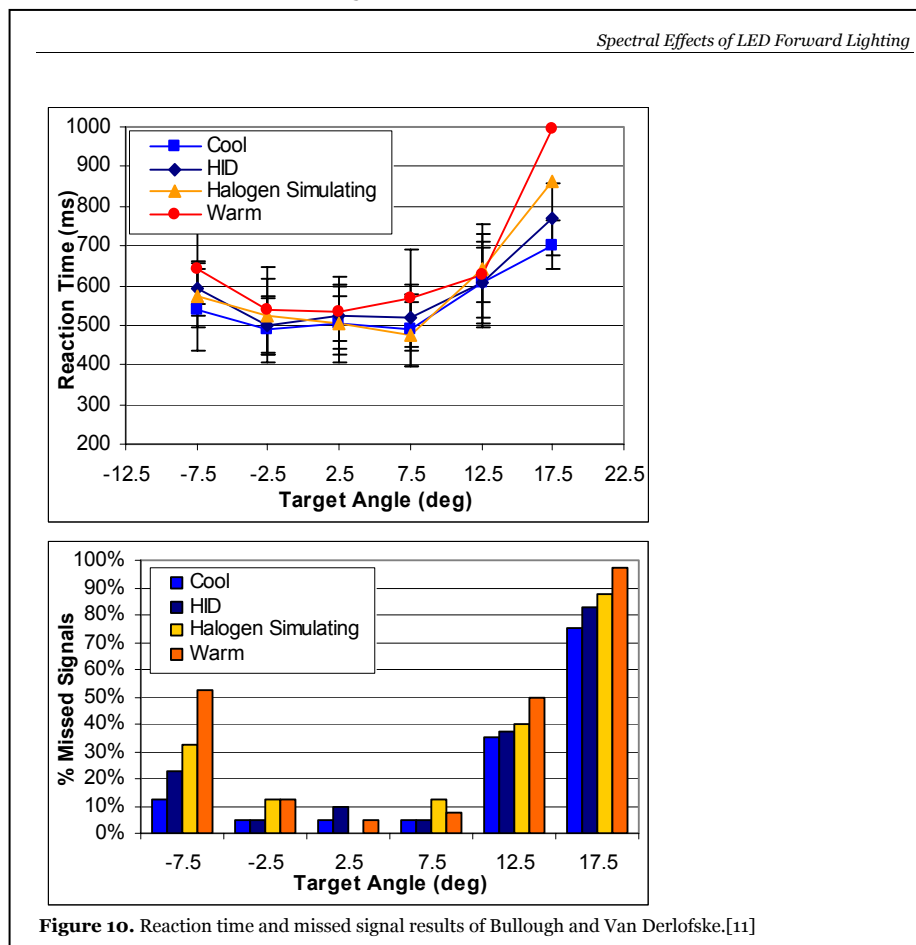


**Figure 8** Reaction Time measured against logarithmic value of Luminance (Source: Arizona Department of Transportation)



<sup>8</sup> [www.resodance.com/ali/pho\\_sens.html](http://www.resodance.com/ali/pho_sens.html)..

**Figure 9 Driver Reaction Times with different colours and angles from central axis**  
(Source: Rensselaer Polytechnic Institute, Van Derlofske 2005)



In a webinar held in the USA on 21 August 2012, presenter Ms Nancy Clanton, Chairperson for the Illuminating Engineering Society of North America (IESNA) Outdoor Environmental Lighting Committee, Mesopic Committee and joint IDA/IESNA Model Lighting Ordinance Task Force, said “What we have discovered is that in outdoor lighting probably High Pressure Sodium is, and has been, the worst choice for outdoor lighting. And yes I know, its like 95% of our highways and parking lots, everything is High Pressure Sodium, I’m hoping that you all at least, will stop the practice and move to a white light source” (Clanton 2012, about 25 minutes in to the presentation, available from the authors or online).

In the LEDs Magazine report on that event is observed: “Perhaps the highlight of the presentation came when Clanton covered some preliminary data from the roadway lighting tests conducted in Seattle back in March [2012]. We described the structure of the tests in our April issue, but these were the first publicly revealed results. The tested 105W LED lighting generally outperformed 400W high pressure sodium lights in small object visibility tests measured by detection distance. The LEDs could be dimmed to 50% and still deliver superior results, and even 25% with dry pavement – especially in the case of a fixture with 4100 kelvin color temperature. Clanton remarked that 4100 kelvin may be optimum because it is very close to the color temperature of moonlight” (LEDs 2012).

In the authors’ view the scientific evidence for a strong preference for white light is extremely compelling. Although yellow HPS lighting constitutes the substantial majority of lighting in New Zealand it should probably be phased out as soon as possible given the availability of more efficient, longer lasting, more environmentally friendly white light alternatives that now exist that could deliver safer night journeys. However, to the author’s knowledge no research exists that relates white coloured light to lower crash rates. Before a national phase-in of

white lighting takes place this research should be conducted. In the author's view this is pressing as it is the only piece of research "jigsaw" that is missing.

Perhaps Australia's higher proportion of older, less energy efficient but white (Mercury Vapour) lighting may be a contributing factor to its significant lower crash rates of 6.1 fatalities per billion vehicle-km compared to New Zealand's 9.4 fatalities per billion vehicle-km (IRTAD 2011). Yellow HPS lighting is estimated to constitute about 76% of New Zealand road lighting based on a sample of 20 Councils (Merrifield 2007) but the proportion could be significantly greater as for example, five years later in Wellington it is 93% (Thessman 2012). In Australia the proportion of yellow lighting is much lower at 53% (Ironbark 2011).

It would seem to be well worth conducting comparative statistical research on Australian and New Zealand crash data to discover if the hypothesis that white lighting contributes to Australia's lower crash rates is correct.

### **3.8. New Zealand light levels**

AS/NZS1158 specifies much lower light levels than those elsewhere in the world. Practitioners suggest the levels have resulted in New Zealand highways being lit to only three-quarters of the levels enjoyed in the UK, Europe and the USA, and our residential streets being lit to as little as a quarter of the lighting levels in other developed countries. In addition industry practitioners suggest that even if the levels set by AS/NZS 1158 were sufficient, inadequate light levels exist because a very high percentage of currently installed lighting in New Zealand is not compliant with the required standards as laid out in AS/NZS 1158 (Bridger 2012).

If this is correct, it may be another contributor to the higher risks of night time accidents identified above (section 2.3) and the higher overall New Zealand injury and fatality crash rates (sections 1.5 and 1.6) than those of comparable countries.

### **3.9. AS/NZS 1158 Lighting for roads and public spaces**

The Australia New Zealand standard does not incorporate the substantially relevant new knowledge gained in the last several years raised above. Standards Australia and Standards New Zealand committee LG-002 is currently reviewing the AS/NZS1158 suite of standards. AS/NZS1158 Part 6:Luminaires is being fast tracked for update to remove the barriers to more energy efficient outcomes including removal of the current "not permitted" status of LED luminaires. Additionally, a Lighting Controls Working Group has been formed within the LG-002 committee to develop a framework for road lighting control, communication, metering and adaptive lighting. Co-author of this paper Bryan King is a member of both of these committees.

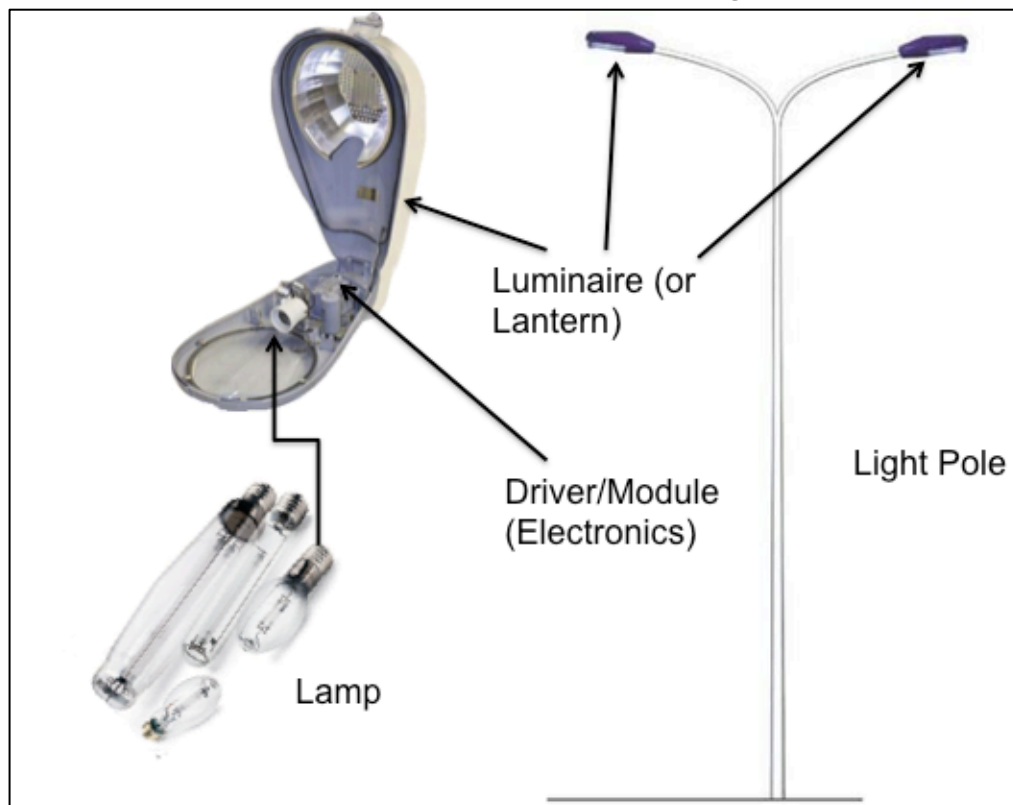
In addition to the observations made above in section 3.8, research conducted by Jackett and Frith in 2009 suggests that even where the lighting levels are in compliance in New Zealand, they are unlikely to be providing the levels of lighting expected. The reason for this is that AS/NZS 1158 uses pavement reflectance properties in the calculations that have been found by their research to be significantly different to those presumed.

Their research observes "The average value found for [reflectance parameter]  $Q_0$  (0.050) is 44% lower than the value currently used in design. This difference is substantial and suggests that our roads are being lit to a rather lower level of average brightness than had previously been anticipated." In its executive summary the study suggests that "using the misaligned r-tables currently specified doesn't just mean that our pavements are less well-lit than previously thought - it also means that motorists are subjected to higher levels of glare than was intended. New Zealand glare levels are already high compared to CIE recommendations, and the increasing age of the driving population draws attention to the need to reduce the effects of glare in road lighting installations. Older drivers suffer greater impairment from glare than younger drivers" (Jackett & Frith 2009).

## 4. LED Lighting

The first practical Light Emitting Diodes or LEDs were developed by General Electric (now called GE) in 1962 as low power sources of light for control panel status indication. Since then LEDs have been developed for high power applications in vehicle lighting and for road lighting. The physics on which LEDs are based is fundamentally very different to that of the three lighting generations that preceded it and therefore provides substantial advantages over the alternative technologies. Descriptions of lighting systems use their own nomenclature, which is shown in Figure 10.

**Figure 10 Components of a conventional, non-LED road light**



The advantages of LED road lighting are:

1. Energy savings, with potential for more than 50% savings over high-pressure sodium;
2. Long life with high performance luminaires rated at greater than 80,000 hours operation until end-of-life (approximately 20 years), defined as when the LED module reaches a lumen output of less than 70% of the original lumen output;
3. Continuously dimmable without as much impairment to energy efficiency as alternatives;
4. Instant on/off switching, without decreasing system life;
5. Ability to integrate computerised control systems that have been reported to increase systemic energy efficiency by up to an additional 20% and also to provide significant additional amenity values;
6. Directional light emission that, with the proper optics, can deliver highly efficient lighting schemes;
7. High colour rendition, generally over 70 CRI;
8. Potential for enhanced visibility and reduced reaction times due to its broader and more appropriate spectral distribution (white light);
9. No toxic Mercury compared to High Intensity Discharge (HID) lamps;

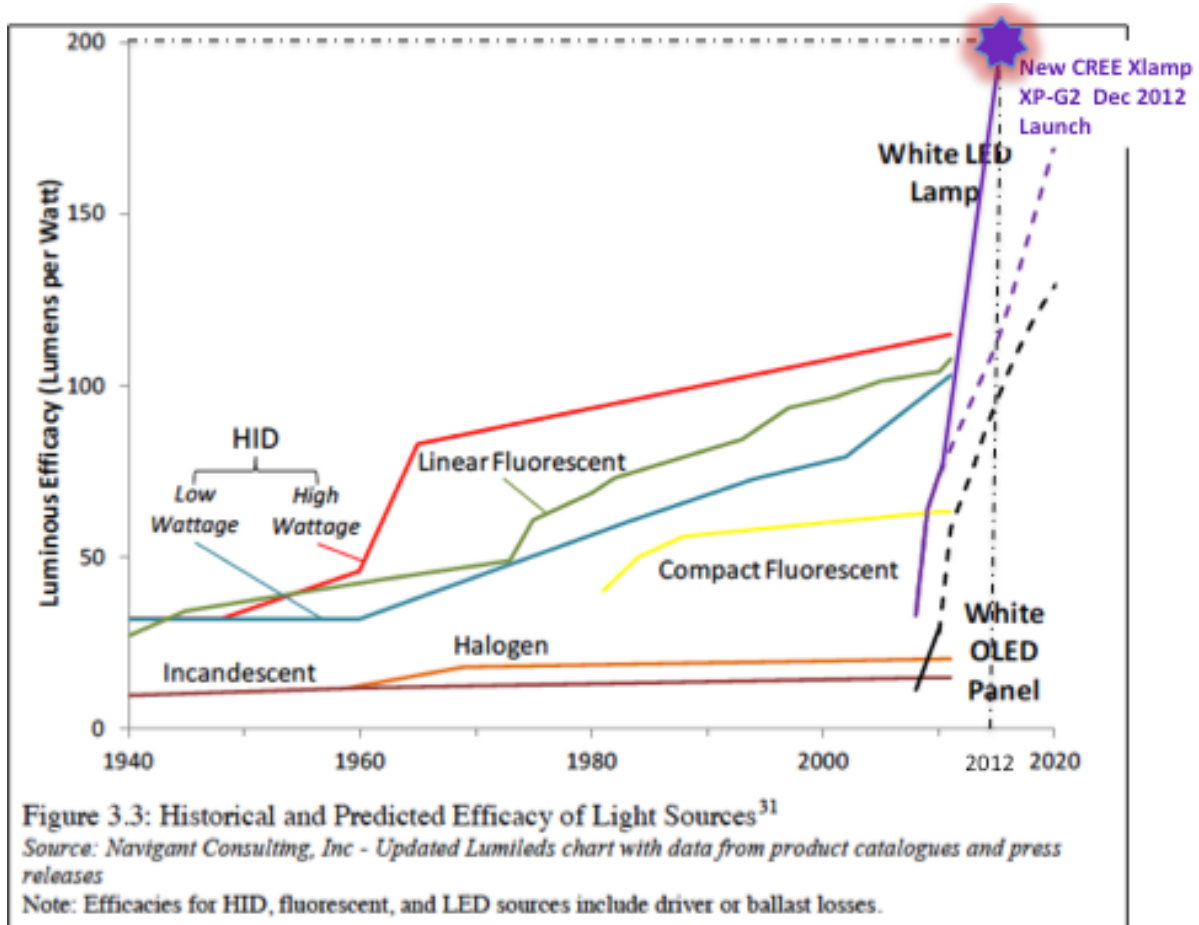
10. More resistant to traffic induced vibration than any of the older technologies

These substantial advantages are some of the reasons why many analysts, including the authors, believe that LED lighting will rapidly displace the majority of existing technologies.

Figure 11 compares the historical progress in efficacy (light output per electrical watt input lm/W) of the lighting technologies since 1940 (DOE 2012).

LEDs are portrayed by the purple dashed line because their rapid trajectory is not easily predicted. Although the data graph originated from the US Department of Energy in 2010-2011, it is already out of date and actual results for CREE, a rapidly growing US LED systems manufacturer, is shown by the solid purple line. CREE has announced that it will have a commercial launch of its 200 lumen/watt XP-G2 **at the module level** in December 2012.

**Figure 11 The technical evidence of impending LED lighting revolution (Source: USDOE 2012 modified by authors)**



Noted international strategy consultancy McKinsey and Company say in their report “The penetration of LED technology just described is driving a far-reaching change to the industry’s structure.... **Upstream industry is experiencing a radical shift, with LED expected to capture a huge share of general lighting** [their emphasis]. LED production methods are very different from those used for traditional lamps, where electrical filaments or plasma with bulky glass covers are used. This is leading to the emergence of an entirely new industry and the upheaval of traditional industry structures” (McKinsey 2011).

Should LED road lighting be introduced for road safety reasons, two further key consequences would be that LEDs would provide Road Controlling Authorities with a substantial increase in flexibility and utility. The findings of this paper and the NZTA report (Bridger 2012) show that the combination of substantial economic and functional benefits

provides an opportunity to both dramatically improve road lighting, reduce traffic accidents and incidence of crime, and improve community amenity whilst making large operational savings. At current equipment prices and interest rates and assuming electricity price inflation of 4% per year (it has historically averaged more than this) a full upgrade of all lighting to LEDs together with computerised control systems appears to provide a payback – **only** on electricity and maintenance savings - of between 7 and 9 years.

## 5. Benefit Cost Ratio (BCR)

The benefit cost ratio analysis below is very simple and only considers the cost of a national road lighting system and its resulting reduction in fatality and injury benefits. The additional benefits of reduced energy consumption, maintenance, additional amenity and lower crime have not been monetised. Despite this, the analysis below suggests a BCR of greater than 10.3.

A study by Hamilton (2003) for Transport Canada suggests, “Hasson and Lutkevich (2002) quote a Federal Highway Administration Study which showed that installing lighting has the highest benefit-cost ratio of all safety improvements.” Elvik (2009) suggests that based on a range of Norwegian assumptions including economics, the BCR for road lighting ranges from 0.21 to 4.01 depending on average daily traffic flows. In the same section Elvik also quotes British research that established a Benefit Cost Ratio for its effects on *crime* of between 1.4 and 3.

### 5.1. Modern road lighting forecast to reduce injury crashes by 35%

If all NZ lighting was changed to modern computer controlled lighting and all the practices outlined in this paper were followed, the authors suggest that the NZTA guideline of 35% reduction in *night time* fatalities and injuries (NZTA 2010a section A6.7) would be a conservative estimation of the outcome. This is conservative as other research cited in this paper indicates a range from 15% to 87% improvements have been experienced internationally, Jackett & Frith (2012) suggest a 33% improvement arises from a 0.5 cd/m<sup>2</sup> lighting level increase, and finally the 35% NZTA figure is conservative because it does not allow for safety improvements from the following which have been costed into the BCR estimation:

- a) increasing insufficient illumination levels (whether specified by AS/NZS 1158 or where lighting is non-compliant);
- b) introducing white lighting;
- c) introducing integrated information to provide optimum lighting location, design, operation or maintenance;
- d) applying a systematic road lighting asset management approach to identify why crashes are occurring where they shouldn't (eg lights were off); and
- e) adding new lighting to areas where none exist at present (see next section).

When this is applied to the most recent 2010 figures of 375 casualties and 14,031 injuries (MoT, 2011a) it results in a reduction in night-time fatalities of 60.90 and a reduction in night-time injuries of 1,537.55 per year.

This conservative model therefore assumes that the introduction of the new lighting systems would provide a single incremental decrease of 35% after the three year installation period, even though one would normally expect improved performances over time as experience grows. As per standard road safety valuation practice, the value of 60.90 fatalities and 1,537.55 injuries is included every year and discounted by the time value of money at 8% which the NZIER suggests is too high for NZTA (NZIER 2012). A reduction in the 8% discount factor would increase the BCR further.

## **5.2. Modern national road lighting forecast to cost \$700 million**

Based on the author's earlier study (Bridger 2012) the modern systems proposed here are roughly estimated to cost about \$700 million across the whole country. At an installation rate of 10,000 luminaires per month the nationwide installation would take about three years to complete. Using NZTA's *Economic Evaluation Manual volume 1 section 2.9*, and the discount factors in A1.6 Table A1.1(a) corresponding to an a conservative 8% discount rate, the Present Value of the three \$233 million costs of the system upgrade comes to \$649.4 million.

Note that this cost is estimated to include upgrading all existing luminaires and provides about \$150 million towards new road lighting. These estimates are of course necessarily approximate.

## **5.3. Modern national road lighting forecast to provide a BCR of 10.3**

The Ministry of Transport uses \$3.5 million as the value of an avoided fatal accident and \$350,000 for the value of an avoided injury in 2009 dollars (MoT 2009).

At these rates, discounted at 8% per year over the (conservative) 20 years the lighting system is expected to last, the present value of the expected reduction in night time injuries and fatalities is \$6.7 billion. This corresponds to a benefit cost ratio (BCR) of 10.3 without factoring any other monetised benefits such as electricity or maintenance savings or reductions in crime.

This is an extremely high BCR which for normal projects would take priority over anything else. For example, NZTA's Roads of National Significance (RONS) is expected to cost \$9.13 billion (un-discounted) with a BCR of between 2.4 and 2.5 (SAHA, 2010).

## **6. Hurdles to overcome**

The authors believe enough evidence exists to warrant major improvement in road lighting to reduce injuries, save lives, reduce crime, save money and improve community amenity. However, there are significant hurdles to overcome.

### **6.1. Road lighting is but a small part of a civil engineering project**

Road lighting has always been a very small part of the very large capital cost of road construction and maintenance. The resources required to move earth, lay concrete, seal pavements and build bridges are at least two orders of magnitude greater than that required for road lighting. The organisational attention required by the civil engineering component of road construction and maintenance means that, worldwide, road lighting does not receive as much attention and optimisation as it deserves.

Road lighting is multidisciplinary and covers civil, mechanical, electrical lighting and electronic engineering, whereas most other facets of road construction are mainly civil. Thus it is important that contracting organisations (NZTA and RCAs) need instructional and supervising capabilities within their own ranks in order to effectively manage the transition to the new era of intelligent lighting.

### **6.2. Road lighting safety strategies and asset management plans**

Of the road safety strategies examined by the authors for New Zealand and perused for Australia, United Kingdom, and Canada, only Canada has a strategy that specifically mentions road lighting but more importantly has corresponding measurables to be reported against. Note that Canada has a specified "long-term vision of making Canada's roads the safest in the world" (Transport Canada, 2012).

The strategies examined all appeared to use similar categorisations as used in New Zealand - Safe Roads (& roadsides in NZ); Safe Speeds; Safe Vehicles; and Safe/Behaviour/Road

Use. The strategies are extremely well thought out and impressive – with the exception that they all - even the Canadian one - overlook road lighting as an important asset class to manage strategically.

### 6.3. NZ Transport Agency

In its 2010-2013 Statement of Intent the NZ Transport Agency identifies that it has “responsibility for allocating over \$2.9 billion in Crown revenue to land transport activities each year.” NZTA manages “New Zealand’s 10,984km of state highways, one of the country’s most valuable assets at \$23 billion” NZTA also works “with local authority partners in addressing transport and land use challenges, investing over \$650 million per annum, in partnership with local authorities, to improve, maintain and renew roads, and around \$360 million to support public transport and build new transport infrastructure assets to meet changes in demand.” (NZTA 2010b).

Of necessity, NZTA’s focus is on the big picture and state highways form 53% of its budget. Where high traffic volumes exist, state highways have high levels of lighting. New Zealand’s rural state highways are extremely long with relatively low traffic volumes and thus benefit cost ratios have probably ruled them out for the provision of lighting – other than “flag” lighting at intersections. Road lighting has therefore logically been a relatively minor concern for NZTA. This analysis is corroborated by two examples.

The study commissioned by the NZTA (Bridger, 2012) found that separately disaggregated figures for road lighting by region were not available after 2007. In 2007 NZTA expenditure for all State Highway lighting was \$2.7 million and on all lighting \$45.3 million (see 6.3). The fact that this relatively small road lighting expenditure did not merit separate financial reporting after 2007 suggests it was not considered worthwhile to separate out these figures.

The second example is found in NZTA’s State Highway Asset Management Plan. NZTA’s 2012-2015 plan says that it “covers the infrastructure assets that form the state highway network, including carriageways, structures, drainage features, traffic facilities and **lighting** [our emphasis], traffic management and other services. It covers all forms of expenditure, beginning with capital investment and including the operation, maintenance, renewal and disposal of assets”. Road lighting is then mentioned in one other place in a general way but that is, as outlined above and below, consistent with a document that is outlining actions being taken for an investment of \$1.538 billion on assets worth \$28 billion (NZTA, 2011).

In comparison to these large numbers, NZTA’s expenditure of \$3.4 million on the state highway road lighting network and \$24.2 million delegated to Councils for local road lighting (after applying 4% inflation to the 2007 figure), is relatively small and is likely to be why up to now road lighting has not been regarded as an issue requiring its attention.

### 6.4. Road Controlling Authorities

In 2007 NZTA investment into local road lighting was \$19.9 million and Local Authority (ratepayer) investment in road lighting was \$22.6 million. Including State Highway road lighting the grand total was therefore \$45.3 million. The authors applied a 4% inflation factor to determine a current estimate of total capex, renewals and maintenance costs of \$55 million per year for road lighting across NZTA and all 66 Road Controlling Authorities.

Local authorities all have other major responsibilities including waste, potable water, stormwater, community events, libraries, museums, property, roading and ensuring democratic governance. From their perspective the approximate \$27 million of ratepayers funding (2011 dollars) dedicated to road lighting represents an average of \$415,000 per local authority. In reality after the five largest cities of Auckland, Christchurch, Wellington, Hamilton and Dunedin are accounted for, the average road lighting spend by all other councils will be far less.

With such fragmentation of expenditure, strategy, management, and activities, the barrier to better, safer, cheaper lighting is significant.

## 7. Conclusions

- 7.1 In contrast to the rest of the comparable world, New Zealand's traffic related injury and fatality record is poor. This is generally explained as being due to its long spread out geography, low population density and lack of economic ability to spend enough per km of roading. On the contrary, the evidence in this paper supports insufficient road lighting and its poor quality being a significant contributor to the poor injury and fatality statistics. Using NZTA's improvement factor of 35% from its Economic Evaluation Manual for reduction in night time fatalities and injuries for a national upgrade to modern road lighting shows a Benefit Cost Ratio of 10.3 without factoring in electricity or maintenance savings or reduced crime. A BCR ratio of better than 4 is considered by NZTA to be "High" and the \$9.7 billion being invested in Roads of National Significance (RONS) is expected to have a BCR of between 2.4 and 2.5. This substantial benefit would make a significant contribution to the NZTA's Road Maintenance Task Force objective to effectively "do more with less".
- 7.2 A 2011 Ministry of Transport survey of 4,600 households indicates that driving light 4-wheeled vehicles at night in New Zealand is 5.8 times more risky than driving during the day. This is in marked contrast to international literature, which suggests risk levels for all vehicles between a third and a quarter of these levels.
- 7.3 Current NZ practice road lighting design works to AS/NZS 1158 which specifies road lighting levels resulting in New Zealand highways being lit to only three-quarters of the levels enjoyed in the UK, Europe and the USA, and our residential streets being lit to as little as a quarter of the lighting levels in other developed countries. In addition, AS/NZS 1158 uses the wrong reflectance parameters which results in lower than intended light levels and also excludes the use of LED road lighting. Furthermore, experienced NZ practitioners suggest that the level of compliance with AS/NZS 1158 across NZ is low and this paper suggests that the accumulation of these factors are likely to be having serious traffic safety consequences.
- 7.4 Road lighting is internationally well understood to have substantial quantifiable beneficial effects on road safety ranging from 15% to 87% reduction in traffic accidents. Despite this, few if any, countries have an active road lighting strategy to systematically manage road lighting assets with an asset management plan approach as exhibited elsewhere in the infrastructure sector. New Zealand certainly has none.
- 7.5 The benefits of applying a systematic asset management approach to road lighting has probably been overlooked due to the fact it needs a multidisciplinary engineering and management approach within a predominantly civil engineering sector.
- 7.6 White light at the same levels as yellow light (used predominantly worldwide) has been scientifically shown to increase visibility and colour rendition, reduce driver reaction times, and increase peripheral vision. It is considered by influential technical leaders, as well as the authors of this paper, to be superior to yellow light in most road lighting applications. However, no scientific research has studied the relationship of white road lighting to accident rates. This is urgently required and is an opportunity for NZTA to demonstrate leadership in areas of road safety and infrastructure economics.
- 7.7 Modern LED lighting and control systems are a disruptive and transformational technology with substantial benefits and opportunities for amenity, economics and road safety. The road lighting sector unaccustomed to rapid change or electronic systems.

- 7.8 A significant opportunity exists to integrate up-to-date traffic accidents, crime statistics, traffic flow, road lighting levels (from Lux Mapping) community/user events and community feedback into council databases as illustrated in Figure 6. Analysing this information do determine road lighting location, design, operation and maintenance – perhaps automatically by computer software – would result in improved traffic accident and crime statistics as well as increased community satisfaction.

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